3D Modeling of Objects Using Laser Scanning

D. Jaya Deepu,
LPU University, Punjab, India
Email: Jaideepudadi@gmail.com

Abstract: In the last few decades, constructing accurate three-dimensional models of real-world objects has drawn much attention from many industrial and research groups. Earlier, the 3D models were used primarily in robotics and computer vision applications such as bin picking and object recognition. The models for such applications only require salient geometric features of the objects so that the objects can be recognized and the pose determined. Therefore, it was unnecessary in these applications for the models to faithfully capture every detail on the object surface. More recently, however, there has been considerable interest in the construction of 3D models for applications where the focus is more on visualization of the object by humans. This interest is fueled by the recent technological advances in range sensors, and the rapid increase of computing power that now enables a computer to represent an object surface by millions of polygons which allows such representations to be visualized interactively in real-time. Obviously, to take advantage of these technological advances, the 3D models constructed must capture to the maximum extent possible of the shape and surface-texture information of real-world objects. By real-world objects, we mean objects with complex geometry that may present self-occlusion with respect to the sensory devices.

Keywords: 3D model, Sensors, Scans, Objects by humans.

I. INTRODUCTION

First, a range sensor must be used to acquire the geometric shape of the exterior of the object. Objects of complex shape may require a large number of range images viewed from different directions so that all of the surface detail is captured, although it is very difficult to capture the entire surface if the object contains significant protrusions. The second step in the construction is the registration of the multiple range images. Since each view of the object that is acquired is recorded in its own coordinate frame, we must register the multiple range images into a common coordinate system. This process helps in the removal of the anomalies due to occlusion. The registered range images taken from adjacent viewpoints will typically contain overlapping surfaces with common features in the areas of overlap. This third step consists of integrating the registered range images into a single connected surface model; this process first takes advantage of the overlapping portions to determine how the different range images fit together and then eliminates the redundancies in the overlap areas.

II. APPLICATIONS OF LASER BASED 3D OBJECT MODELING

The laser based 3D object modeling finds a wide range of uses. With the advances in technology this technique has become fast and less cumbersome. It can be used in the following areas:

1. Reverse Engineering: RE is the ability to create computer-aided design (CAD) models of existing objects. These techniques would help in digitization of the CAD modeling of objects. Recent advances in laser-based range imaging technologies have led to the exploration of these technologies as r*everse engineering* (RE) tools.
2. Deformation Measurement and monitoring: These techniques can be used for examining the smoothness of a surface. This finds a lot of use in industries which require very high end surface finish.
3. Modeling ancient artifacts: These techniques can be used to model ancient artifacts. These are very fragile and any physical contact can ruin these.
4. Special Effects, games and virtual world: Synthetic imagery is playing an increasingly prominent role in creating special effects for cinema.
5. Implants design and reconstructive plastic surgery: Plastic surgeons can use the shape of an individuals face to model the scarred tissue and see the outcome of the surgery.

III. PROCESS ALGORITHM

The Algorithm that has been followed is:

Step 1: A beam of laser is projected on to the surface of the object. The laser beam illuminates some points on the object. This pattern of illuminated points is captured by a camera.

Step 2: Step 1 is repeated several times with varying laser beam positions such that the entire object is covered. The same process is repeated for different views.

Step 3: The captured image which is in the form of a RGB file is first converted into a grayscale image by taking the mean of the Red, Green and Blue intensities for a given pixel.

Step 4: A threshold limit is defined between the intensity of the illuminated points and the background. The image is now converted to a binary image, such that the points with intensity less than the threshold are considered as dark and the points with intensity greater than the threshold are considered bright.

Step 5: The image is now skeletonized so that we get a single pixel thick line representing the illuminated region. This is done by taking the bright point with maximum y co-ordinate for every x. An infinite impulse response filter is now applied so as to remove any noise that might have crept in.

Step 6: The line joining the points with least and maximum x is treated as the baseline. The distance of any point from this line is proportional to the height of that point. The co-ordinates in the 3D space for all the illuminated points are calculated.

Step 7: Steps 3 through Step 6 are now repeated for all the images of that scene and then for the different scenes to obtain there range images.

Step 8: The range images of all the scenes except the first one are now rotated by the negative of the angle that the object was rotated to take the pictures.

