

DEVELOPED TECHNIQUE FOR AUTOMATIC POINT CLOUD TEXTURING USING MULTI IMAGES APPLIED TO A COMPLEX SITE

A. Abdelhafiz *, W. Niemeier

Institut für Geodäsie und photogrammetrie, TU Braunschweig, Gauss Str. 22, 38106 Braunschweig, Germany

A.Abdelhafiz@tu-bs.de, W.Niemeier@tu-bs.de

KEY WORDS: Laser Scanning, Digital Photogrammetry, Data Fusion, Multi images , Textured Cloud, Traffic Crossing.

ABSTRACT:

The reconstruction of the textured 3D models seems to be very important in almost all the industrial and the engineering fields. These models will aid in defining the problems and consequently finding suitable solutions. In some cases, the final solution could be also simulated on the computer before the applying on the real site. Recently, the laser scanning technology is widely used in capturing the object geometry, whereas the texture is extracted from digital images which are parallel taken to the site. The images are captured either by a camera attached to the laser scanner itself or by a free hand camera. The camera attached to the laser scanner will limit the wide vertical field of view of the laser scanner which exceed the 300 degree, further more the best color quality will be obtained at the best lighting conditions of the image which may not be at the same position of the laser scanner. This is why the free camera positions registered to the laser point cloud approach is still having the potential. The challenge in this approach is how to deal with the occlusions, which normally causes wrong color on geometric details in case of blind texturing. In this paper, a new technique is developed for the texture extraction from multi images applied to the free camera positions registered to the point cloud approach. This technique uses the computer intelligence to automatically detect the occlusions and differentiates between the various planes in the 3D model, which enabling correct texture extraction process. Details on the developed technique together with the approach execution on a real engineering application will be presented. As a part of this work, a special software for the color extraction considering the technique of the occlusions detection is also developed. The final result is a textured 3D point cloud represents the real site.

1. INTRODUCTION

In almost all the industrial and the engineering fields, man seeks to get textured 3D models for the sites under investigation. These models will aid in defining the problems and consequently finding suitable solutions. In some cases, the final solution could be simulated on the computer before the applying on the real site.

The terrestrial laser scanning has become recently one of the standard technologies for object acquisition, as the laser scanner almost immediately delivers a 3D data set with no further complicated compilation processes. At one or more instrument position the entire hemisphere could be surveyed and a dense point cloud of polar measurements with a rather high distance accuracy could be delivered. Add to that, the laser scanning is an active technology, therefore, there is no problems with daylight or illumination conditions, the laser also does not care with heavy cast shadows or severe brightness contrasts (Jansa et al, 2004). On the other hand, the resulted point clouds bear no information about the object's texture. Researchers like (Kern, 2003; Caprioli et al, 2003; and Guaranie, 2004) compared the laser scanning technology and the photogrammetric technology with their combination results, and stated that optimal models will be obtained from the fusion of the two technology.

Nowadays, the laser scanning technology is widely used in capturing the object geometry, whereas the texture is extracted from digital images which are parallel taken to the site. The images are captured either by a camera attached to the laser scanner itself or by a free hand camera. As the camera attached to the laser scanner will limit the wide vertical field of view of

the terrestrial laser scanners which exceed the 300 degree, and the best color quality will be obtained at the best lighting conditions of the image which may not be at the same position of the laser scanner. So, the use of free hand cameras with the suitable mathematical approach are still the better solution.

Some approaches use the photogrammetry to register multi scans in one coordinate system (Guidi et al, 2002), then the approaches extended to use the photogrammetry to model the main shapes while laser scanning capture the fine details (El-Hakim et al, 2003a) and (Alshwabkeh et al, 2004). (Abdelhafiz et al, 2005b) attach the point cloud to the 2D image to deliver a 3D Image on the computer screen. Surveying points are used to set up the reference frame for the texture images and the point cloud, which is scanned with low cost scanner (El-Hakim et al, 2004). Free camera positions are also registered with the point cloud using extracted points from the cloud itself (Abdelhafiz et al, 2005a). The challenge in this approach is how to deal with the occlusions, which normally cause false color extraction in case of blind texturing, and they are not managed manually.

