TRAFFIC CONSTRUCTION ANALYSIS BY USE OF TERRESTRIAL LASER SCANNING

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ABSTRACT:

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. With laser scanner systems, capable of working in most real world environments under a variety of conditions, numerous applications have opened up. State-of-the-art, high precision, high speed laser scanners provide accurate visual and geometric measurements. To realise surveying tasks for traffic construction analysis, point clouds, measured by the laser scanner, are transformed into three dimensional models, describing the environment geometrically. In addition, the visual information of the data measured is used to determine surface conditions of the objects, indicating possibilities of cracks and other damages in the structure itself. Geometric constraints like planes, cylinders or meshing techniques may be adapted resulting on a CAD model, representing the existing environment. This paper reports applications of the laser scanner IMAGER 5003 with highway bridge clearance measurements. It focuses on the accuracy of the system and reports the realised approach from physical measurement to "as built" models in the end. It shows 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.

1. INTRODUCTION

Monitoring of man-made objects is not only important in areas at risk where for example earthquakes are expected. Due to varying exposure und wear, damages can arise, which can be detected by a specialist in a very early stage. In Germany the regulation DIN 1076 determines that every 6 years a traffic bridge needs to be monitored by an expert accompanied by an examination every 3 years and annual inspections. Additionally, the clearance profile of streets is regulated in Germany. An example is that the space above the road surface must be 4.5 m. The actual values alter when plants grow inside these profiles but also due to modifications in the surface. The controlling of the regulations requires the frequent surveying of these buildings. A thorough examination by an expert is necessary. However, damages and changes which are detected via spatial data ought to be assessed in an uncomplicated fashion. That does not apply to levelling, the conventional method. This is the reason why developments culminating in contact-free devices which enable to acquire the whole shape of the object should be used to reconstruct the bridges and support monitoring in a convenient way.

1.1 Surveying of nearby objects

Reconstructing objects and buildings in a realistic and accurate fashion is an important and well known research topic. In recent years the main focus of researchers concentrated on three dimensional reconstructions based on two dimensional image data. Here, two overlapping photos of the same part of an object can be used to get three dimensional information. Förstner for example (Förstner, 1999) compares airborne laser range data and aerial images to gather three dimensional city models. Among others he points out that the disadvantage of images for the reconstruction of buildings are the lack of one dimension and the occurrence of occlusions. Both can be overcome by use of laser scanning data. This technique offers the acquisition of true three dimensional data. That leads to the main advantage in case of monitoring of three dimensional buildings as a difference calculation between two different points in time can be automated. Beside three dimensional range information, some laser scanners offer usually additional three dimensional reflectance information. Both information – reflectance and range information – correspond to each pixel one to one. By extracting features in an accurate way, the combination of image processing methods and three dimensional geometric information is possible. Another big advantage of the laser scanning technology is that for measurements no additional illumination is needed. This is the reason why operation in total darkness as well as in daylight is feasible.

1.2 Monitoring of traffic constructions

Conventional methods to monitor traffic constructions like bridges use tachymeters. As a new approach based on conventional methods, Kuhlmann and Gläser used a tachymeter without reflector at the University of Stuttgart (2002). Current systems for the acquisition of traffic infrastructure base on the combination of sensors mounted on a moving vehicle. Examples for this kind of surveying method are the Kinematic Survey System KiSS and the the Mobile Street Acquisition System (MoSES). Both have been developed by the company ikv in Munich. They support the acquisition of street data without interfering traffic. Here, a vehicle moves along the street and gathers all the time position and orientation. The data is gathered by GPS, an intertial measurement unit, digital cameras and in MoSES additionally by two laser scanners which are mounted on the roof of the vehicle. In a 30 m corridor all objects and the street condition are determined. The Dutch company DelftTech developed the ScanVan which was used together with the Cyrax 2500 scanner to measure all clearances around the Rotterdam Ring Highway.