Step 9: The left bottom corner for the different scenes are identified and the range images are so aligned so that the corner points overlap.

Step 10: All the points thus obtained are considered to be a point cloud on the original object. We now use interpolation to obtain a mesh representing the object surface.

Step 11: A median filter is applied to the mesh thus obtained in order to remove any irregularities in the surface, due to registration.

Step 12: A 3D volume data is now constructed from the interpolated mesh.

IV. ACQUISITION OF GEOMETRIC DATA

The first step in 3D object modeling is to acquire the geometric shape of the exterior of the object. Since acquiring geometric data of an object is a very common problem in computer vision, various techniques have been developed over the years for different applications.

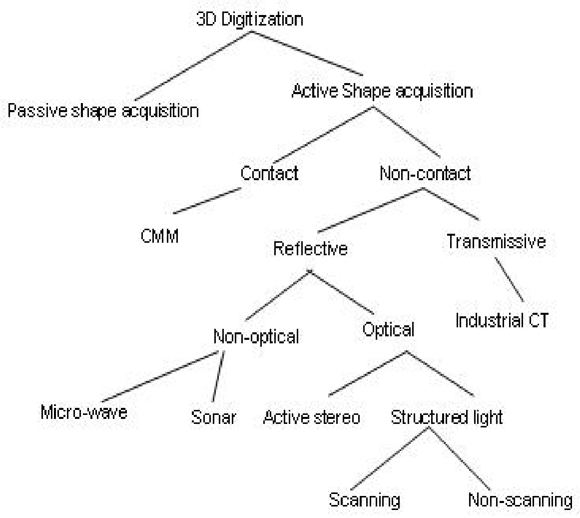


Fig. 1: 3D Digitization Methods

In general, methods of acquiring 3D data can be divided into passive sensing methods and active sensing methods.

The passive sensing methods extract 3D positions of object points by using images with ambient light source. Two of the well-known passive sens3D Modeling of Real-World Objects Using Range and Intensity Images are Shape-From-Shading (SFS) and stereo vision. The Shape-From-Shading method uses a single image of an object. The main idea of this method derives from the fact that one of the cues the human visual system uses to infer the shape of a 3D object is its shading information. Using the variation in brightness of an object, the SFS method recovers the 3D shape of an object. There are three major drawbacks of this method: First, the shadow areas of an object cannot be recovered reliably since they do not provide enough intensity information. Second, the method assumes that the entire surface of an object has uniform reflectance property, thus the method cannot be applied to general objects. Third, the method is very sensitive to noise since the computation of surface gradients is involved.

The stereo vision method uses two or more images of an object from different viewpoints. Given the image coordinates of the same object point in two or more images, the stereo vision method extracts the 3D coordinate of that object point. A fundamental limitation of this method is the fact that finding the correspondence between images is extremely difficult. The passive sensing methods require very simple hardware, but usually these methods do not generate dense and accurate 3D data compare to the active sensing methods.

The active sensing methods can be divided into two categories: contact and non-contact methods. Coordinate Measuring Machine (CMM) is a prime example of the contact methods. CMMs consist of probe sensors which provide 3D measurements by touching the surface of an object. Although CMMs generate very accurate and fine measurements, they are very expensive and slow. Also, the types of objects that can be used by CMMs are limited since physical contact is required. The non-contact methods project their own energy source to an object, then observe either the transmitted or the reflected energy. The computed tomography (CT), also known as the computed axial tomography (CAT), is one of the techniques that record the transmitted energy. It uses X-ray beams at various angles to create cross-sectional images of an object. Since the computed tomography provides the internal structure of an object, the method is widely used in medical applications.

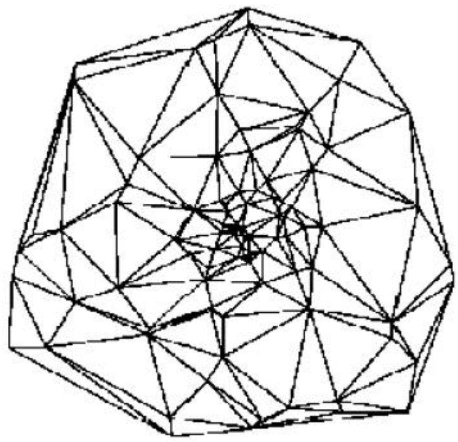
The active stereo uses the same idea of the passive sensing stereo method, but a light pattern is projected onto an object to solve the difficulty of finding corresponding points between two (or more) camera images. The laser radar system, also known as LADAR, LIDAR, or optical radar, uses the information of emitted and received laser beam to compute the depth.

