From Point Clouds to Triangular Meshes

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ABSTRACT

The revolutionary development of digital cameras and image processing technology, their simultaneous integration in smart devices, such as mobile phones, tablets, laptops and video systems and the online availability of their results has led to an explosion of the number of photographs taken every day. Currently, the number of images stored online and available freely has reached unprecedented levels. It is estimated that the increase of digital images and videos available on Internet is growing exponentially; in 2012, there were over 200 billion photographs and 50 billions of videos stored in a selection of major social media and photo/video management sites (Pingdom, 2012). In addition to this technological phenomenon, advances in the fields of photogrammetry and computer vision have led to significant breakthroughs, including the Structure from Motion algorithm, which creates 3D models of objects using their two-dimensional images (SfM, Guofeng Zhang, 2009 and 2010, Fritsch, D, 2012). The existence of powerful and affordable computational machinery has led not only the reconstruction of complex structures but also entire cities (VCITY). Objects of different sizes and complexity can be modelled using image sequences from commercial digital image and video cameras, which are then processed by web services and freely available software packages. Such a low cost system can be used for numerous applications (Remondino, F. et al., 2008, T. P. Kersten et al., 2012) . This paper presents a new technique for the 3D volume reconstruction of objects from a set of copyright free, adjacent images online available,, using an advanced algorithm with the aid of the Voronoi Diagrams and the Delanay triangulation.

1. INTRODUCTION

Significant progress has been made in recent years in terms of automatic creation of 3D models, which have become an essential part of many applications, including digital archiving, restoration, visualization, inspection, planning, AR/VR, gaming, entertainment, etc.
The 3D reconstruction from digital images is an efficient and intuitive way to create 3D digital models of objects. Compared with conventional geometry-based modeling and hardware-heavy approaches, the image-based modeling method can be employed to extract original points, texture and illumination directly from images for visual 3D modeling, without the need for complicated processes, such as geometry modeling, shading and ray tracing (Nguyen, H. M., et al. 2012). Several commercial packages are available for image processing and image matching which provide different possibilities for the semi-automatic 3D reconstruction of an object from a set of different overlapping images, without any a priori information about the scene to be reconstructed. These techniques, termed Structure from Motion (SfM), tend to be less accurate, but offer intuitive and low cost methods for reconstructing 3D scenes and models (Remondino, F. et al., 2008, T. P. Kersten et al. 2012).
Such low cost methods for creating and modeling 3D objects from a set of overlapping images can be used for Cultural Heritage imaging is the creation and modeling of 3D objects from a set of overlapping images. Such reconstructions in the area of Cultural Heritage (sites, monuments) are already used for

- Documentation and Archiving in 3D digital libraries as the Europeana,
- GIS Applications and Tourism,
- Education and the Game industry,
- Reverse Engineering and 3D printing,
- Conservation and Preservation of the objects,
- Finite Element Simulations.

Several reconstruction algorithms and methods have been developed, which can be classified into two groups: 3D surface reconstruction and volume or voxel reconstruction (Ioannides et al. 1993). A brief description of a newly developed reconstruction approach is presented below, which includes theoretical issues regarding how to merge adjacent images and create a unigue 3D volume oriented model.

2. THE RECONSTRUCTION PROBLEM

3D reconstruction using the Voronoi Diagrams and Delaunay Triangulation are fundamental approaches in computational geometry that are widely used in image processing, mesh simplification, non-photorealistic rendering, and many other engineering applications (Ocabe et al., 1992, Aurenhammer, 1991). Moreover, stereo-vision and scene flow estimation requires optical flow, as well as, disparity estimation. Both of these can be formulated as problems of finding corresponding points in different overlapping images. However, this is a complex task, as a scene's objects generally have different shape and appearance or colors depending on time of day and point of view. The challenge of finding corresponding points in different images is at the essence of image processing flow and matching, whose outcome is pivotal for 3D reconstruction and scene flow estimation algorithms. This paper proposes a method for finding the corresponding points to mosaic the images in such a way that a 2D set of polygons can be created to represent the 2D mosaic contour of the object.

