TOWARDS A 3D TRUE COLORED SPACE BY THE FUSION OF LASER SCANNER POINT CLOUD AND DIGITAL PHOTOS

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ABSTRACT:

The fusion of the laser scanner data, with its very rich point cloud, and the digital image, with its very detailed information about the radiometric characteristics, to produce optimum 3D model, not only from the accuracy point of view, but also from the simplicity of capturing and the visualization quality as well, is considered recently one of the important tasks in the surveying field.

In this paper, an approach to combine the laser scanner point cloud with the digital images to produce a 3D true colored point cloud will be presented. The main idea is to register the images with the point cloud in one coordinate system then each point of the cloud will be fed back by its correct color from the digital image. To extract the fine details appearing in the image and to fuse them in the point cloud with their true colors, a new technique is developed, in which the corresponding 3D coordinates for the in between image pixels are computed using the 3D coordinates of the adjacent pixels. The developed approach could be used in representing real objects more adequately with a good metric accuracy and it seems to be beneficial in fields of cultural heritage documentation, and industrial applications.

1. INTRODUCTION

Although, the digital photogrammetric technique dealt since many years with the 3D reconstruction of objects from one or more images and there are many commercial software available for image processing and 3D modeling in addition to the earlier developed texture correction and visualization procedures, which give the potential to the current results from image-based modeling, but the use of the laser scanning combined with high-resolution texture maps should be considered (El-Hakim et al, 2003b).

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 single 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. Further more, the laser scanning is an active technology, therefore, there are no problems with daylight or illumination conditions, the laser also does not care of heavy cast shadows or severe brightness contrasts (Jansa et al, 2004). On the other hand, the resulted point clouds bear no information about the color of the captured objects. Nowadays, the optional true color channel, integrated in some laser scanner types, provides the color of the target's surface as an additional information to each measurement. Other laser scanner types attach camera or video camera to capture the object color, for more details see www.cyra.com, www.riegl.com, and www.mensi.com. Although these types of laser scanners are very expensive, but they still not with the desired quality for two main reasons; firstly, 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. Secondly, the texture between the scanned points, which are available in the image, are not captured by the laser scanner. A proposed solution for these is to acquire geometry and texture by two independent devices and combine the two sets of data.
Many researchers compared the laser scanning technology and the digital photogrammetry with their combination results, and stated that the optimal solution is the fusion of the data (Kern, 2003; Caproili et al, 2003; and Guaranie, 2004). Different approaches and techniques for the data fusion are also developed. (Guidi et al, 2002) used the photogrammetry to register multi scans in one coordinate system. Photogrammetry has been used to model the main shapes while laser scanning captured the fine details (El-Hakim et al, 2003a) and (Alshawabkeh et al, 2004). Surveying points are used to register the texture images with the geometry (El-Hakim et al, 2004). The point cloud is attached to the digital image to generate a complete map on the computer screen, (Abdelhafiz et al, 2005).

In this paper, a new technique is developed to obtain a true colored 3D point cloud using a laser scanner, with no color channels, and a digital camera. In this technique, the images are registered with the point cloud system coordinate using close approximation values of natural points extracted from the cloud. After the registration, the pixel colors are extracted from the image and fused in the point cloud. The fine details provided by the image pixels are also exported to the point cloud using the 3D coordinates of the adjacent pixels. A computer program '3D Image & Colored Space' was developed as a part of the PhD work of the first author, to execute the pre mentioned process.

A major advantage of this approach that, real objects could be represented adequately together with a good metric accuracy as the 3D true colored point cloud, resulted from this approach, is already a complete representation for the scene without any further modeling processes. This would give the approach the potential to be used for many applications in field of cultural heritage, industrial, or medical. In the cultural heritage field, 3D models represent an interesting tool for as-built documentation and interactive visualization purposes, e.g. to create virtual

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reality environments (Jansa et al, 2004). The developed technique was employed here to generate a 3D true colored point cloud for our Institute of Geodesy and Photogrammetry, IGP, which presents a complete 3D model for the building.

A detailed description will be presented in the following sections. Section two provides the associated problems and the proposed solutions. Section 3 describes the applied approach in order to deliver the desired 3D colored cloud in some detail. The developed program is presented in section 4 and a practical application in field of cultural heritage using the developed technique is presented in section 5. The paper conclusions are summarized in section 6.

