

## LASERSCANNING AND MODELLING INDUSTRIAL AND ARCHITECTURAL APPLICATIONS

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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.

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. The laser sensor thus provides an active illumination, non-contact measurement of the environment. This is advantageous in many situations, where operator access is limited or poor ambient lighting exists.

To realise surveying tasks in industrial areas as well as architectural, archaeological and cultural landscapes conservation, the point clouds measured by the laser radar are transformed into 3D models, describing the environment digitally by means of meshed surfaces. If possible, geometric constraints like planes, cylinders may be adapted optionally resulting in a CAD model. After meshing, resulting “as-built” models are the base to generate a data base of the existing monument.

This paper reports design and applications of the Z+F IMAGER 5003. It reports the realised approach from physical measurement to “as built” models in the end. It presents different applications and shows the process from measurement in the field to the modelling. In a first example we show results from three individual cultural landscape conservation projects. Furthermore, we demonstrate the application of the 3-D laser radar in generating a model of an industrial environment (manufacturing area).

## 1. INTRODUCTION

### 1.1 Laser scanner for surveying the environment

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 4200 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.

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.



Figure 1: IMAGER 5003

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 semiautomatic process, done by special algorithms of programs which are developed especially for processing the point clouds.

## 1.2 Software for 3D Model Generation

### 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. 2) 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. Fig. 2 is the result of the survey of the famous castle of Neuschwanstein in Germany.

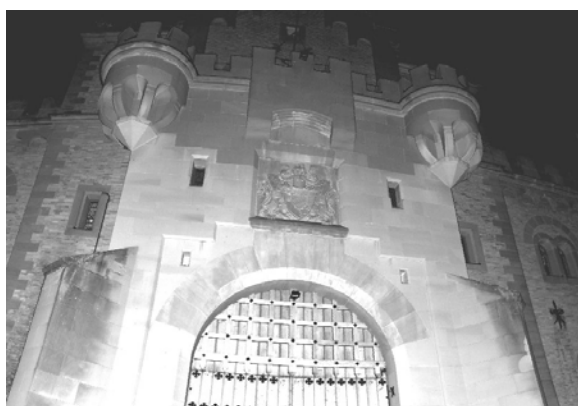


Figure 2: Reflectance Image

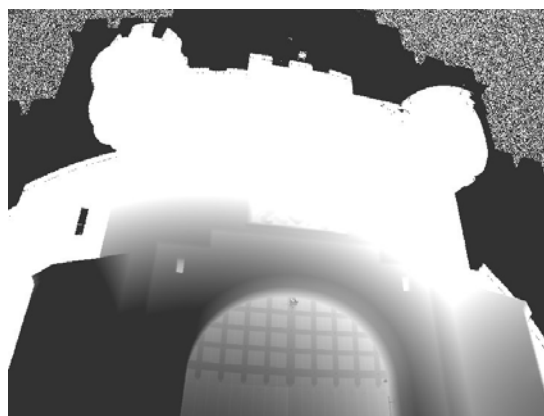


Figure 3: Range Image (grey coded)

Another way of checking the scan is with the grey-coded range image (Fig. 3). It is the complimentary image to Fig. 2, 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 4: 3D Pointcloud of Imager 5003

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.

### LF Comparator

In many cases, it is not necessary to create a CAD model of the point cloud generated by the laser sensor. This is the case when the customer already has a CAD object and this is suspected or known to be inaccurate or insufficiently detailed for the engineering purpose in mind. In these instances it is not deemed cost effective to remodel the whole area but it is effective to survey the area quickly and to compare the existing model with the laser data captured. For these applications, the LF Comparator has been developed. This tool allows the user to import a CAD object and to compare it with the point cloud of the sensor. Within minutes, the user knows the differences between the CAD object and the point cloud due to detail or inaccuracy. These can be modelled to bring the model up to date and into a usable engineering tool.

## 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.

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.

## 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.

## 2. APPLICATIONS

### 2.1 Architecture and Heritage

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 informations, we use two systems, the IMAGER for geometry and reflectance measurements in combination with a panoramic colour camera from the Deutsches Zentrum für Luft- und Raumfahrt (DLR).

In the following three different applications for architectural and cultural heritage applications are demonstrated using both systems :

#### Castle Neuschwanstein

For the castle Neuschwanstein we used the IMAGER 5003 in combination with the DLR panoramic camera. Multiple scans had been taken inside and outside of the castle and combined with respect to scanning positions of the individual scans and images.

