ABSTRACT: 3D reconstruction of outdoors objects by means of terrestrial laser scanner (TLS) point clouds has been one of the most important and reliable technical methods. However, TLS point clouds have two main drawbacks. They don’t have sufficient information about the object texture, and sometimes a complete perspective of the facades cannot be got due to the irregular circumstances. Photogrammetric images contain the required texture and can be used to generate dense point clouds by further processing. Therefore, a flexible approach for getting 3D information from photogrammetric images is applied within this paper. Two steps are taken in this approach. Firstly, Structure from Motion reconstruction is used to derive orientations and sparse surface information. Secondly, with the resulting orientations and information, SURE software, which is developed by Institute for Photogrammetry of Stuttgart University, is applied to obtain dense point clouds. Before 3D modeling, these two kinds of point clouds have to be brought into a common main reference system by means of Helmert (seven-parameter) transformation and ICP algorithm. Based on the processed point clouds, Leica Cyclone software and Google Sketchup can be used to produce geometric and texture wrapped model. The textured model is shown and the quality of modeling and visualization is validated.

1. INTRODUCTION

For 3D model generation, terrestrial laser scanning and photogrammetry are two typical kinds of method. Dense 3D point clouds of the surface of the object can be collected by the two methods which can be processed later to generate CAD model.

Terrestrial Laser Scanning is a ground based technique to measure the position and dimension of objects in the three dimensional space. Terrestrial Laser Scanning can do reliable measurement and can get very dense point clouds of the object surface, and also it is very accurate and high speed although the instrument is expensive. Thus it is very fitful to do the 3D reconstruction and high definition surveying which can be short as HDS can be done.

Photogrammetry point clouds generation consist of close and far range photogrammetry which both have been using in this thesis. 3D point clouds generation can be performed by using stereo image pairs. The 3D coordinates of the points on an object can be determined by measurements made in two or more images taken from different positions. Image matching needs to be done to find the common points on each image. By using collinearity equation a line of sight can be constructed from the camera location to the point on the object. Forward intersection can be done by the intersection of these rays that determines the 3D location of the point. Thus, the 3D point of the object can be got.

3D models are very important in in digital preservation as reference scale model, and also can contribute to the city project planning, road analysis, building maintenance in digital city. But due to the complex environment of the urban area, there is still no optimal approach or procedure which is adequate for all cases. Although the terrestrial laser scanning is very fitful for the point clouds acquisition, it still can’t get all data for the 3D reconstruction because of occlusion. Thus, 3D point cloud acquisition using both aerial photogrammetry and close-range photogrammetry has been used to get the missing area and roof landscape.

2. TERRESTRIAL LASER SCANNING

The terrestrial laser scanner emit a narrow laser beam that sweep across a target object, such as bridge or a building, gathering millions of closely spaced measurement (points with a unique X,Y, and Z, values). The scanned data are collected and grouped to show the position and geometry of the objects in the three dimensional space. Modern 3D-laser scanners are available from a number of manufactures, e.g. Faro, Leica, Riegel, Topcon, and others. Since
the interest area of this thesis is in the city center which has a lot of people passing by, Leica HDS3000 has been chosen because the laser beam emitted from it is eye-safe. It can get 1800 point in one second and large datasets including intensive maps scalar field and RGB colors can be generated.

The scanner has a limited view, and according to the structure of the task area. It needs more than one station. Scan points are recorded and saved in a coordinate system which is related to the scanner, so different scans have different local coordinates. Therefore, it is necessary to determine the spatial relationship between the different scan stations, which is called scan registration. And the step from the scan coordinate system into the overall coordinate system is called transformation. The reference objects are needed for the registration. For the registration, it needs more than 3 reference objects to do the coordinate transformation. There are two common references: natural references (planes, slabs, pipes, corner points, etc.) and manually placed references (spheres, circular flat, checkerboard references, etc.). After registration, the final result can be shown in Cyclone.

After finished the registration of each stations, a complete point cloud of the block and the neighboring area with acceptable scanning accuracy and registration accuracy can be got. But this point cloud is not sufficient to do the modeling. The inner part of the block is missing since the roof can’t be scanned by the terrestrial laser scanning. And also some areas of the block are missing since the problem of occlusion. Occlusion is the problem which can always happened due to the irregular circumstance of the field work. Figure 1 shows the missing area of laser scanning.

The terrestrial laser scanning can deliver almost everywhere which can be viewed from the station, but some areas are still missing because of occlusion. The missing part of the block is the roof which can’t be scanned by the terrestrial laser scanning. And also the limitation of HDS3000 the irregular circumstance around the station can cause the data missing during the field work. Some other method need to be combined to make up the drawback of the terrestrial laser scanner.