In the research project Natscan forest parameters of trees are derived from terrestrial laser scan data (see Simonse et al. 2003; Thies et al., 2003). To verify if the developments of this project can be used for man-made objects as well, three highway bridges around Freiburg in South Germany were scanned from different locations. This paper presents the setup and first results of this feasibility test.

2. DATA ACQUISITION AND SYSTEM DESCRIPTION

For the scanning of the highway bridges the laser scanner Imager 5003 was used as well as its software to analyze the data. The following chapter presents the main features of the hard- and software as well as the setup for the application.

2.1 System Features

The visual laser scanner IMAGER 5003 of Z+F (Figure 1) is an optical measuring system based on the transmission of laser light (see Fröhlich, 2002; Stephan et al., 2002; Haertl et al., 2001; Heinz et al., 2001; Langer et al, 1998). The environment is illuminated on a point by point basis. Then the light is reflected in case 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: IMAGER 5003

The laser scanner is designed for non-tactile, high performance measurements with high robustness and accuracy. Due to the large field of view of the scanner (360° horizontal, and 310° vertical coverage), the scene to be modelled has to be surveyed only from a few viewpoints.

The system itself has four different scanning modes, which differ in the spatial point distance and can be selected according to the application and specific requirements. They range from super high resolution (20000 pixel per 360^o horizontally and vertically) to preview mode (1250 pixel per 360^o horizontally and vertically). One characteristic of the device is the rapidity of the acquisition time. Take the following as an example: The mode, which is most popularly used to gather data in an industrial environment (10000 points horizontally and vertically) takes just 3.20 minutes for a full 360^o scan. This mode is recommended for data acquisition for the monitoring of traffic constructions. The preview mode enables more than 12 million points to be scanned in less than 20s.

2.2 Software

The basic software for operating the scanner and performing simple measurement tasks is designed for scanning in the field. It is very easy to handle by use of predefined settings for the scanning. The preview of the area to be scanned in detail can be measured and afterwards selected to be rescanned using a higher point density. The software support the user in visualisation purposes and online data measurements by means of a so called "virtual surveying" functionality.

Directly after the measurement, the first results can be seen on the computer. Usually the reflectance image is used to get a photorealistic impression of the scanned area. An example of a forest scenery can be seen in Figure 2. It is similar to a black-and-white photo and therefore does not require much experience to interpret. By use of it, the surveyor can see directly 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 2: Reflectance image

Another way of checking the scan is with the grey-coded range image (see Figure 3). It is the complimentary 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 3: Range image

To get an overall view of the scanned area, a three dimensional model of the data is essential. All measured points are transformed to the third dimension so that the whole point cloud is shown as a three dimensional model which gives a good impression of the scanned region. An example is presented in Figure 4. Here the data was taken from three viewpoints, which are displayed in different colours. Like in the reflectance image, hidden areas can be easily detected in this view.

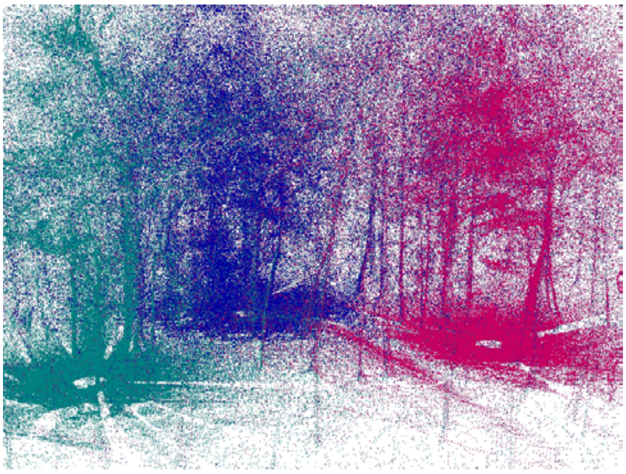

Figure 4: Three dimensional visualization of point cloud

Measuring features allow the user to get the most important measures on site and a feeling for the dimensions. The user just needs to click on two points, and the program calculates the distance between them. By using this feature, first on-side measurements and data evaluation tasks can already be taken in the field.