In this paper, a new technique is developed for the texture extraction from multi images applied to the free camera positions registered to the point cloud approach. This technique uses the computer intelligence to automatically detect the occlusions and differentiates between the various planes in the 3D model, which enabling correct texture extraction process. Details on the developed technique together with the approach execution on a real engineering application will be presented. As a part of this work, a special software for the point clouds texturing using the occlusions detection technique is also

* Corresponding author.

developed. The final result is a textured 3D point cloud represents the real site.

A detailed description will be presented in the following sections. Section two provides the main issue and its proposed solution. Section 3 describes a survey for a real traffic crossing using the free camera positions registered to the point cloud approach, the developed technique is used here for the site texturing. The paper conclusions are summarized in section 4 together with some precautions which have to be considered.

2. THE MAIN ISSUE AND THE PROPOSED SOLUTION

The applied approach here, which will be described in details in the following section, register the images with the point cloud by computing the exterior orientations of the images relative to the coordinate system of the point cloud to put them together in one coordinate system as shown in the beginning of figure 5. After this step, the point cloud could be textured from one or more of these images. One can decide, using the photo interpretation principle, which part of the cloud has to be textured using which image considering the occlusions in the scene.

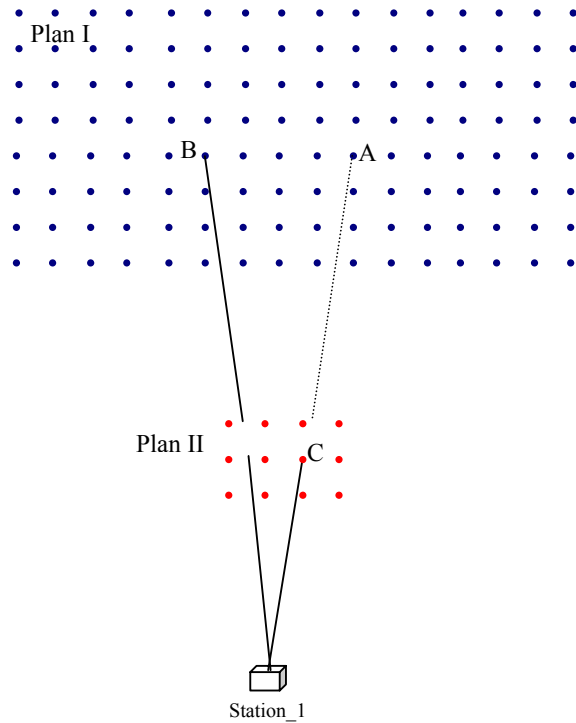
Trees, cars, traffic signs, shields, peoples, and so on are not the only occlusions in the scene to be considered, some building's parts are also act as occlusions for other parts of the same building. For example; the building's façade can act as an occlusion to their side walls and a projected window or any other parts from the façade can act as occlusion to the façade surface itself from specific angels of view, see the blue areas in figure 5 for this type of occlusion.

2.1 Defining the problem

Figure 1 describes the texturing procedure from one image and the effect of the occlusion on the texturing process. Considering a main plan I and an occlusion plan II as a set of points captured by a laser scanner. Points A and B lay on plan I and point C lay on plan II. From the magnification figure of the image pixels with their corresponding coordinates from the point cloud and in case of blind texturing, the two points A and B will be false textured by the occlusion plan color, whereas point C will be correctly textured.

Step further, point A could be protected from the false texturing as point A and point C are laying on one ray projected from the exposure station, so both of them are corresponding to one image pixel and it is easy now to decide which point (A or C) is captured by the camera, which is the nearest to the exposure station. So, it could be decided that point C is the corresponding point to the image pixel and points like A are separated to be textured from another image from another angle of view.

The real complications will appear with points like B on the main plan I which has no corresponding point captured by the scanner on the occlusion plan II. The light-ray connected between the point B and the exposure station passes through the set of the captured points of the occlusion plan and didn't hit any of them. Such points will be false textured with the occlusion plan color and there is no way in case of using one image to detect the occlusion existence. This type of points is quite frequent and has a great effect, see figure 2 for a real example for a traffic sign and a building in the background to see the effect of points like B on the texturing.