There are mainly two methods that are widely used: (1) using amplitude modulated continuous wave (AM-CW) laser, and (2) using laser pulses. The first method emits AM-CW laser onto a scene, and receives the laser that was reflected by a point in the scene. The system computes the phase difference between the emitted and the received laser beam. Then, the depth of the point can be computed since the phase difference is directly proportional to depth. The second method emits a laser pulse, and computes the interval between the emitted and the received time of the pulse. The time interval, well known as *time-of-flight*, is then used to compute the depth given by t = 2z=c where t is time-of-flight, z is depth, and c is speed of light. The laser radar systems are well suited for applications requiring medium-range sensing from 10 to 200 meters.

The structured-light methods project a light pattern onto a scene, and then use a camera to observe how the pattern is illuminated on the object surface. Broadly speaking, the structured-light methods can be divided into scanning and non-scanning methods. The scanning methods consist of a moving stage and a laser plane, so either the laser plane scans the object or the object moves through the laser plane. A sequence of images is taken while scanning. Then, by detecting illuminated points in the images, 3D positions of corresponding object points are computed by the equations of camera calibration. The no scanning methods project a spatially or temporally varying light pattern onto an object. An appropriate decoding of the reflected pattern is then used to compute the 3D coordinates of an object.

V. DELAUNAY TRIANGULATION

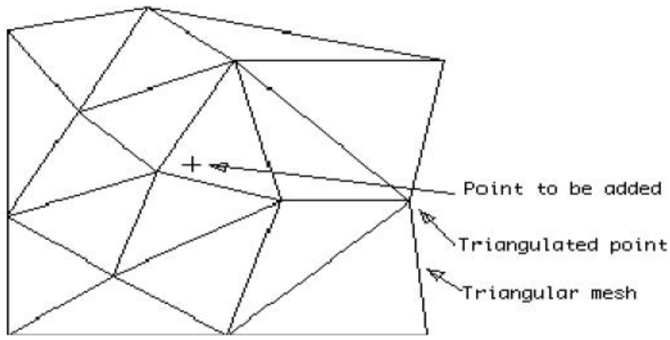
Most commonly used algorithm to generate triangulated surface from an unstructured point set is Delaunay Triangulation algorithm. The Delaunay triangulation of a point set is a collection of edges satisfying an "empty circle" property. A Delaunay triangulation of a vertex set is a triangulation of the vertex set with the property that no vertex in the vertex set falls in the interior of the circumcircle(circle that passes through all three vertices) of any triangle in the triangulation.



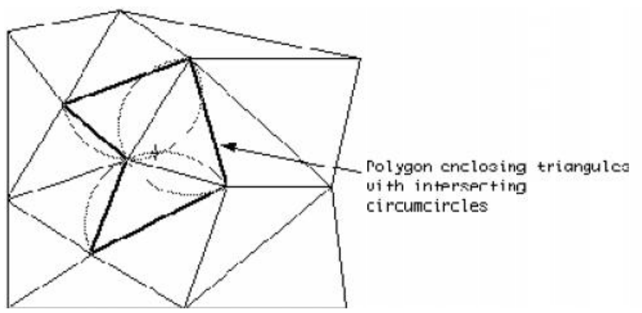
The above figure shows the Delaunay triangulation of the given set of points.

The algorithm followed is-

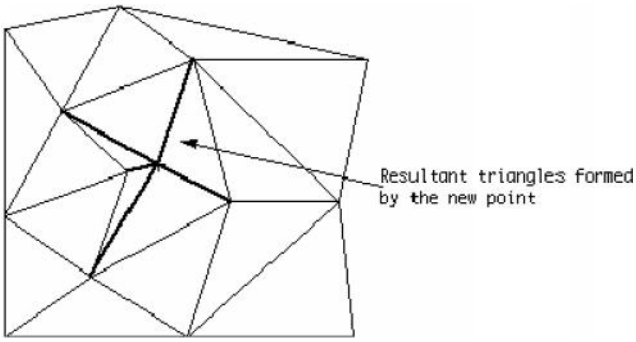
Suppose that the shown point is to be added to the triangulation-



First of all we find the triangles within whose circumcircle the point falls.



