FUSING LASER SCANNING AND PHOTOGRAMMETRY CREATING CLOSE RANGE ARCHITECTURAL ORTHOIMAGES

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ABSTRACT

When monuments are seriously damaged, or completely destroyed, the amount and quality of documentation becomes highly important. Nowadays orthophoto's have become a standard tool in archeological and in cultural heritage documentation. By analyzing two existing software packages that are used to create orthophotographs today, we find that standard automatic surface modeling techniques as well as laser scanning do not fulfill the high needs of close range architectural orthophotography because of the large amount of discontinuities in the surface. In this paper we plan to combine the use of laser scanning, photogrammetry and image processing to overcome these problems. The major problem lies in achieving automation and efficiency together with robustness and reliability so that the algorithms and methods can be used for a successful and economically feasible implementation in practice.

I INTRODUCTION

Architecture is a substantial part of our cultural heritage. Since architectural monuments are in use, and in many cases endangered by long term influences like air pollution and weathering or destructive events like earthquakes, fire or war causing heavy damage, they have to be documented for the future. 'Precise documentation' in conservation works, deals with the use of techniques capable of acquiring geometry as well as texture information with high precision and integrity. This 'measured dataset' can be used as a mapping instrument for the recording of thematic content like historical, pathological or conditional analyses.

Nowadays orthophoto's have become the standard tool in archeological and in cultural heritage documentation. They have the qualitative merits of an image document and the metric attributes of a map, as it is a photographic orthoprojection. The digital orthoimage allows an efficient and economic way for the representation of measured data, containing texture information [12]. The generation of orthophoto's requires a dataset which consists of a description of the object's surface (DSM: digital surface model), one or more images of the object and the orientation of these images according to the surface model.

The acquisition of an accurate surface description is the first and probably the most important task in creating orthophotographs. The accuracy of the surface description is directly linked to the quality of the orthoimage. So surface modeling is the key factor when aiming at textured representations both geometrically and visually.

Traditionally, digital photogrammetric workstations are used to collect surface points using stereoscopic viewing. Manually selecting points of interest, as in the early days, has become a lengthy and labor intensive task. Therefore automatic matching algorithms have been created and are commercially available today. These automatic surface reconstruction techniques have become widely used thanks to their efficiency and cost effectiveness of the production process [16, 18]. They are highly recommended in open and flat areas, and when using small and medium scale imagery. However, most software packages perform poorly in areas with abrupt changes in depth, as in close range projects. The decline in the performance of softcopy photogrammetric packages can be caused by failures of the image matching process. Such failures may be due to factors like a lack of texture in the images, poor image quality, shadows in the images and occlusions which arise mainly from surface discontinuities. Many people creating close range orthophotographs today, try to use these algorithms, which are generally created for aerial photogrammetry, in close range application at the cost of a time-consuming editing phase afterwards.

Recently the use of terrestrial laser scanning has also given us the possibility to generate digital surface models of architectural objects. They have already shown promising contribution in overcoming lengthy, intensive manual interaction when measuring buildings [3, 5, 14]. These range-based measurement techniques are capable of sampling enormous numbers of surface points in a very fast way and may thus be used to produce surface models for orthorectification.
But besides the high cost, laser scanning also has its problems. Even though current laser scanners can produce large point clouds in a fast and reliable way, its resolution is the weak factor. In smooth and flat areas the scanner returns an overflow of data, while in other parts, especially near edges and linear surface features, its resolution is often insufficient. The laser scanner tries to substitute the 'intelligence" of a human surveyor by means of the redundancy of the acquisition [19]. The result of the measurement process is a raw point cloud, possibly with low resolution color information. In order to be able to generate highly accurate orthoimages, the acquisition of separate images with higher resolution will be necessary [10, 11].

The post-processing of such point clouds also remains a lengthy process which includes noise filtering, hole filling and registering multiple scans. Finally the point cloud is transformed into a mesh using interpolation techniques which often do not cope with discontinuities in the surface.

By analyzing two existing software packages producing orthophotographs, we try to get a good overview of the problems we are facing. Both packages are originally designed for aerial or space photogrammetry, but with minor intervention they can also be used for close range application.

II SUPRESOFT VIRTUOZO

The first package is called Virtuozo [21] and is created by a Chinese firm called Supresoft Inc. Goossens & Devriendt [4, 8] have provided us a thorough analysis of the system and its problems in close range applications. Virtuozo is a photogrammetric package that starts from digital stereo image data. It generates digital surface models using automatic high end image matching techniques. The resulting DSM can be viewed using polarized glasses as to have a better understanding of the scene.