The proposed method, requires that the adjacent images have an overlap between them, have a perspective projection, which is written as a permutation matrix and use digital image interpolation, which includes the shifts, rotation and distortion of the photos. Stitching is used to blend the seams of the photographs. Finally, cropping, touch-up and post-processing of the image are required. The proposed method uses an algorithm to generate polygons which define the shapes of the objects and contours of each shape. These contours of may be approximated by polygons, taken from different perspectives and also embedded within in each other, which are linked together in order to create a 3D model. The major challenge of the method is to match the object in the best approximation of the original images, in terms of perspective and size. Then, the different contours of the adjacent images of the object are stitched, creating a continuous 360 degree mosaic of the object. Following, if each polygon of the adjacent images can be approximated in terms of perspective and size, then a 3D model can be generated. In order to generate an accurate 3D model, it is necessary to know the position of the central projection, which indicates the relationship between 3D and 2D coordinates and the relationship between the focal length and the field of view.

As the general topology of the reconstructed object depends on the correspondence problem of the contours on the adjacent images, finding the corresponding points is critical for the 3D modeling. Currently available automatic methods are not effective due to the multiple possibilities that can fit the initial set of data.Several factors are critical for the final 3D result, including the orientation of the polygons on the adjacent different images, the complexity of the contours and the resolution of the images.

In the proposed method the polygons are subdivided in the different adjacent images into Voronoi regions, which are extended by creating the Delaunay triangles.

Assuming that the adjacent images have the same size, resolution, illumination and orientation, the next step involves the issue of overlapping and correspondence between the polygons. This can be calculated by noting which part of the contour is located inside and which one is located outside. If there is a one to one correspondence between the polygons which have to be connected, then an approximation between the points on both overlapping polygons can be activated and they can be connected together as indicated in figure 1. One condition the reconstructed object has to satisfy is: If we cut it along the original contours, we must get the actual regions.

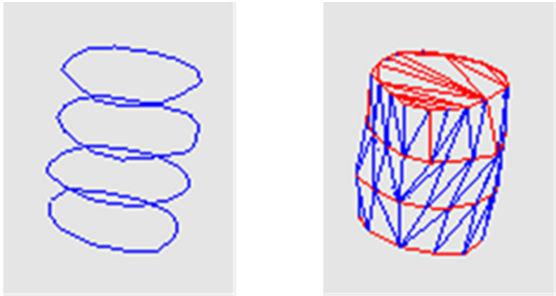


Figure 1: A common 3D Reconstruction from planar cross sections.

3. PREVIOUS WORK

Image-based modeling techniques are an important tool for producing 3D models in a practical and cost effective manner. The field of computer graphics was the first to focus on the use of surface reconstruction from planar contours, scattered points or from different adjacent images. Various algorithms, such as the Voronoi Diagram's and Delaunay Triangulation (see fig. 1), have been used for the triangulation of scattered point clouds and the reconstruction of surface triangles along contours (see fig. 2) between adjacent planes (Kepel, 1975 , Boissonnat, J. D. 1984). Accurate image-based models are dependent on precise perspective projection, image calibration and digital image interpolation, which can be created automatically in computer vision and photogrammetry programs. (Remondino, F. et al., 2008, T.P. Kersten et al., 2012).

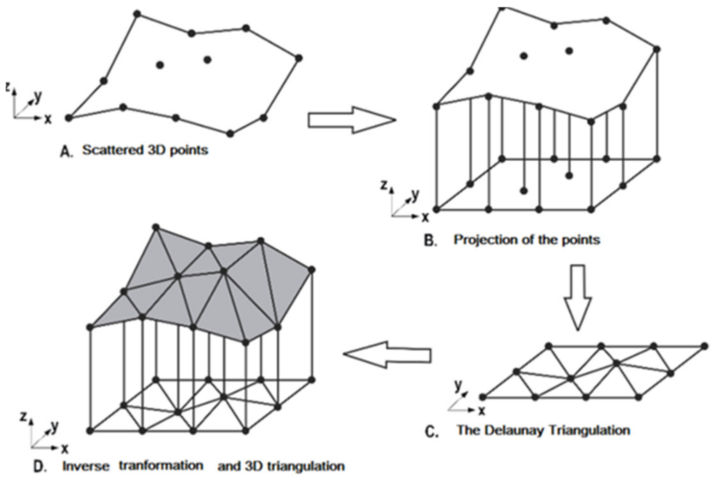


Figure 2: Triangulation of scattered points.