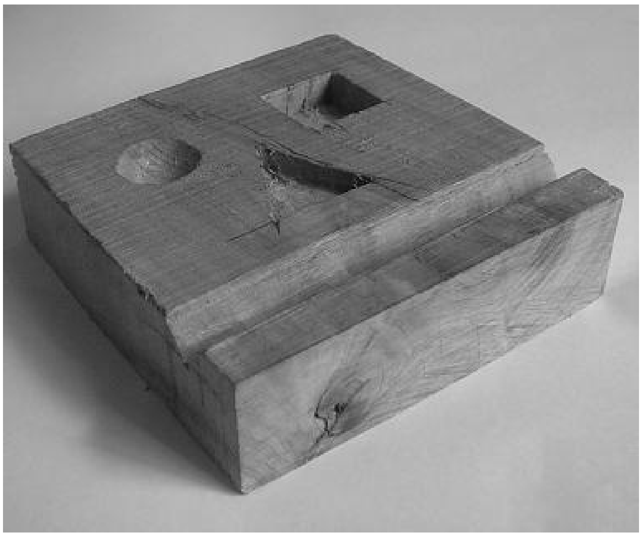
Now the vertices of the triangles and the point are so joined that the condition for delaunay triangulation is satisfied.



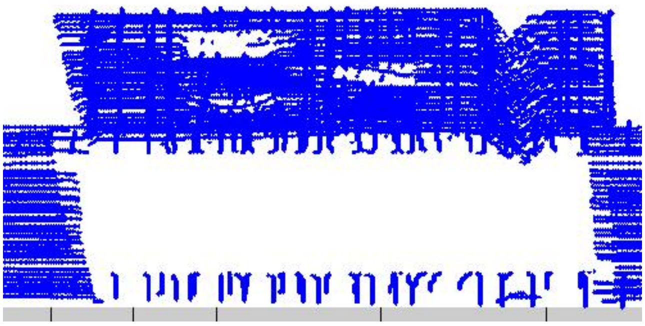
A rectangular grid is now made with a 2 mm resolution along x and y axis and the z coordinates are calculated for the grid points. We have use linear interpolation for the purpose.

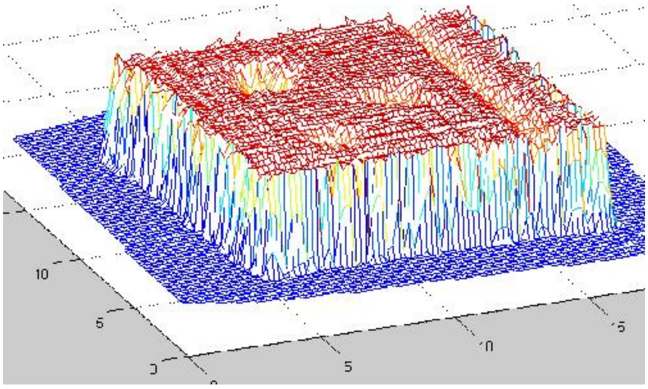
VI. RESULTS

Sample1



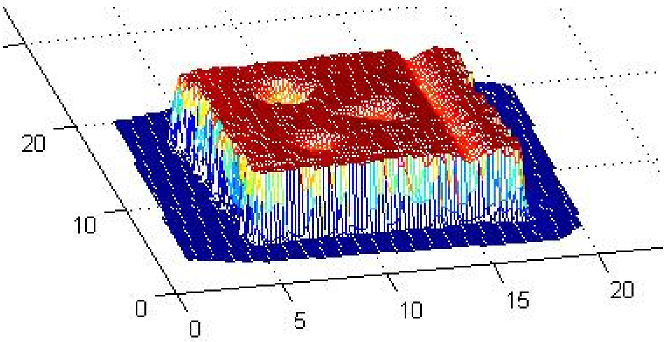
This is the photograph of the first sample that was modeled.