In the processing of dose range scenes, different problems arose. When generating the surface description using the automatic image matching module of Virtuozo, the resulting DSM contained a lot of spikes and it shows the surface discontinuities in a smoothed way. This can be explained by the nature of the matching process. Image matching processes generally compare image patches using a correlation measure. Because of noise in the images, lack of texture, shadows and occlusions these matching algorithms may fail. By introducing certain constraints researchers have tried to solve this, often at the cost of a certain interpolation inaccuracy. This results in some areas still having errors and other areas being smoothed (see Figure 1).

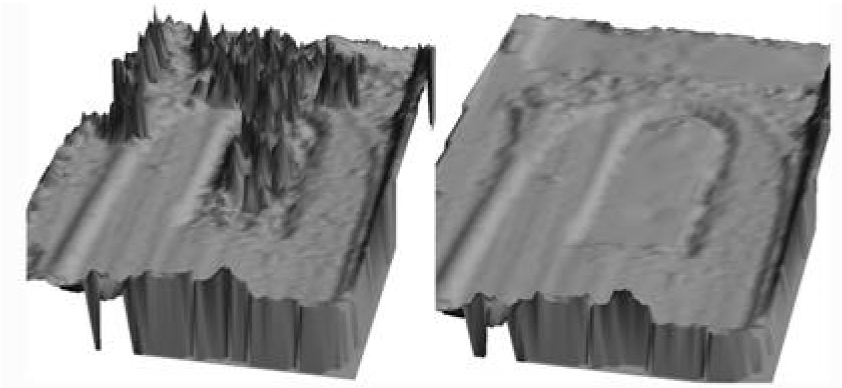

Figure 1 : DSM before and after editing

These problems can be partially solved or minimized by manually ‘editing’ the DSM after the automatic matching process has taken place. By looking at the result of the matching process, we can locate the places with errors. By manually adding point, line or polygon constraints we can guide the matching process. Basically this means adding breaklines at places with discontinuities and setting the DSM height to an average value in places of low texture and thus where spikes appear.
Since the software can only work with one pair of stereo images, this implies that some areas will not be visible on either of source photographs because of stereo shadows. In these areas where no texture information is available, Virtuozo stretches the nearby color values as to fill the leaping gap. This means that the final orthoimage will contain blurred patches in these regions (see Figure 2).

Figure 2 : Blurring in areas where no texture information is available

This also means that for larger architectural objects, multiple orthophoto’s have to be made which have to be stitched afterwards. Because of differences in the lighting conditions and possibly in scale when taking the photographs, the seamlines between these orthophotographs can be seen.

III INTERGRAPH IMAGESTATION

Thanks to the department of environment and infrastructure of the Flemish government, we were also able to test the Imagestation software [9,20]. Imagestation provides a photogrammetric workflow production and has been developed by the firm Intergraph. The full line of photogrammetric software modules has different possibilities going from automatic triangulation to orthophoto generation. The base software for these modules is called 'Imagestation' and works under Microstation. The software has been developed for aerial surveys but tests at the department of environment and infrastructure have proven that it is also usable for terrestrial applications.

The software basically works the same way as many commercially available photogrammetric packages.
After an interior, a relative and an absolute orientation process, one can start generating the DSM. This is done by manually referencing a grid in two images using a stereoscopical view. In cases where the object has lots of discontinuities, additional points will have to be placed in these regions. To get an accurate result one also has to incorporate breaklines. Imagestation works with multiple images, which is a benefit because lesser stereo shadows will appear. However in areas where no texture information is available, the final orthoimage will appear stretched.

Different tests were made to use the software with DSM's created from laser scanner point clouds, but the results were unsatisfactory. Only after a lengthy editing process of manually adding breaklines to the DSM, the result could be used (see Figure 3).

Figure 3 : Orthophoto from laser scanner before and after editing

IV A NEW TECHNIQUE TO CREATE ACCURATE SURFACE MODELS OF CLOSE RANGE ARCHITECTURAL OBJECTS

In ongoing research at the department of architecture at the Catholic University of Leuven, we are investigating methods that can provide us with highly accurate surface models of close range architectural objects. In this context we are exploring the potential of combining terrestrial laser scanning, image processing and close range photogrammetry.