3. PHOTOGRAMMETRY POINT CLOUDS GENERATION

Photogrammetry point clouds generation consist of close and far range photogrammetry which both have been using in this thesis. And 3D point clouds generation can be performed by using stereo image pairs. The 3D coordinates of the points on an object can be determined by measurements made in two or more images taken from different positions. Image matching needs to be done to find the common points on each image. By using collinearity equation a line of sight can be constructed from the camera location to the point on the object. Forward intersection can be done by the intersection of these rays that determines the three dimensional location of the point. Thus, the 3D point of the object can be got. By very dense image matching, each pixel of the object on the images can be processed and a very dense point cloud of the object can be generated which is sufficient for the modeling. By using photogrammetry method the missing area of the building facade and the missing roof landscape in the terrestrial laser scanning can be made up. Then the generated point clouds need to be brought into a common main reference system by means of a Helmert (seven-parameter) transformation and the ICP algorithm before 3D modeling.

3.1 Close Range Photogrammetric Image Acquisition

Close range photogrammetry is done by using photographs taken at closer range, often less than 1,000 feet (about 300 meters) and is used for detailed three dimensional renderings and plotting of small-scale features and objects. By taking images in different position with different orientation, the forward intersection can be done and the point cloud can be generated. For the missing area in terrestrial laser scanning, although the laser scanning stations can’t be set on the opposite side of the river, but the images can still be taken from the opposite side of the river. So the close range
photogrammetry can be used to make up the drawbacks of the terrestrial laser scanning.

To start close-range photogrammetry the images need to be taken firstly. Then in the digital images acquisition part, totally 12 images with different orientation and positions have been taken. The acquisition of digital images considers desired coverage of the main façade, and should be taken in different positions and orientations to form stereo images. Figure 2 shows the pictures which were taken by the Nikon camera 4288x2848pix CCD and 20mm focal length. The configuration of the images will affect the result of 3D reconstruction so the places of taking images need to be well arranged if possible. And the SFIT operator will be used to get the orientations and positions of the images.

Figure 2 Bridge images for close-range photogrammetry

3.2 Close Range Photogrammetric Image Data Processing

Since the data we got is only the images of the missing area of the bridge which are not sufficient to do the 3D reconstruction, the images needed to be processed first. 3D reconstruction needs the position and orientation of each image which can be calculated by bundle adjustment, but for bundle adjustment the common points on each image are needed. So the image matching needs to be done first.

Scale-invariant feature transform (SIFT) is an algorithm to detect and describe local features in images. And important characteristic of these features is that the relative positions between them in the original scene shouldn't change from one image to another. After getting the common feature points by SIFT operator, the bundle adjustment can be done, the relative position and orientation can be calculated and a sparse surface of the object model can be got. In this paper, Pairwise Feature Based Image Matching for GPU (SIFTGPU) and Multicore Bundle Adjustment (PBA) were used in VisualSFM open-source software to obtain the sparse 3D reconstruction in model space. And the RANSAC robustness estimation is also used for filtering mismatching. After 3D reconstruction, the relative orientation and position can be got as figure 3(left), and a sparse surface of the missing area can also be got.

But this sparse surface is not sufficient to do the 3D modeling. What the 3D modeling needs is a very dense surface point cloud. SURE software, which is developed by Institute for Photogrammetry of Stuttgart University, is applied to obtain dense point clouds. SURE is a software solution for multi-view stereo, which enables the derivation of dense point clouds from a given set of images and its orientations. Up to one 3D point per pixel is extracted, which enables a high resolution of details. Two kinds of data need to be input to the software first, one is images and the other one is orientation. For images formats are JPEG, TIF and PNG. For the orientation and position information, the project file in .prj format and visual SFM file .nvm are supported. Within a first step images are undistorted and pair-wise rectified. Within a second step, suitable image pairs are selected and matched using a dense stereo method similar to the Semi Global Matching (SGM) algorithm. And forward intersection of each pixel can be done. Thus, a very dense point cloud can be generated. The generated point clouds are in .las format and can be check in cloud compare software. Figure 3(right) shows the point cloud which generated by the SURE software.
3.2 Aerial Photogrammetry

Aerial photogrammetry is a technique for creating two dimensional (2D) or three dimensional (3D) models from aerial photographs, which are pictures of the Earth from a high point, usually an airplane. For the missing area of the roof landscape, the aerial photogrammetry has been used to generate the point clouds of this area. The generated point clouds can not only used in making up the missing area of roof landscape, but also in georeferencing of the point clouds. The aerial images are provided by ifp. Totally 6 images with 10cm ground resolution are available. With using the georeferenced EO parameters in project file, the DIM model in Gauss-Kruger coordinates system can be created by SURE software. Within a first step images are undistorted and pair-wise rectified. Within a second step, suitable image pairs are selected and matched using a dense stereo method similar to the Semi Global Matching (SGM) algorithm. And forward intersection of each pixel can be done. Thus, point clouds with 10cm interval can be generated. And the generated point clouds are georeferenced directly in Gauss-Kruger coordinates.