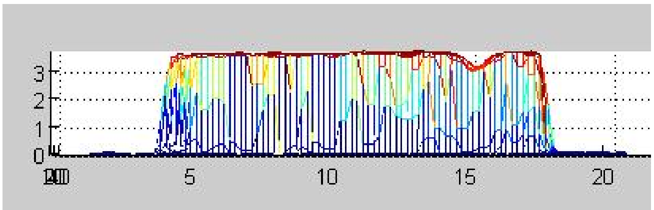


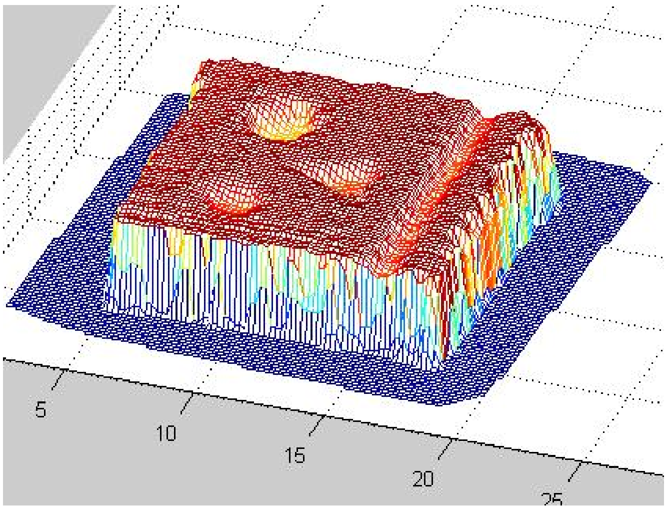


Top: Cloud of points obtained by registering the range images obtained from different views.

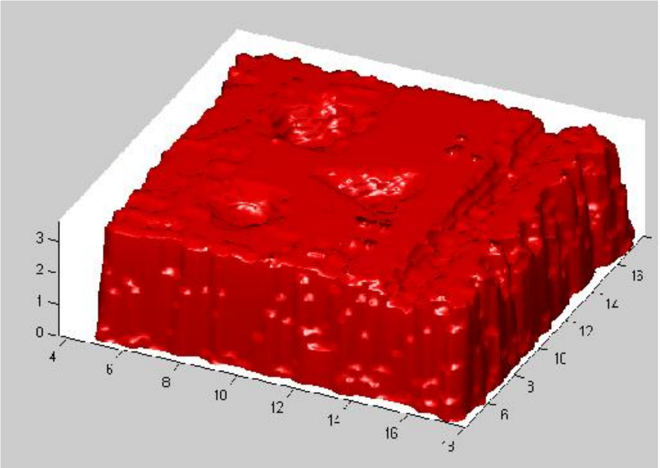
Bottom: The results obtained on interpolating the point cloud.







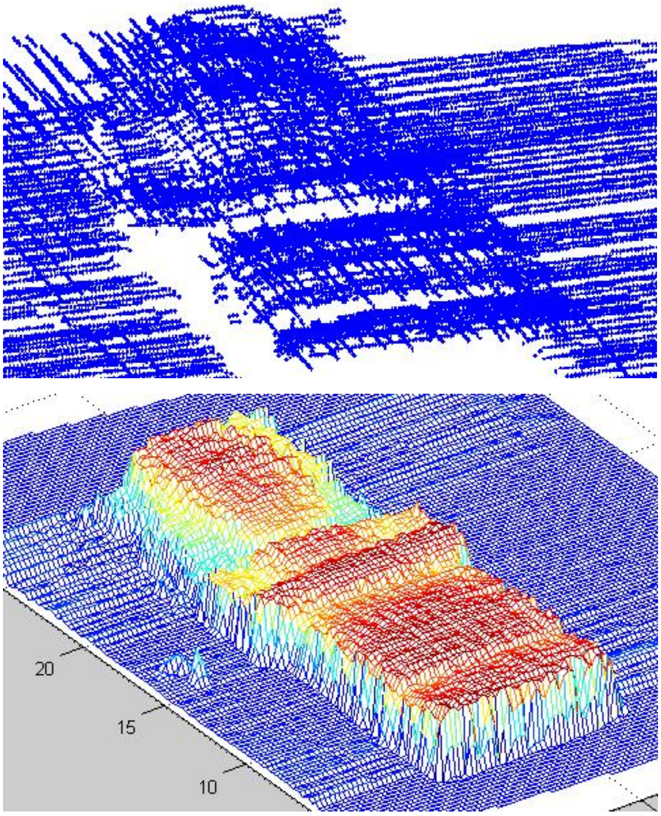
The figures above show the object from three different angles after the median filter was applied on the interpolated results.