Investigations and observations comparing DSM's produced from laser data and those derived from digital photogrammetric methods have been made in several research studies. The complementary nature of the two data sources has been widely recognized and their combination has been suggested by researchers since several years, this as well in aerial applications [1, 13] as in close range applications [5, 6, 17].

Close range applications usually face complex object shapes. If we have a look at a simple façade, we see that architectural objects are highly characterized by abrupt changes in their surface continuity. Their curvature stays identical over large areas and changes suddenly. Other problems in close range applications are due to the fact that the ratio of height differences to image acquisition distance is much bigger than in aerial photogrammetry – a fact raising significant occlusion problems and large deformations.

Using contemporary technology like stereo image matching or laser scanning, breaklines have to be introduced manually to refine the surface model generated using these techniques. This post-processing step is a lengthy task and can generally be compared to tracing the interesting features of the scene. In this paper we suggest a new technique that detects these breaklines automatically and uses them to refine the surface geometry.

The point cloud resulting from laser scanning can be interpreted as a coarse depth dataset. It provides accurate points with high spatial frequency; however, breaklines are not explicitly present in the data. Because of this coarseness, meshing algorithms fail in reconstructing accurate discontinuities in the surface (see Figure 4).

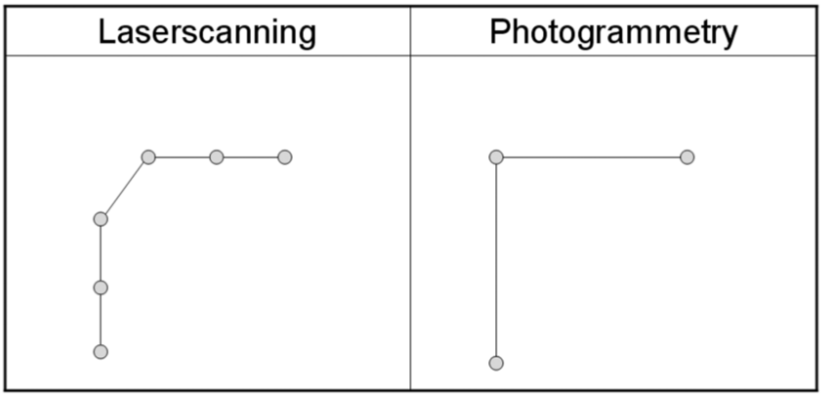

Figure 4 : DSM interpolation with and without breaklines

The idea is to overcome this coarseness by using information from the photogrammetric dataset. Photogrammetry works with images and is therefore based on changes in color intensities.

Using sub-pixel edge detection techniques developed in image processing we can detect most discontinuities in the image. However, doing so, also other edges are detected that are not real discontinuities but for instance a change in color of stones. To overcome this problem, we start detecting approximate edges in the 3D point cloud. This is done using a planar segmentation technique for range data developed by I. Stamos [15]. This technique finds locally planar point clusters in the point cloud and merges neighbouring clusters if certain conditions have been fulfilled. Using this method we divide the point cloud into surface patches. The intersections of these surface patches provide us with the approximate three dimensional edges we are looking for. Another possibility to filter these breaklines from the point cloud is by using a combination of the robust filtering method described by Yokohama and Chikatsu [19] and a 3D breakline growing process described by Briese [7].

Using the orientation data, these approximate 3D edges can be back-projected into all available images. For every approximate edge a snake-like energy equation is defined. The snake's energy-function can be minimized using different constraints like its stiffness, its originally projected position in the image and the intensity gradient of the image around the edge. This way the edge's position will be refined as to be in an optimal position according to the available depth information from the laser scanner and the intensity information from the image.

When using multiple images, one can re-project these refined image edges into 3D space as to integrate breaklines into the 3D laser scanner dataset. These breaklines constrain the mesh triangulation method that reconstructs the surface geometry from the point cloud.

We believe that fusing the data of different layers will improve the accuracy of the original point clouds because of the strong correlation between the scenes depth and its image intensity. Special attention will be put to structural conserving noise suppression because of the importance of the building details in the reconstruction.

V ORTHOPROJECTION PROCEDURE

Once an accurate description of the surface is available, the orthoprojection can be started. In close range application this orthoprojection process requires a different approach than in aerial surveys. Because of all the breaklines and stereo shadows, hidden areas must be taken into account. Therefore the orthoprojection procedure needs to be more sophisticated. In our implementation we follow the process described by Grammatikopoulos [10].