2. PROBLEMS AND POSSIBLE SOLUTIONS

Three main problems are addressed in this section together with their proposed solution in the developed approach.

2.1 Images and Point Cloud Registration

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. Interactive selection of corresponding points in the 3D model and in the images usually results in the internal and the external orientations (Beraldin et al, 2002). Surveying points are also used to set up the reference frame for the texture images and for the scanned points, but the several manual operations required make this technique dependent on human interpretation and can be error prone (El-Hakim et al, 2004).
The use of artificial targets, white circles with black background or any other automatic recognized shape, with the suitable algorithm and software (e.g. Australis) will turn the image marking process to be accurate and automatic. As placing artificial targets will limit the flexibility of the approach, so natural points are used in the developed technique.
The proposed solution, to limit the effect of the human interpretation in the points extraction process from the 3D point cloud, is to decrease the weight of their exact values by using them as approximation values in the bundle adjustment solution. This will require more marked image points from 30 to 40 points, to give a robust bundle solution. It is not a must to get approximation values for all the marked points, 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.

2.2 Color Extraction

To feed the 3D point cloud with the color information from the digital images, an image simulation process using the collinearity equations is employed to calculate the image coordinates for each point of the laser scanner point cloud, then the image coordinates are transformed to the computer coordinates in pixels. The color composition red, green, and blue is then extracted from the corresponding pixels, and the desired data fusion is executed.

2.3 Texture Extraction

The concerned texture here are the fine details on the image pixels which lie between the mesh of the point cloud. The texture extraction process is normally executed, after the triangulation of the point cloud or of the modelled objects. In case of large spacing point cloud, the cloud does not provide sufficient data to construct outlines for all surface features of the scanned object, even though they are clearly defined in the reality which will affect the quality of these edges, so the information on edges and linear surface features should be based on the analysis of the images (Alshawabkeh et al, 2004). for more details on procedures developed earlier for texture correction and visualization, see (El-Hakim et al, 2003b).

The following technique is developed, in this work, to serve in extracting the remaining texture, lying between the point cloud without triangulation or modeling processes. for each pixel of the image which is not textured before, its 3D ground coordinates are calculated depending on the adjacent 3D coordinates in a given search radius. The calculated 3D coordinates with its color composition are then exported to the point cloud. A dense point cloud with all the image texture is resulted. Figure 6e and 6f show the IGP crown before and after the applied texture extraction. The approach uses the average, the inverse distance and the inverse distance square algorithms to calculate the 3D coordinates for the in between pixels. Another method, to use the trend of the adjacent points, will be considered in our future work.

2.4 Dead Areas Managing

In some cases, dead areas are remain in the 3D point cloud and they are appear in the digital images. A possible solution to cover these regions is presented in the developed technique. The main points are obtained from the photogrammetry see figure 4a then these points are used to generate true colored point clouds for the surfaces with a given point spacing, which could be defined by the user, to match the original point cloud density see figure 4b. The desired colored point cloud for the dead area is finally fused in the original point cloud see figure 4c.

3. THE APPLIED APPROACH

The combination between the laser scanning and the digital photogrammetry has been executed in several ways to get use of the metric information provided by the cloud and the rich radiometric characteristics provided by the digital images, see section1. The presented approach gives solution to the pre mentioned problems in section 2. A computer program '3D Image & Colored Space' was developed, as a part of this work, to execute the developed technique which is general and can be applied to any site and with any scanner for the following reasons: Firstly, The registration process doesn't need extra surveying points. Secondly, The technique doesn't require a highly accurate laser scanner as the extracted points from the cloud are used as approximation values in the photogrammetric solution. Thirdly, It isn't a must to acquire the data with the two systems at the same time. In this work, the two acquiring systems are not available together.
The approach aims to feed the point cloud with the color information from the digital images to generate a true colored point cloud using a relatively low price laser scanner, which may have no color channels or poor color channels, and a