XYZ	XYZ			XYZ
XYZ			XYZ1 XYZ2	XYZ1 XYZ2
XYZ1 XYZ2			XYZ	XYZ1 XYZ2
XYZ	XYZ1 XYZ2	XYZ (B)		XYZ1 XYZ2 (A&C)
XYZ1 XYZ2		XYZ1 XYZ2		XYZ
XYZ		XYZ	XYZ1 XYZ2	XYZ

Figure 1: Texturing from one image in case of occlusion existence with a magnification of the image pixels with their corresponding coordinates from the point cloud

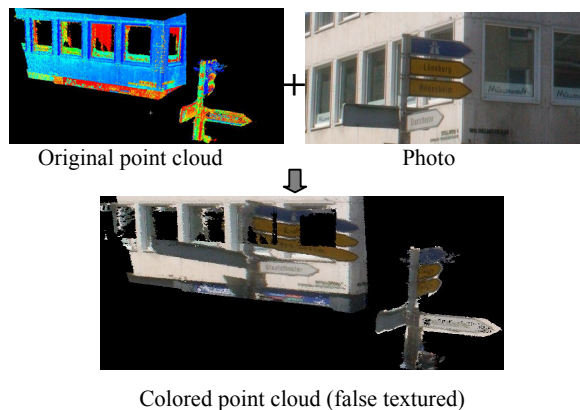


Figure 2: Occlusion effect

2.2 Proposed solution

To manage this problem, we involve more than one image in the texturing process. Figure 3 shows a sketch which illustrates the main concept. By analysing the rays projected from the three stations to the targeted points A, B, and C, the texture at each point from the three stations could be extracted, see table 1.

From the table, point C has the same texture from the three stations. Point A and point B are true textured from stations 2 and 3, while they are either false or not textured from station 1. So, the texture from station_1 has to be rejected and the two points have to be textured using image_2 or image_3.

It is clear from the sketch that, the idea will work correctly if the images capture each part of the scene from at least two different angles of view without occlusions. At the same time employing images taken from the same position or lay on one line with different distances can trigger false texturing in case of occlusion existence especially if it is in the image centre.

One further important issue here is the illumination variation obtained from each photo for the same object. As most of the work is likely to be outside under the sun light, so different illuminations are expected from each photo even the same object is considered i.e. the true texture from different photos hasn't the same RGB values as shown in figure 4. So, a certain color criteria has to be used to decide if two sets of RGB values are corresponding to the same object with different illuminations or they are for two different objects. Studying the behaviour of the RGB value towards the illumination, one can notice that the three color components will decrease or increase together according to the decrease or the increase of the light considering the same color. The amount of the increase or the decrease is depending on the variation in the illumination between the used photos and this amount is considered as our criteria here, which could be also changed according to each set of photos and it is recommended to be around 10. The used conditions here are formulated in the following:

- $\Delta R \leq \text{criteria}$ AND $\Delta G \leq \text{criteria}$ AND $\Delta B \leq \text{criteria}$
- $\Delta R \geq 0$ AND $\Delta G \geq 0$ AND $\Delta B \geq 0$ OR $\Delta R \leq 0$ AND $\Delta G \leq 0$ AND $\Delta B \leq 0$
- $\Delta \text{max.} - \Delta \text{min.} \leq 0.75 \times (\text{criteria})$

Where,
 criteria is a given value by which the computer can judge the accepted and the non accepted illumination variations.
 ΔR , ΔG , ΔB are the differences between the red, green, blue components in order.
 $\Delta \text{max.}$ and $\Delta \text{min.}$ are the maximum and the minimum difference from the three color components differences (ΔR , ΔG , ΔB).