3.3 Registration

After getting the point clouds of the missing areas, the point clouds from different resource need to be combined. After open the laser point cloud and photogrammetry point clouds at the same time in the cloud compared, the position, orientation and scale are totally different which means the data need registration before using.

3D Helmert transformation can also be called as seven-parameters transformation in which 7 parameters need to be calculated including 3 translation T=(tx,ty,tz), 3 rotations angles $\alpha,\beta,\gamma$ as corresponding Euler angles refer to the rotations around x, y, z main axis respectively and scale factor $\lambda$. For each common point, 3 equations can be set. In order to calculate these parameters, more than 7 equations need to be set which means the for the Helmert transformation at least 3 common points are needed to defined the unknown parameters. To combine the closed-range photogrammetry data and the laser data of the bridge together, 6 common points are chosen manually. For getting a better result, the common points need to be chosen very carefully and the positions of the points need to be well
arranged. After getting a better result, the result RMS is 0.278 meter which is not good enough since the common point is chosen manually which can’t be accurate enough. Thus, some other method needs to be applied also.

The ICP algorithm is chosen to get a better result. In the algorithm, one point cloud, the reference, or target, is kept fixed, while the other one, the source, is transformed to best match the reference. The ICP iteratively revises the transformation (translation and rotation) needed to minimize the distance from the source to the reference point cloud. It can combine two point clouds with similar shape together without needing common points, but it required the good geometry of the two point clouds with partial aligned; otherwise this algorithm can worsen the result. So the point clouds need well selected before registration. Figure 6 shows the result of ICP registration without and with corresponding area selected, and after the ICP registration, the result RMS are 3.610 m and 0.199m respectively.

![Figure 6 without corresponding area selected (left); with corresponding area selected (right)](image)

After repeat the 3D Helmert transformation and ICP algorithm for several times, the final registration result of the bridge can be got by combine the close range photogrammetry point clouds and laser point clouds together. And the RMS is 0.08m which has been improved a lot. And the missing area has been made up. And the same method can be applied to the registration of aerial photogrammetry. Since the aerial photogrammetry point cloud is georeferenced in Gauss-Krüger coordinates, the aerial photogrammetry point clouds can be used as reference to georeference the close-range photogrammetry point clouds and laser point clouds. After combining all data together, a complete point cloud of the block have been generated and can be used for the 3D modeling.

![Figure 7 Final registration result of the bridge (left); Final registration result (right)](image)

**4. 3D MODELING**

3D reconstruction can be done by using cyclone software. In 3D reconstruction procedure, CAD models need to be generated from the point clouds. The generated model will be combined with texture mapping for good visualization. In modeling part, the basic modeling is done in Cyclone. In Cyclone, it can generate plane, pipe, and sphere, surface and so on. In this step, both buildings and terrain were generated. During the modeling, the geometry of the building should be considered since the shapes of the buildings are irregular. Simple objects provided by Cyclone need to be generated and combined together perfectly to fit the point cloud as well as possible, which means no gaps should appear on the generated model.

![Figure 8 3D reconstruction of two areas of calw market](image)
Modeling in Cyclone can generate the basic geometry model, but it can only get an approximation of real shape. Still some details and important surface information is missing. This can be done in Google SketchUp, and it can complete the surface color and other representation. For texturing, the photos with less distortion of scanned area are necessary. For better photo quality, Photoshop was used to adjust photo color, cut out the suitable area. After wrapped all the textures on to the model, the photorealistic model can be generated with good visualization.

![Figure 9 Generated 3D model after texture mapping of calw market](image)

5. CONCLUSION

3D photorealistic model was created by means of HDS. And Photogrammetry is a good method to make up the drawbacks of HDS. Although due to the inconvenience and limitation of the Terrestrial Laser Scanning, some information can’t be got by TLS, the photogrammetry can almost make up all the missing area of the TLS. TLS is a very stable and accurate way for point cloud acquisition. And Photogrammetry is a more flexible and convenient way compare to TLS. By combined two methods together, complete point clouds of the block and neighboring area can be delivered. But the quality of registration which combined the TLS data and photogrammetry data together is very important. By using Helmert transformation and ICP algorithm a result with a mean error of 0.08m can be got, but the quality can still be improved by using different method in further research.

Although the objectives of this paper have been accomplishment and related research has been done, the 3D modeling reconstruction is still a very time consuming work. The procedures including 3D reconstruction by using Cyclone and photo processing in texture mapping take much time especially. A more effective method need to be developed to fit the growing demand of the 3D modeling. Further research should consider accuracy and efficiency improvement.

References