The most fundamental step required before 3D reconstruction is the estimation of correspondent points between different images. Extensive research has been conducted in this area, as it is an extremely important and complex task for image retrieval, object detection and 3D reconstruction. The most common approach for finding correspondent points between different images is the detection and selection of points that are unique (or nearly unique) and can be parameterizable in such a way to be comparable to other correspondence points in other images. (Theo Moons et al., 2013). This method has been used in techniques such as image corners (J. Shi and Tomasi, 1994), SIFT descriptor (Lowe, 2004), SURF descriptor (Bay et al., 2008, 2006) and RIFT descriptor (Lazebnik et al., 2005). Although these methods are capable of detecting and selecting the most prominent points for finding correspondences between different images, based exclusively on local information, they are not capable of describing the internal structure of an object or an image.

4. THE VORONOI SEGMENTATION AND THE DELAUNAY TRIANGULATION

A Voronoi diagram is a way of dividing space into a number of regions. In the proposed method a set of points, called contour points, are specified beforehand, and for each contour point there is a corresponding region consisting of all points closer to that contour than to any other.

Contour lines are approximated by simple closed polygons (see fig. 3g). Triangulating the polygons vertices may result in a triangulation where contour segments are not guaranteed to be edges of the triangulation. Since the objective is to create a 2D unique polygon where the intersection of the given polygons yields in the original contours, therefore our triangulation should fulfill the following requirement: all contour segments have to appear as Delaunay Edges in the Delaunay triangulation. A simple method to accomplish this is to insert new points on the concerned contour edges, so that the contour shape is unchanged. Once the previous containment condition is fulfilled, the Delaunay triangles can be divided in two groups the internal triangles which are lying inside and to the external triangles lying outside the polygons (see fig. 3i).

To guarantee that the internal Voronoi skeleton lies inside its contour polygon, new vertices were added onto the contour segments involved in obtuse Delaunay triangles. Increasing the number of polygon vertices results in the Voronoi skeleton focusing towards the center of the polygon. this is a linear approximation of the medial axis, which is the locus of points with equal distance to at least two contour points and represents the metric and topological properties of a silouette/form. In the case where there exists more than one contour in one image, the external Voronoi skeleton or external medial axis forms a kind of "intelligent" cells. The points inside such an intelligent Voronoi cell are closer to its contour than to any other contours. Hence the external Voronoi diagram is the locus of equidistance from at least two contours. In this case, the Internal Voronoi Skeleton is the medial axis (see fig.3j).