The data flow for the process, considering just one point (P), will go forward by the following sequence:

- Texture (P) using all the given photos to get its color components (R_i & G_i & B_i), where (i) is the image number.
- Investigate the results from the different photos and one of the following cases will be obtained:
 Case 1: The point (P) doesn't lay in any of the photos, then remove the point from the cloud
 Case 2: The point (P) lays in just one photo; so depending on the available photos, the user has to give a pre-decision to accept texture from one photo or not.
 Case 3: The point (P) lays in two images or more; so search for the most two matching texture then apply the pre-mentioned color criteria conditions. If the checked two textures are

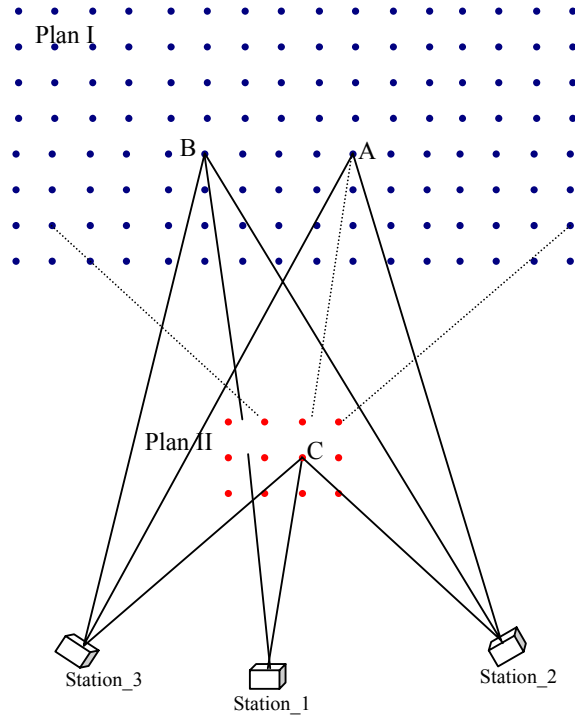


Figure 3: Texturing from multi images in case of occlusion existence

	station 1	station 2	station 3
Point A	No texture	True texture	True texture
Point B	False texture	True texture	True texture
Point C	True texture	True texture	True texture

Table 1: The validity of the extracted texture from the used three stations

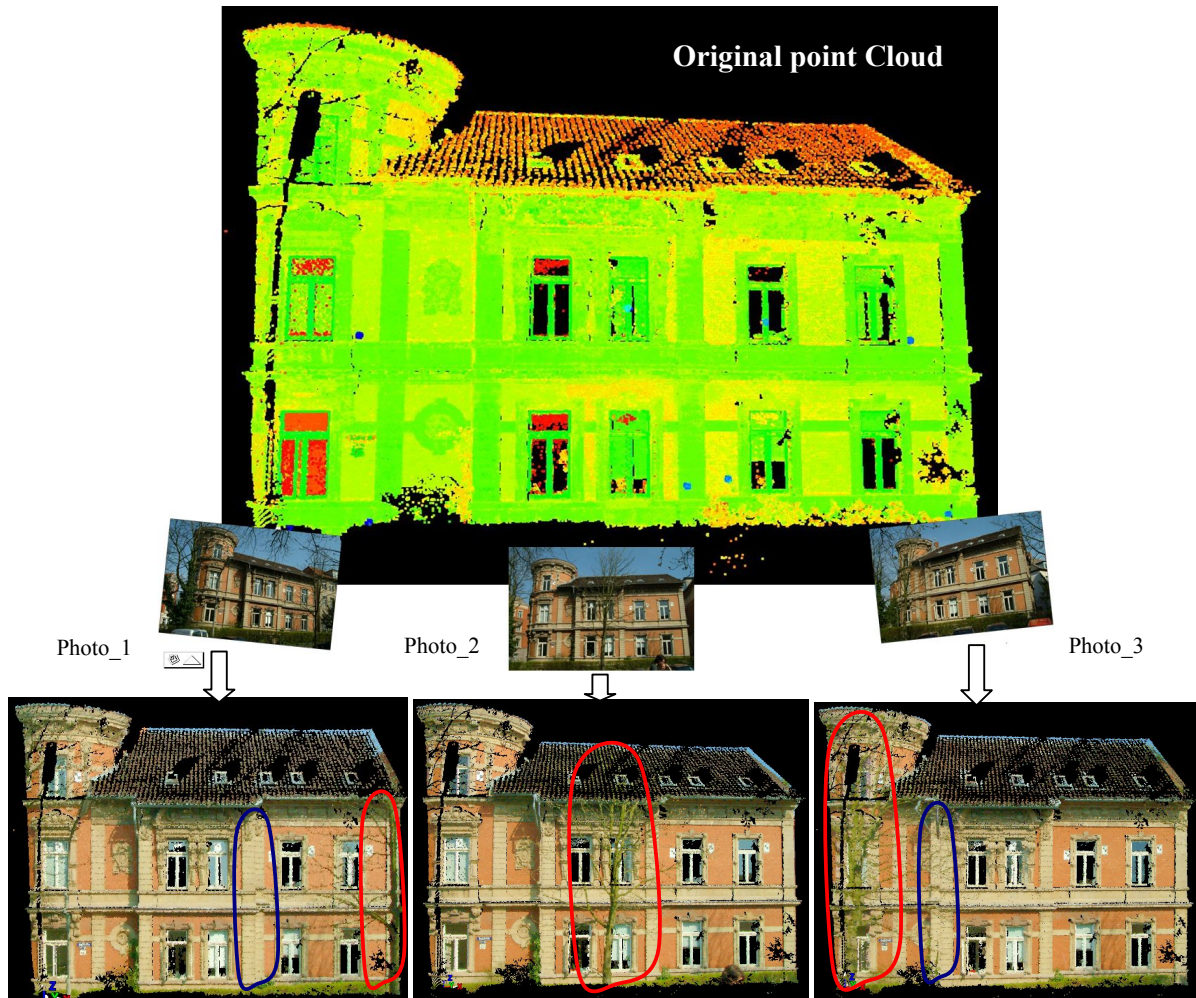
R = 170	R = 180	R = 190
G = 90	G = 100	G = 110
B = 50	B = 60	B = 70