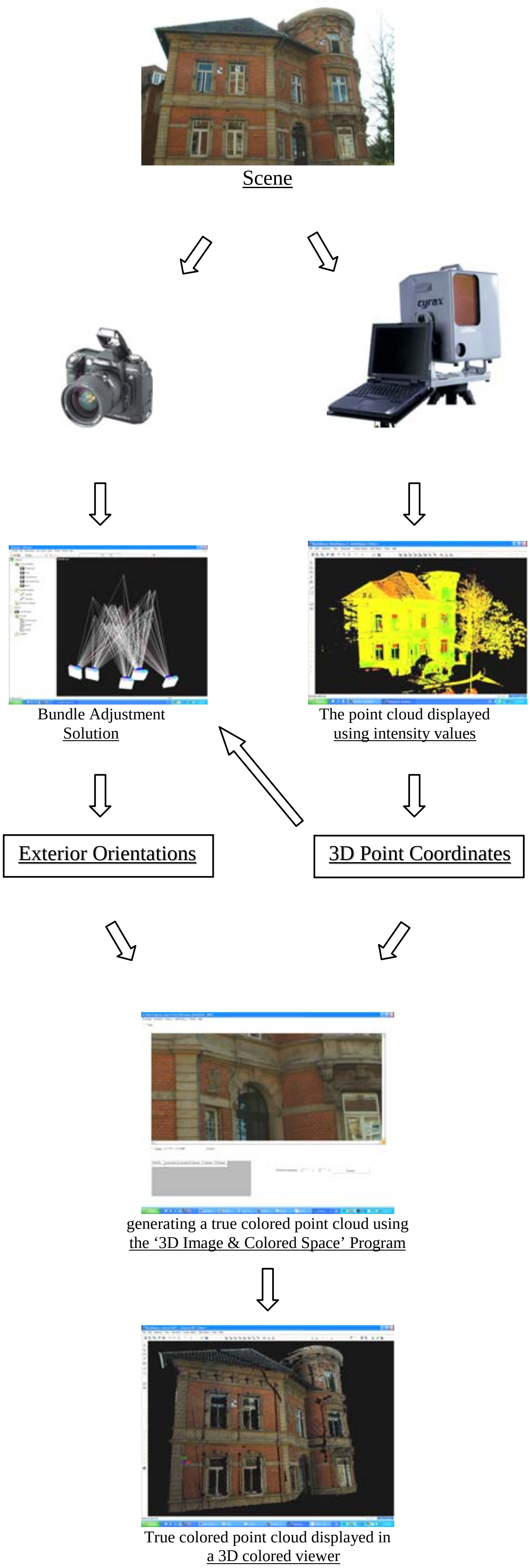


Figure1. The Approach Flow Chart

digital camera. Then to feed the image pixels with the corresponding 3D coordinates to represent the fine details appeared in the images. The execution sequence of the approach will be described in details in the following sub sections. A flow chart for the technique is also shown in Figure 1.

3.1 Data Acquisition And Reduction

The preliminary test was executed inside the photogrammetric laboratory, IGP. The laser scanning technology and the digital photogrammetry were applied on the scene; the details will be discussed in the followings.

3.1.1 Digital Photogrammetry

A pre-calibrated 24 mm zoom lens attached to a general purpose professional digital camera, Fuji FinePix S2 Pro, was employed to capture six photos for the scene by the highest available camera resolution (6.17 million pixel). The camera CCD sensor size is 23.3 x 15.6 mm with maximum effective resolution 3024x2016, which mean that the minimum pixel size of that camera is 7.7 micron. The camera positions configuration were considered according to the available photogrammetric configuration rules see Figure 2. The average camera object distance was about 7.5 meter and the ground pixel size was about 2.3 millimetres, which depends on the scale of the captured image Abdelraheem et al, 2000.

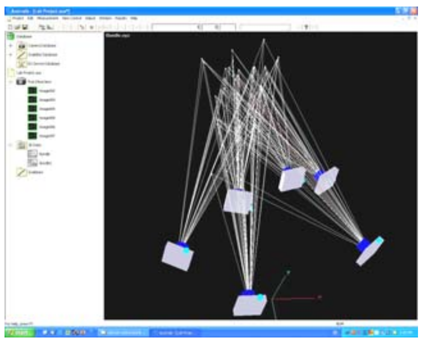


Figure 2. Actual camera positions

Forty points were marked in the images. Eight of them were extracted from the 3D point cloud, which were sufficient to compute approximation values for the rest of the marked points through the intersection process. The Australis software was employed to calculate the external orientations using the pre determined internal orientations. The extracted eight coordinates are used one time as control points and another time just as close approximation values to evaluate and compare the two photogrammetric solutions.