The algorithm requires the following input:

- a triangulated 3D mesh
- some photographs of the scene (preferably more than 1)
- the orientation parameters (interior and exterior) of the photographs
- a description of the reference plane in space
- the pixel size of the final orthophotograph

The main problem of orthoprojection is visibility. Which part is visible in the final orthoimage and from which source image can we get the texture information for this part?

Before starting the computation of the digital orthoimage, the exterior orientation data and the mesh data is transformed into a different coordinate system in which the xy-plane is parallel to the reference plane. Using this information one can generate a depth map by orthogonally projecting all the mesh triangles onto the reference plane and rasterize them. In this final depth map, the pixel color represents the distance from the reference plane to the mesh which corresponds to the z-coordinate of the mesh in the transformed coordinate system. The interpolated depth value of each pixel is compared with a possibly already existing depth value from other triangles. In this case larger elevation values replace lower ones. At the same time the triangle ID number is stored for each orthoimage pixel. Using this principle the visibility problem has been solved for the orthoprojection.

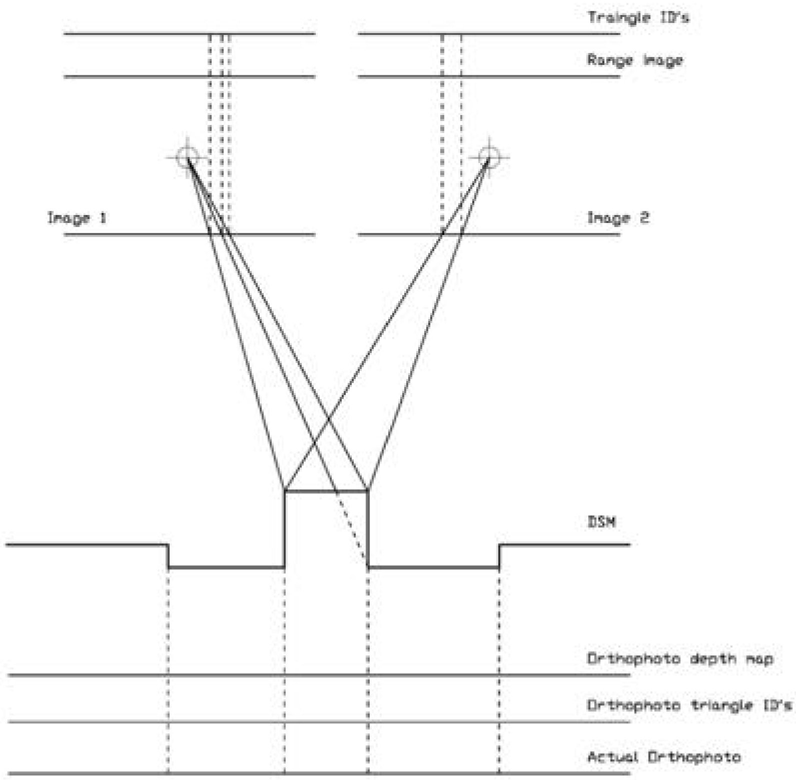

Figure 5 : scheme of the orthoprojection

Next we have to check the image visibility. Therefore we project all mesh triangles onto the source images using the orientation information. Each triangle is rasterized and for each resolving image pixel the distance from the focal point to the actual mesh point is calculated. Using the same method as for the orthoprojection, the larger distance values are replaced by pixels that are closer to the image plane. For each image pixel, the triangle ID number is also stored (see Figure 5).

In a final step, every orthoimage depth pixel is projected into the images and its triangle ID is compared to the ID of the image range map. If the triangle ID's are the same, the pixel is in fact visible in the orthoimage and also visible in the image. For all the images in which the pixel is visible, the corresponding color value is interpolated and stored. Finally a weighted interpolation is used to calculate the final pixel orthopixel color. The weighting factors are determined by the distance of the projected points to the principal point of the image.

VI CONCLUSION

Merging techniques of laser scanning, image processing and photogrammetry can exploit the benefits of each dataset and facilitate the generation of an accurate surface model. Using this DSM leads us to a more efficient way of creating orthoimages of close range objects. The major problem lies in achieving automation and efficiency together with robustness and reliability so that the algorithms and methods can be used for a successful and economically feasible implementation in practice.

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