Figure 4: One color with different RGB values resulted from the illumination variation

matched together so texture the point by the average color, otherwise remove the point from the cloud.

The 3D Image software which is a part of the PhD work of the first author, is updated to execute the developed technique to turn the texturing process from multi images to be automatic. The software accepts all the available photos for the scene with their corresponding point clouds to generate a true colored point cloud in one step. The user has also the ability to export the coloured cloud in a DXF format to be opened in a CAD environment. Photos with different resolutions captured with different sensors are also accepted.

Figure 5 shows three photos for a façade with their blind texturing results using individual photos. One can see the false textured areas from a tree (red areas) and from projected parts from the façade (blue areas). The false textured parts could be manually cut and re-textured from other images. But, after employing the developed technique the occlusions are automatically detected and a colored point cloud for the façade free from the occlusions is generated in just one step, as shown in the end of figure 5.



Point clouds for the façade resulted from blind texturing using one photo (each point cloud under its corresponding photo), the marked areas show the false texturing due to different types of occlusion



The textured façade free from the different types of the occlusions (textured using the three photos)

Figure 5: The developed technique effect on texturing a real facade

3. ENGINEERING APPLICATION

The vehicle's manufactures are interested in the 3D reconstruction of the traffic crossings to investigate the traffic safety on those cross-sections not only from the geometric design point of view but also from the vehicles safety point of view as well (Abdelhafiz and Niemeier, 2006).

The used technique here is general and can be applied to any site and with any laser scanner with no need for artificial targets or total station work. The technique aims to present all the available information, geometry, intensity, and texture about the object points in one environment. The data is captured by two independent sensors, a scanner and a camera. The two data sets are then registered in one coordinate system which enable the data fusion. The execution sequence of the application will be presented in details in the following sub sections.

3.1 Data Acquisition

The experimental work is executed on a real narrow traffic crossing with thick trees and limited field of view. The geometry and the intensity are captured with a laser scanner and the texture is captured by a digital camera as follows.