2.3 Setup

For monitoring the clearance of bridges the height of specific points is measured on a regular basis. Differences in the height assist experts in discovering damages. Fulfilling this task by use of laser scanner data covers the data acquisition on site, the generating of digital three dimensional data and the measuring of the clearance on the screen.

A typical highway bridge was chosen to demonstrate the application. It is located at the highway No 5 at exit Freiburg centre. From a surveying point of view, only the bottom side of the bridge interests. Three scanning viewpoints were necessary to get the data information needed to fulfil the measurement tasks. Figure 5 shows the reflectance image of the first viewpoint.

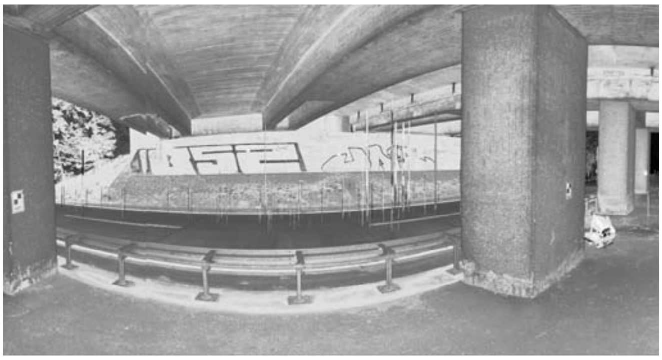

Figure 5: Reflectance image of one viewpoint of the bridge

Dependent on the shape of the bridges to be measured, one to three different viewpoints are necessary. Targets have been used to match the scans together and to refer each scan to the local coordinate system. The matching was accomplished by a semi-automatic target finder (Abmayr et al., 2004). By clicking somewhere on a 10 cm by 20 cm chess-pattern (see Figure 6), the user gets the target middle point with subpixel accuracy, and its corresponding three dimensional value respectively. This calculation needs to be precise and accurate, as this three dimensional information is the basis of calculating the orientation of each scan. For calculating the orientation itself for several scans, bundle adjustment with standard tools is used.

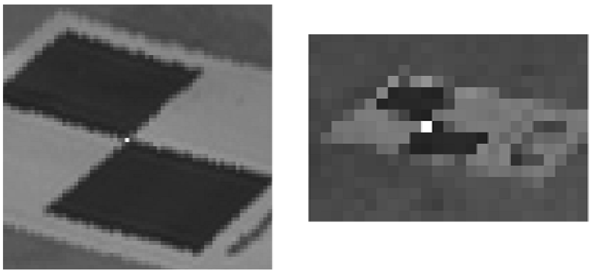

Figure 6: Result of the target finder in different scan modes

The measurement task itself was solved by using the measuring functionality in the three dimensional point cloud of the software. To calculate the distance between a specific point *p* on the road and the critical part of the bridge, a section around *p* is approximated by a plane, and then the normal of this plane is projected onto the bridge (see Figure 7).

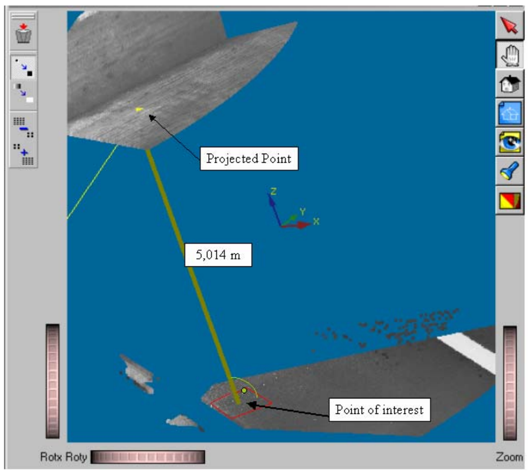

Figure 7: The normal of a plane around the point of interest is projected onto the bridge.

3. RESULTS

To compare the values with the results of conventional methods reference values were acquired by use of a measurement bar. Figure 8 shows a sketch of the location of these points in the corresponding form of the road department.