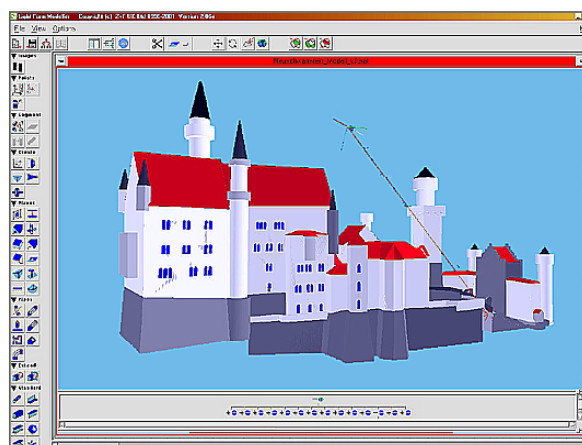


Figure 5: 3D Model of the castle Neuschwanstein

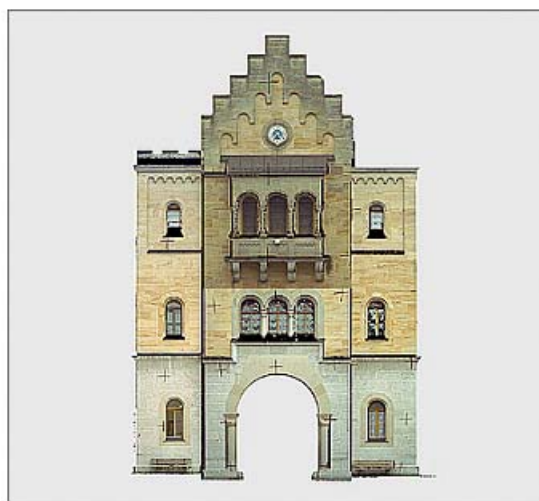


Figure 6: Orthophoto of entrance to the castle

Targets were placed at strategic points around the site. The centres of the targets were surveyed using a total station, but they are recognisable in the scans, too. The modelling software locates the centres of the targets and has also access to the data generated by the total station, so that the scans can be registered into the global framework.

The result shown in Figure 5 and 6 show the result of the surveying from the outside of the castle. Especially the orthophoto generation by superimposing the geometric information of the laser scanner and the colour information by means of the DLR camera show good results with both systems and enables scanning with colour informations.

Both systems showed good performance while scanning.

### Chapel in Wangen

In the next example a chapel in our hometown Wangen was scanned and afterwards modelled using LF Architect. Figure 7 shows the model of a chapel surveyed with the laser scanner and modelled using LF Architect



Figure 7: 3D model of chapel (outside)



Figure 8: 3D model of chapel (outside and inside)

This model can be imported in various CAD programs like AutoCAD or Microstation. For a better and realistic view, the surfaces have different colours. When digital photos are taken of the object, the surfaces can be drawn with the original textures in LF Architect as well as special programs like 3D StudioMax. In this way, the images of the laser scanner can be used to generate virtual reality.

In Figure 8, several walls are not shown to have a better view of the interior of the chapel whereas Figure 9 illustrates the superimposing of real texture by means of the image on the chapel wall.



Figure 9: Superimposing real texture (painting)

### Castle in Sweden

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 DLR 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.

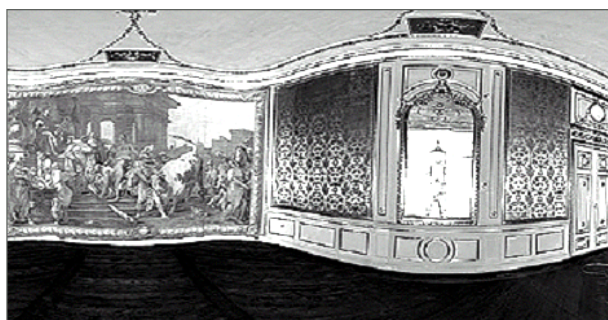


Figure 10: Reflectance Image of Imager (section)

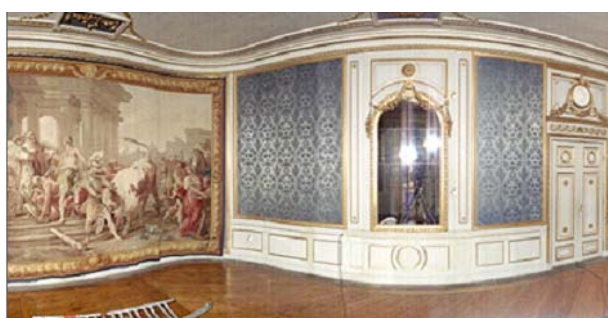


Figure 11: Panoramic image of DLR camera (section)

The surveying was performed in less than one day and the modelling afterwards took approx. 1 week. Especially the superimposing of colour informations 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 10 shows the measured raw data of the Z+F IMAGER 5003 (Figure 10) and of the DLR camera (Figure 11). These

informations are combined and result in both the orthophoto shown in Figure 12 and the 3D colour point cloud in Figure 13, superimposed from measurements of the IMAGER and the DLR camera.