3.1.1 Digital Photogrammetry

A professional digital camera, Canon EOS 350D, eight MP was employed to capture a set of photos for the crossing, see figure 6 for a general layout for the scene. The photos were captured with a 24 mm lens. The CCD sensor of the camera is 22.2 x 14.8 mm with maximum effective 3456x2304 pixels. The camera positions configuration were chosen according to the best available photogrammetric configuration rules. The average camera object distance was ranging between 30 to 40 meters which resulted in about 8.0 to 10.7 millimetres ground pixel size.

Camera Calibration:

The camera can be calibrated under control in the laboratory (Faig, 1975) or calibrated using the same project images (self-calibration) (Fraser, 1997). Self-calibration is normally used if the camera settings are vary between images. Certain geometric configurations of images, which restrict the imagining, are considered to achieve accurate and reliable self-calibration. Since this is not guaranteed at the project site, it is sensible to employ a professional camera and fix the settings in the calibration and the field work. In this work, the camera calibration was executed in the IGP- photogrammetric lab with the help of a control field shown in figure 7 equipped with two scale bares. The Australis software was employed to apply the bundle solution to get the camera interior orientations. All the lens distortion parameters, radial, decentering, and affinity were also determined in this process.

3.1.2 Laser scanning:

Figure 8 shows the layout of the three captured scans using the Imager 5003 laser scanner, which uses laser safety class 3R (DIN EN 60825-1) and capable of capturing up to 500,000 points per second. The maximum captured rang for this scanner is 53.5 meters with linear error less than 5 mm, its beam diameter at 1 m distance is 3 mm circular. It has a 360 by 310 degree field of view with 0.02° accuracy. The noise range at 10 m is 1.3 to 3.3 mm, and at 25 m is 3.0 to 9.0 mm depending on



Figure 6 : General layout

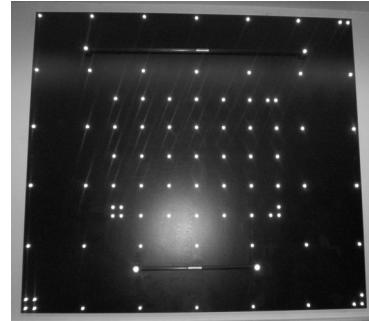


Figure 7: Calibration field equipped with two scale bares

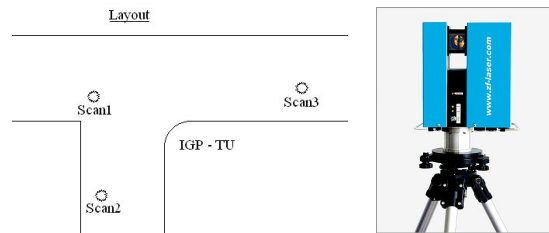


Figure 8: The scanning layout and the Imager5003 laser scanner

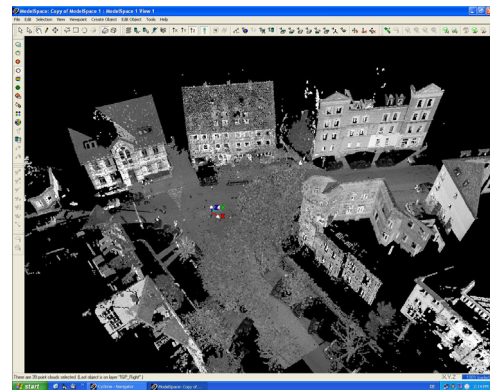


Figure 9: The three registered scans displayed in cyclone software using the grey scale

the reflectivity from the white to the dark grey. Along with the Cartesian coordinates of each of the scanned points, the laser also measures the intensity value of each point.

The points spacing is ranged from about 4 mm near to the scanner to about 5cm far away. The three scans positions are then registered using natural points to reconstruct the 3D model as shown in figure 9.

3.2 Registration of images and point cloud

The registration process aims to define the exterior orientations of the camera stations and the 3D point cloud in one coordinate system. The point cloud here is not limited to be only one scan but it could be a composition of pre-registered multi scans, or even a part of it. Surveying points could be used to put the point cloud coordinates and the image's external orientations in the surveying points coordinate system. Interactive selection of corresponding points in the 3D model and in the images could be also resulted in the internal and the external orientations (Beraldin et al, 2002). But the several manual operations, in marking the image points and in the points extraction from the point cloud, make these techniques dependent on human interpretation and can be error prone.