All the artificial and natural points in the scene were measured in the experimental work with a total station LEICA TCRA1101 PLUS without reflector, which delivered 3D coordinates with about three millimetres accuracy. These ground coordinates were registered and compared with the 3D coordinates resulted from the photogrammetric solution and the root mean squares were calculated in all directions as follows:

Case 1 the eight points act as control points: The root mean squares were 4mm [X], 4mm [Y], and 10mm [Z].

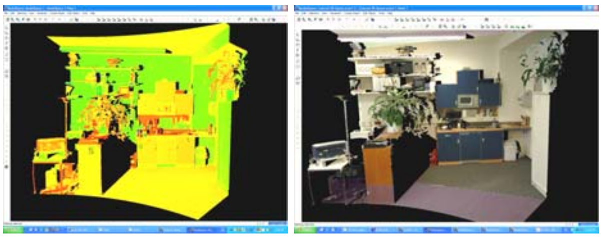
Case 2 the eight points act as approximation values: The root mean squares were 5mm [X], 6mm [Y], and 8mm [Z].

From the above results, it could be said that using close approximation values in the photogrammetric solution give

reasonable results. This method gives potential for this technique as it will eliminate the human interpretation errors in the points extraction process.
In some cases, in which the selected points are not well distributed on the images, the photogrammetric solution will need extra approximation values from the point cloud for the intersection calculations.

3.1.2 Laser Scanning

One point cloud for the scene was surveyed by the Cyrax2500 laser scanner with 4 millimeters point spacing. The Cyrax2500 scanner uses a rapid-fire pulsing green laser (class II eye-safe). The laser is used with state-of-the-art high speed timing electronics to perform time-of-flight measurements, for more details see Lichti and Harvey, 2002. The resulted 3D point cloud coordinates are relative to the scanner and have an aggregate expected accuracy of 6 millimeters (one sigma standard deviation). Along with the Cartesian values of each of the scan points, the laser also measures the intensity value of each point, which is a measure of the color and texture of the objects from which the laser reflects (Cyclone user's manual, 2002). The intensity values of the points are used to display the cloud in the cyclone software see figure 3a, from which the 3D point coordinates needed to the photogrammetric solution were extracted.
Although the software has the ability to define any coordinate system through three defined points to give the user the flexibility to choose his own coordinate system, but in this work no coordinate transformation was needed, as the point cloud coordinate system will be considered to be also the photogrammetric coordinate system.



a. intensity color b. true color

Figure 3. The Point Cloud for a part of the photogrammetric laboratory

3.2 Registration Of The Image With The Point Cloud

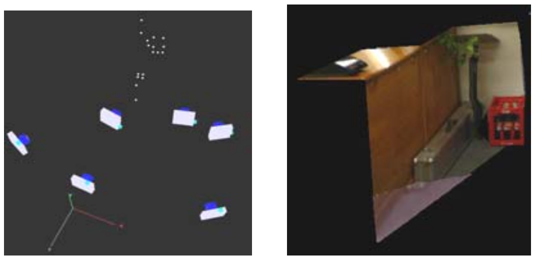
As the images exterior orientations are calculated from the extracted 3D coordinates from the point cloud. The exterior orientations and the point cloud are lying in the same coordinate system, which is the point cloud coordinate system. This mean that after section 3.1, there is no need to register the images with the point cloud as they are already registered.

3.3 Color and Texture Extraction

The corresponding image coordinates for each point of the cloud are calculated using the collinearity equations, then transformed to pixels. The desired pixel colors are exported to their corresponding 3D points to obtain the true colored 3D point cloud.
As the average point cloud spacing in this test is 4 millimeters and the average ground pixel size is 2.3 millimeters, there is about one pixel, between each two points of the point cloud, in the image still not textured. The '3D Image & Space' program is employed using one pixel search radius and the average algorithm to get the fine details from the image. An over view on the developed program will be described in the section 4.