Figure 12: Orthophoto of one wall in castle

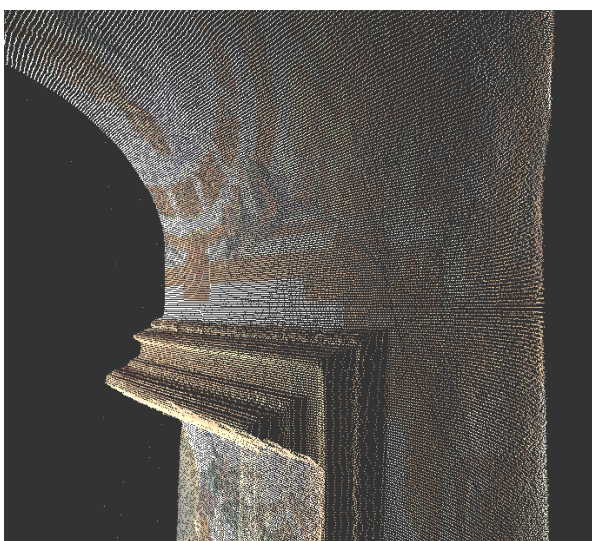


Figure 13: 3D colour point cloud of Imager 5003

## 2.2 Industrial applications

In industrial applications, the time needed for surveying is an important factor, as long down-times in production should be avoided. It is therefore an ideal environment for using the Z+F laser scanner. Beside generating CAD models of the environment for as built documentation it is also essential for simulation purposes.

**Documentation:** Main points of interest in a production hall is the pipework and the supporting pillars which have to be taken into consideration when planning changes in the hall. The level of detail of the modelling is varying. For some applications, only pipes with certain diameters are interesting, for some other applications a very detailed CAD model is necessary. The following images show a chemical production facility which has been modelled with a very high level of detail.

The production facility has been surveyed from several different viewpoints. Targets have been used to match the scans together and to refer each scan to the local coordinate system of the facility. As mentioned above, target recognition and registration are a semi-automatic process. The extended pipework in this facility leads to many hidden areas, so the surveyor must con-

sider this when choosing the scanner positions. Careful visual checks are needed by the operator to ensure that all of the target objects are correctly scanned.

**Simulation:** Main point of generating of CAD Models for simulation and optimisation purposes of existing plants as well as design studies of new equipment being placed in an existing environment is the building structure and the free space between fixed structures such as walls, pillars and steel work.

The entire building hall is surveyed by positioning the system on different locations. It includes several welding cells with multiple robots in it as well as the typical building structure consisting of pillars and steel work. Especially the technical equipment, such as water and air connections cable trays and power connectors are of main interest.



Figure 14: Section of 3D CAD model of plant

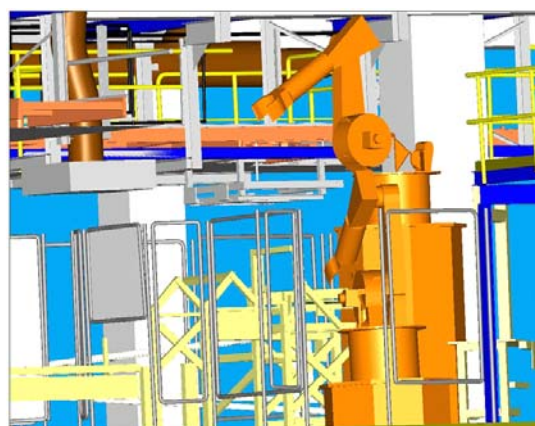


Figure 15: 3D CAD Model exported to AutoCAD

Fig. 14 shows the resulting CAD model of a part of the building with different technical equipments modelled in different colours. However, the pedestals of the robots were modeled precisely in order to fix the exact position of the robots within the work cell. By positioning the robot model, taken from the CAD library of the manufacturer, onto the pedestal (Figure 15) and connecting the robot arm to its end-effector, a complete model of the robot in its reference position can be generated. All objects were modeled from measurement data of the visual laser scanner and can be well recognized.

With the help of geometric models like these and a CAD library of known parts and machines, entire production runs can be simulated and optimized. For this purpose, software packages are used which already contains a direct interface for importing data of our system.

Figure 16 shows the final model (section) in AutoCAD for further steps in documentation and simulation tasks.

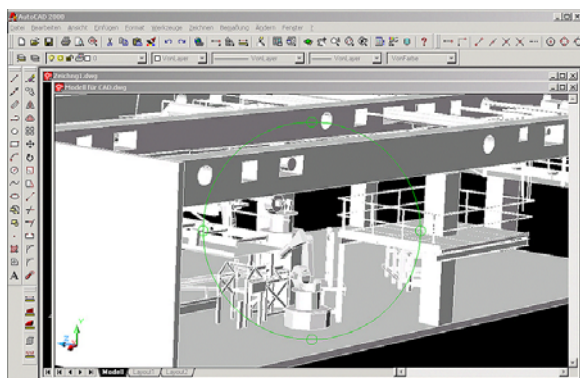


Figure 16: 3D CAD model exported to AutoCAD

Exports to most CAD systems (Microstation etc.) as well as simulation packages are supported so that the user can directly import the generated models in his software package.

### 3. 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 industrial as well as for 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). The semi-automatic and interactive model generation in LF Modeller is integrated for the standard geometric primitives sphere, tube and plane. Together with the meshing tools and LF Architect a broad variety of industrial environments and 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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