The above figure shows a 3D model of the object obtained after the filtered interpolated results were used to construct a volume data. Generation of the figure uses isosurface concept.

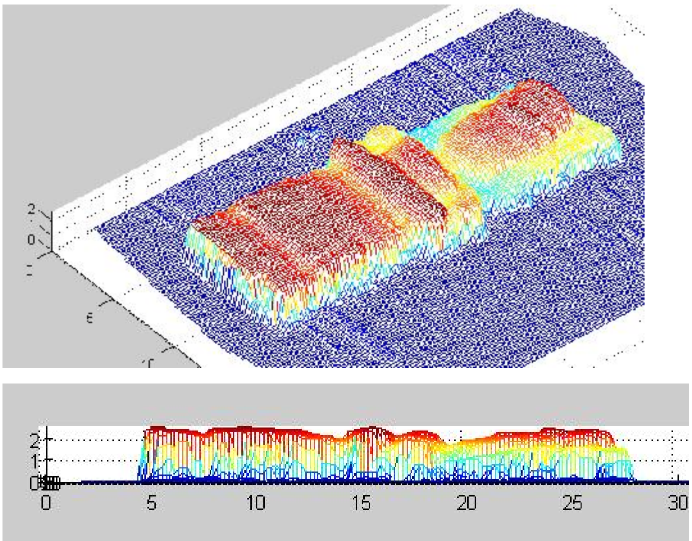
Sample 2

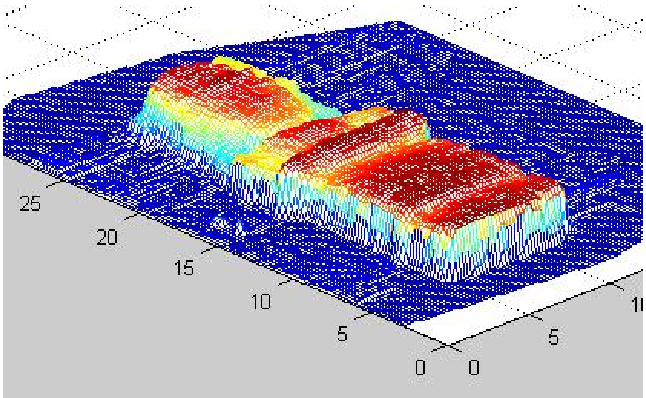
Above is the photograph of the second sample object that has been modeled.



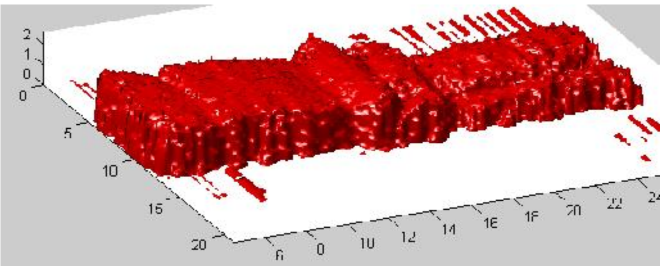
Top: The figure shows the registered point cloud.

Bottom: The figure shows the results on interpolating the point cloud into a rectangular grid.





Above figure shows three different views of interpolated results after filtering.



The figure above shows the 3D model of the object obtained after the filtered interpolated results were used to construct a volume data.

VII. CONCLUSION

The results obtained for the two scanned samples are found to be satisfactory. The dimensional details of the 3D models is accurate to about 1-2 mm, however the finer details of the objects could not be captured.

Feature based registration technique has been used. Although it provides satisfactory results but the Iterative Closest Point algorithm should be used for even better results. The results from feature based registration can in that case be treated as a very good starting point.

There are many oscillations in the resultant image (which are more predominant for a complex surface). I have used a median filter with a 3x3 window to suppress these. But there is still room for further improvement.

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