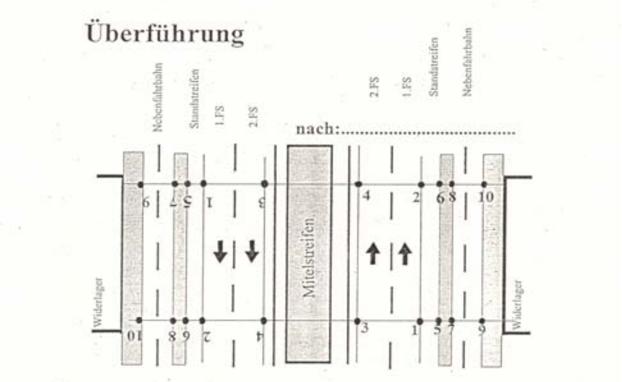

Figure 8: Form for bridge monitoring

On these locations the point heights by use of the three dimensional point cloud were measured. As an example six of the measured points are compared with the reference values. The reference heights were measured conventionally by use of a measurement bar:

Point No	Conventionall y measured height [m]	Height measured in digital three dimensiona l model [m]	Differenc e [cm]
1	4.78	4.76	2
2	4.65	4.65	0
5	5.85	4.86	-1
6	4.70	4.71	-1
9	5.18	5.21	-3
10	5.02	5.01	1

The results show that the differences are rather minor and may arise due to variation in the location of the measurements as well as different accuracy ranges, i.e. the scanner delivers the values in millimetre whereas the measurement bar offers the results in centimetre. The problems caused by the measurement location can be avoided by marking the positions of the points where the measurements should be taken. It can be assumed that these positions can be detected in the reflectance image. This would enhance the verification of the positions. In case of an automatic determination of differences of two point clouds respectively three dimensional models this marking is not necessary. In this case not point wise but shape wise differentiation is carried out.

To demonstrate the possibility to create such a three dimensional model, the software was used again: Conversion from three dimensional 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.

Model construction takes place on a hierarchical basis, i.e. 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.

In Figure 9 the result of the reconstruction process is shown. For transforming the three different point clouds into one overall coordinate system, bundle adjustment was used. The modelling itself was done as described above: the highway for example was approximated by a plane, the brackets of the bridge by cuboids respectively.

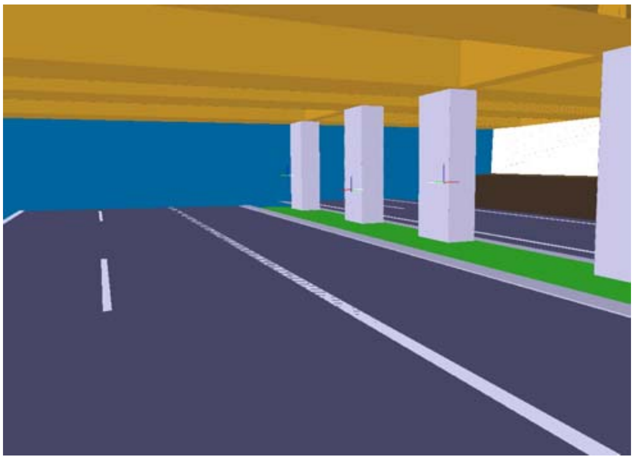

Figure 9: Result of the modelling process

4. CONCLUSIONS

The use of terrestrial laser scanning data for monitoring of traffic bridges was presented in this paper. To do so, at one to three viewpoints the scanner data was acquired, three dimensional models of the bridges deduced and clearance measurements accomplished. The results show that the accuracy is comparable to the one gained with conventional surveying methods. Advantages of this kind of technique for application in traffic construction analysis are that much more data can be acquired with little personnel and time costs. While gaining the data contact free measurements lead to a more secure and more economical working environment. Especially when monitoring complex buildings the examination of digital data requires less effort than surveying specific points on site. Additional measurements are easier to perform. The advantage of this kind of data for monitoring tasks is the uncomplicated determination of three dimensional differences. Especially when automating this procedure the use of digital data is essential.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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