3.4 Dead Area

A good feature in this approach is the ability to cover dead areas, which may appear in the point cloud see Figure 3b, using the digital photos. The main points are computed from the photogrammetry then the '3D Image & Space' program will generate the desired colored point cloud for the dead area, see figure 4a and 4b.



a. Points form photogrammetry b. after the surface creation

c. After the fusion in the original point cloud

Figure 4: The covered dead area

The sequence is applied as follows: The photogrammetric points are used to generate a small point cloud for the surfaces with a given density, which is defined by the user, to match the original point cloud density. The pixel color information is also extracted and the surfaces with their true colors are fused in the original point cloud.

3.5 Accuracy Evaluation for the Used Technique

During the approach execution to get the true colored 3D cloud, no changes occur on the original point cloud coordinates and the only change occurs on the colors, i.e. the accuracy of the point cloud coordinates is only dependent on the used laser scanner and its accuracy.
The discussed accuracy here is the accuracy of locating the corresponding image coordinate on the image to extract the pixel color. In this work about forty actual and artificial points were measured with a total station to be check points.
The root mean squares between the measured image coordinates and the calculated image coordinates through the image simulation process was calculated for the six used images and was ranging between two to three pixels. These two or

three pixels doesn’t affect the visualization significantly, but It appears in the zooming on some object edges.
In the texture extraction process, the accuracy of the computed 3D coordinates for the fine details depends mainly on the nature of the object, the point cloud spacing, and the applied algorithm.

4. THE ‘3D IMAGE & COLORED SPACE’ COMPUTER PROGRAM

A computer program was developed in the Visual Basic language as a part of this work to execute the color extraction process. The developed program is user friendly and easy to be used. The program input is the point cloud, which could be one scan, a composition of pre-registered multi scans, or even a part of it, and one photo with its interior and exterior orientation.
The program uses the collinearity equations considering the radial, decentring, and Affinity distortions, see Manual of Non Topographic Photogrammetry, 1989, and Atkinson, 1996, to obtain the corresponding image coordinates. A 2D coordinate transformation with scale change for the obtained image coordinates is applied to get the corresponding image pixels. The corresponding color composition red, green, and blue for each pixel are then recognized and attached to the 3D point coordinates. To extract the fine details from the image pixels which lie between the mesh of the point cloud. The program scans all the image searching for the non-textured pixels. Their 3D ground coordinates are calculated depending on the 3D coordinates of the adjacent pixels in a given search radius. Three algorithms are used by the program, the average, the inverse distance, and the inverse distance square. The calculated 3D coordinates with their color composition are then exported to the point cloud.
The output of the program is a pts file which bears information about the 3D coordinates in addition to the intensity and the true color for each point. The resulted (.pts) file format could be opened in any colored 3D viewer such as the cyclone software. Figure 3b and 6a show the program output displayed in the Cyclone software.

5. PRACTICAL APPLICATION IN CULTURAL HERITAGE FIELD

The developed technique was used to generate a 3D true colored point cloud for the institute of geodesy and photogrammetry, IGP, which considered one of the old buildings in Braunschweig. The execution procedure will be described in the following sub sections.

Figure 5: The layout of the IGP

5.1 Data Capturing

The occlusion from the trees around the building have pushed to survey four scans by the Cyrax2500 laser scanner. The required registration between the four scans was made inside the Cyclone software to get one model for the building with about 3 centimetres point cloud spacing. The scanned trees was deleted from the scan world which results in many gabs in the model see for example the crown in Figure 6e. The required approximation values which are necessary to the photogrammetric solution are also extracted from the scan world.
Figure 5 shows the layout of the building. It is clear that, the trees make a great difficult to get one photogrammetric solution for all the captured photos. So, two individual sets of images each of five images were considered to each side of the building using the Fuji camera with the 24 mm zoom lens and with (3024x2016) resolution , The average camera object distance was about 17.5 meter, which gives about 5.6 millimeter ground pixel size.
About forty points were marked in each image and the extracted approximation values from the point cloud were employed to run the Bundle adjustment using the Australis software to calculate the exterior orientations for the camera stations for the two set of the photos. During the bundle process, the interior orientation, which is resulted from the camera calibration, was set as fixed values.