The image marking process could be turned to be automatic and accurate by using special artificial targets, white circles with black background or any other automatic recognized shape, with the suitable algorithm and software (e.g. Australis and i-witness). In our developed technique, natural points are used, as placing artificial targets will limit the flexibility of the approach.

The points extraction from the 3D point cloud, which is widely affected by the human interpretation, could be limited by decreasing the weight of the exact values of the extracted 3D coordinates by using them as approximation values in the bundle adjustment solution instead of using them as control points (Abdelhafiz et al, 2005a). This will of course require more marked image points from 30 to 40 points to give a robust bundle solution, but, it is not a must to extract approximation values for all the marked points from the 3D model, as the available close approximations could be employed in an intersection process to get approximation values for the rest of the marked points and for the external orientations as well. Then the bundle solution will try to shift and rotate the bundles of light-rays so that all conjugate light-rays intersect at the corresponding object points to get the final results of all redundant.

The registration of the images and the point cloud is an important step in the applied approach as the texturing process is severely affected by the registration accuracy. This accuracy depends mainly on the photogrammetric solution, which consequently relies on:

- The point cloud accuracy and the spacing between the points.
- The number of the photos which are used to reconstruct the photogrammetric model.
- The ground pixel size of the captured photos, (Abdelraheem et al, 2003) which is affected by the imager dimensions (Mega pixel of the camera), and the average image scale (f / H_{av}), where f is the focal length and H_{av} is the average distance between the camera and the object.

3.3 Data fusion

It is required for the data fusion to know the corresponding image pixel for each point from the point cloud. To compute the image coordinates for a known 3D ground coordinates point, collinearity, coplanarity and direct linear method could be in principle employed, using the exterior and the interior orientations of the camera stations (Manuel of photogrammetry). In this work the colliniarity equations are

employed and the radial, decentering, and affinity distortions are considered in the solution. A 2D coordinate transformation is then needed to get the corresponding image pixels.

Once, for each point from the cloud, its corresponding image pixel is known, all the information about the point, which are the 3D coordinates, the intensity, and the three color components, are ready to be fused. Our developed technique is therefore employed during the texturing process to could manage the occlusions in the scene.

3.4 The final 3D cloud

The following steps are executed in our application to get the textured 3D point cloud:

- A photogrammetric model is reconstructed for the captured images using extracted points from the cloud together with the precise interior orientations obtained from the camera calibration, then the exterior orientations for all the camera positions are computed using the Australis software.
- The point cloud is segmented into parts to save the processing time, and the corresponding photos for each part is used for the texturing.
- A batch file describes all the segments and their corresponding photos is created and consequently a 3D textured cloud is generated.
- The visualization could be achieved now through any 3D colored viewer.
- The light reflection on the asphalt is widely varying from photo to photo, therefore the streets are better visualized in grey scale.

The 3D Image software is used here to obtain the textured 3D point cloud which is opened in the cyclone software. Figure 10 shows some snapshots from the final 3D model.



Figure 10: Some snapshots for the crossing true colored point cloud displayed in the cyclone software

4. CONCLUSIONS

In this paper, a new technique is developed for texturing the terrestrial laser scanner point clouds using multi images. The developed technique seems to be promising and have potential in detecting and dealing with the occlusions especially in complex sites. As a part of this work a special software is developed to execute the technique full automatically. A successful documentation for a real traffic crossing is also presented and a textured 3D point cloud is generated, which completely represents the scene with no need for any further modelling processes.

The followings are some precautions to be considered during the technique execution:

- One has to capture each part of the scene with at least two photos, occlusions free, and from different angles of view.
- Employing the very near photos, the same photo two times, horizontal and vertical photos from the same position, or photos lay on nearly one line projected from the object will result in false texturing in case of occlusions existence.
- The images and the point cloud registration accuracy, as it plays an important role in the texturing result and generally the more accuracy obtained in the registration stage the better quality obtained from the texturing process.