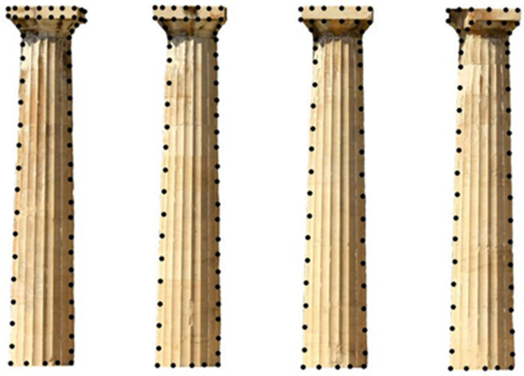
a) Front side of Parthenon

b) Filtered front side of Parthenon

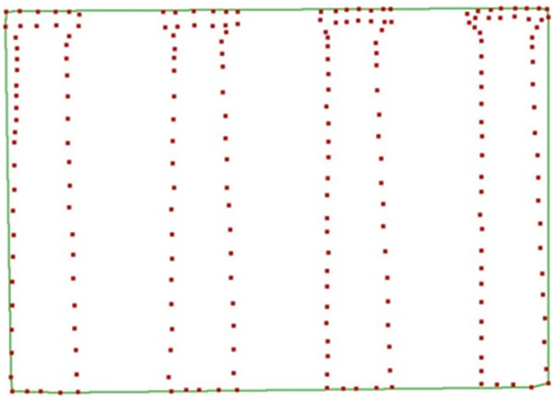
c) First image

d) Second overlapping image

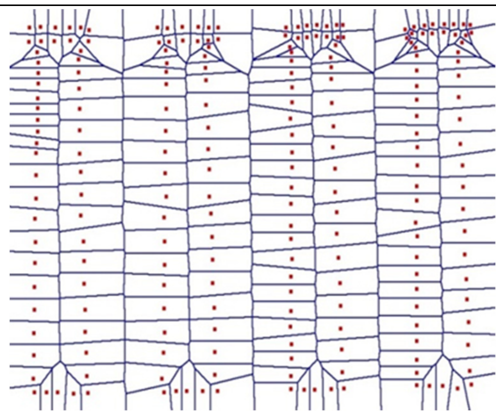
e) The four common pillars



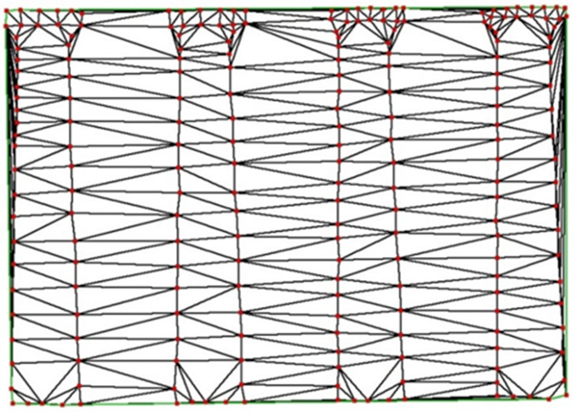
f) The pillars and their corresponding contours



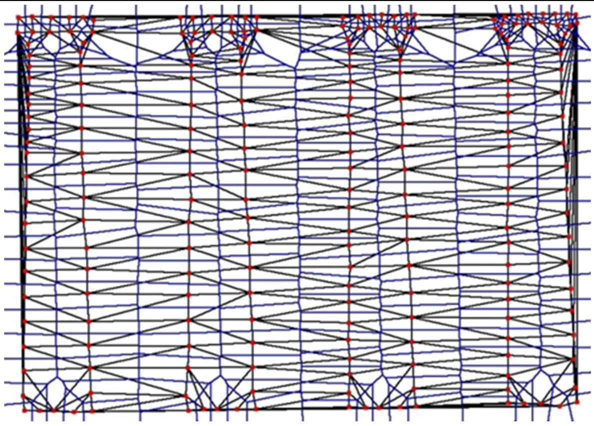
g) The four contour sets



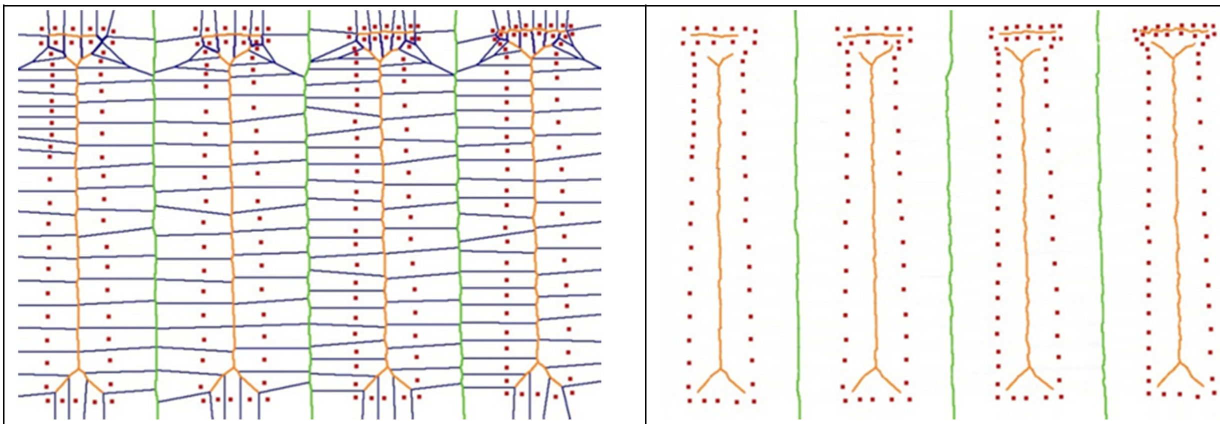
h) The corresponding Voronoi diagram



i) The Delaunay Triangulation including the internal and external triangles



j) The Voronoi diagramm together with the Delaunay triangles



k) The External and Internal Voronoi Skeletons together with the Voronoi diagram

l) The Voronoi Internal and External Skeletons (Medial Axis)

Figure 3: The creation of the Intarnal, External Vornoi Skeletons and the Delaunay Triangulation.