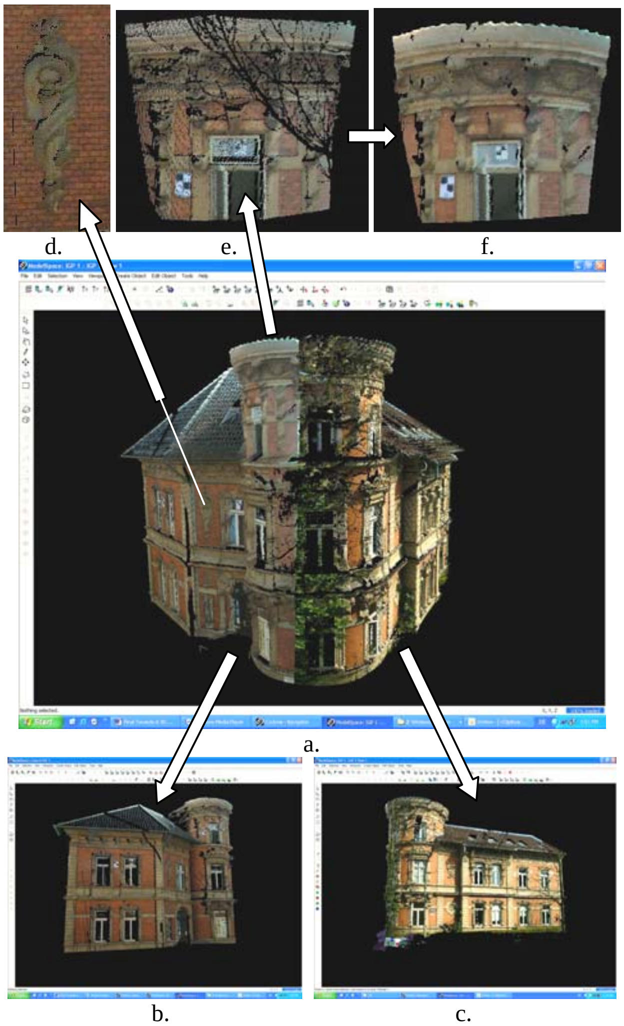


Figure 6. Details of the final colored point cloud for the IGP

5.2 Data Fusion and Texture Extraction

All the images are now registered with the point cloud in the same coordinate system and the color extraction process could be executed using the '3D Image & Colored Space' Program. The original point cloud was divided into two files, each one with the suitable image, to generate the desired 3D true colored point cloud for the building, see Figure 6a, which represent the 3D model in the Cyclone with no extra modelling processes. The fine details are also extracted using the developed technique, in which the inverse distance square algorithm and five pixel search radius are chosen. This technique gives good result with the small gabs but the large gabs beyond the search radius are still without filling.
As the thick trees in this application prevented capturing photos for the building itself at the middle part with no appear for the trees, false colors extraction for the middle part of the building are resulted. Another issue here, that the lighting variation between the two used images is significant, which resulted in the isolation line appeared at the round part of the building. This is usually happen in an outdoor environment where the lighting is not controlled. Using color correction from multi images should decrease the effect of the outdoor lighting variation.

6. CONCLUSIONS

In this paper a new technique is presented to generate a 3D true colored point cloud using a laser scanner and a digital camera. After the registration of the images in the same coordinate system of the cloud using natural points. The '3D Image & Colored Space' computer program was developed to extract the true pixel color from the image and import it in the point cloud. The developed technique is also used to extract the fine details from the image using the 3D coordinates of the adjacent pixels. The main features of the used technique are stated in the followings:

-No changes occurs to the original point cloud coordinates during the whole calculation processes, which means that there is no loss in the point cloud coordinates accuracy during the approach execution.

- Although, some points might feed back by non correct color, but this doesn't affect the visualization quality significantly.

- The use of natural points extracted from the point cloud reduces the field work and employing them as approximation values in the bundle solution eliminates the effect of the human interpretation in the extraction process and give the approach more flexibility.

- The technique is extended to extract data from the photogrammetric solution for the dead areas and create the required surfaces then fuse them in the laser scanner point cloud with their true colors..

- The developed technique for the texture extraction could be an alternative for the modeling process with all its needed time and effort.

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