5. REFERENCES

Abdelhafiz A., and Niemeier W., 2006. 3D Reconstruction of a real traffic cross section based on the combination between the laser scanner point cloud and the digital photos. 5th International Symposium Turkish-German Joint Geodetic Days, Berlin, Germany.

Abdelhafiz A., B. Riedel and W. Niemeier, 2005a. Towards A 3D True Colored Space by the fusion of Laser Scanner Point Cloud and Digital Photos. International workshop 3DArch, Mestre-Venice, Italy.

Abdelhafiz A., B. Riedel and W. Niemeier, 2005b. "3D Image" as a Result from the Combination Between the Laser Scanner Point Cloud and the Digital Photogrammetry. 7th Conf. Optical 3-D Measurement Techniques, Vienna.

Abdelraheem, Farrag, and Abdelhafiz, 2003. Studying some factors affecting the digital photogrammetric applications. International Conference Of Civil Engineering Sciences, ICCESI, Assiut, Egypt.

Alshawabkeh Y., Norbert Haala, Integration of digital photogrammetry and laser scanning for Heritage documentation. Commission V WG 4, 2004.

Beraldin, J.-A., Picard, M., El-Hakim, S.F., Godin, G., Valzano, V., Bandiera, A., Latouche, C., 2002. Virtualizing a Byzantine Crypt by Combining High-Resolution Textures with Laser Scanner 3D Data, Proc. VSMM, Korea, Sept., pp. 3-14.

CAPRIOLI M. and A. SCOGNAMIGLIO, 2003. Photogrammetry and Laser Scanning in Surveying and 3D Modelling of Architectural Heritage. FIG Working, Paris, France, April 13-17, 2003.

El-Hakim, S.F., Beraldin, J.-A., Picard, M., Vettore, A., 2003a. Effective 3D modeling of heritage sites, 4th Int. Conf. 3D Imaging and Modeling (3DIM'03), Banff, Canada, pp. 302-309.

El-Hakim, S.F., Fryer, J., Picard, Modeling and visualization of aboriginal rock art in the Baiame cave. Proc. ISPRS XXth Congress, Istanbul, July 2004, pp. 990-995.

Faig, W., 1975. Calibration of close-range photogrammetric systems. *Photogrammetric Engineering & Remote Sensing*, 41(12), pp. 1479-1486.

Fraser, C., 1997. "Digital camera self-calibration", *ISPRS J. of Photogrammetry and Remote Sensing*, 52(4), pp. 149-159.

Guarnieri A., Antonio Vettore, 2004. Photogrammetry and Ground-based Laser Scanning: Assessment of Metric Accuracy of the 3D Model of Pozzoveggiani Church. FIG Working Week, Athens, Greece.

Guidi G., Tucci, G., Beraldin, J.-A., Ciofi, S., Ostuni, D., Costantini, F., and El-Hakim, S., 2002. Multiscale archaeological survey based on the integration of 3D scanning and photogrammetry, Proc. Int. Workshop on Scanning for Cultural Heritage Recording, Corfu, Greece. Sept., pp. 58-64.

Jansa J., N. Studnicka, G. Forkert, A. Haring, and H. Kager, 2004. Terrestrial Laserscanning And Photogrammetry – Acquisition Techniques Complementing One Another. Commission III WG 7.

Kern F., 2003, Automatisieren Modellierung von Bauwerksgeometrien aus 3D-Laserscanner-Daten, PhD dissertation, Institut für Geodäsie und Photogrammetrie, Technische Universität Braunschweig.

References from Books:

Manual of Photogrammetry, fifth edition, 'American Society of Photogrammetry and Remote Sensing (ASPRS), 2004.

American Society of Photogrammetry and Remote Sensing (ASPRS), 1989. 'Manual of Non-Topographic Photogrammetry', second edition.

Atkinson K., 1996. Close range Photogrammetry and Machine Vision.

Australis user's manual, January 2004.

Cyclone user's manual, December 2002.

Moffitt F. and Mikhail E., 1980. PHOTOGRAMMETRY, third edition.

Monadjemi P., 2000. Microsoft Visual Basic.