5. THE RECONSTRUCTION

In each image the input consists of one or several closed simple polygons, which may partially lie one inside each other and/or next to each other. The contours (polygons) are oriented in such a way that the inside of the object they are describing the inside is on its right side, the outside on its left.

The contours are first generated on each adjacent image and the corresponding Voronoi diagrams. Finally, the Delaunay triangulation is calculated. If necessary, additional vertices are added on the contours, to satisfy the contour containment condition and to avoid obtuse angles.

The first advantage of this method is the data reduction, due to the fact that the number of triangles is directly related to the number of contour vertices. Addittional reasons for using the proposed algorithm are i) the relationship to Voronoi diagrams provides the possibility to perform fast point location, ii) the shape of the Delaunay triangle tends to be compact, thereby maximizing the minimal angle.

5.1. 2D to 2D mapping

Starting from the first image Pi the polygons, including the corresponding Voronoi diagram, the Medial Axis and the Delaunay triangles are projected to the next adjacent image Pi+1. For each triangle on Pi , we search to find the neighboring vertex from Pi+1which lies closest to the circumcircle of this particular triangle. The triangle from Pi is stitched with the vertex from Pi+1. The same is created with Pi+1and Pi inversed.
Following, all connections having an edge in Pi or Pi+1 outside the contours need to be removed, which is accomplished by removing (killing the address of the first external voronoi vertex: the start of the external voronoi skeleton) all vertices lying on external Voronoi skeletons.

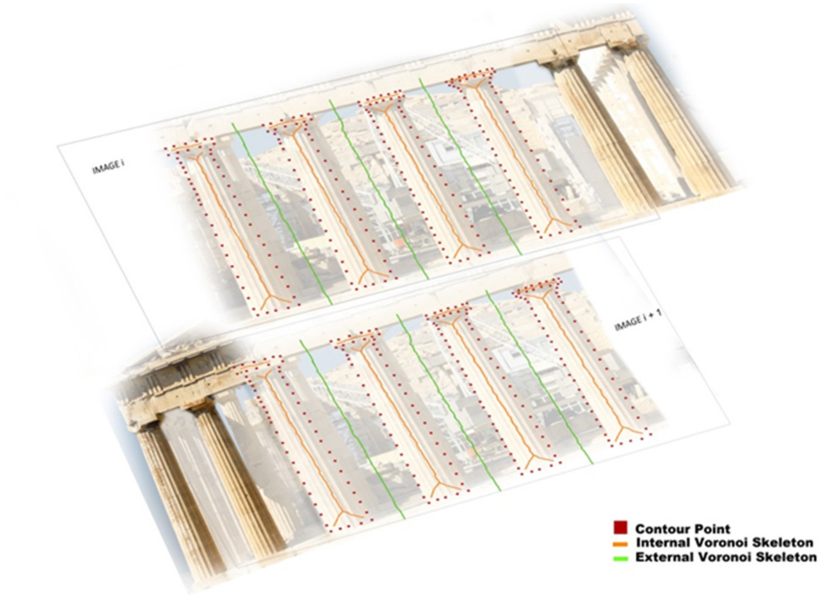


Figure 4: Two projected adjacent images with their overlapping contours and the corresponding voronoi diagrams (Green line: The External Voronoi Skeleton, Orange line: The Internal Voronoi Skeleton.

6. CONCLUSIONS

This paper presented a proposed method to the reconstruction problem using adjacent 2D images together with Voronoi diagramms and Dealauny triangles. Our approach takes advantage of the medial axis, using the nearerst neigbor connection between adjacent images so that the polygons can be stiched together. Indeed, this paper provides a detailed explanation on how to create an approximation of the reconstructed object contour by using the medial axis, whose quality is adjustable by automatically adding vertices on and inside the contours. The proposed method provides automatically an object mosaic reconstruction from adjacent images in order to create a 3D reconstruction of cultural heritage objects.

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