



10-2022

(SI10-124) Inverse Reconstruction Methodologies: A Review

Deepika Saini
Graphic Era Deemed to be University

Follow this and additional works at: <https://digitalcommons.pvamu.edu/aam>



Part of the [Other Computer Sciences Commons](#)

Recommended Citation

Saini, Deepika (2022). (SI10-124) Inverse Reconstruction Methodologies: A Review, Applications and Applied Mathematics: An International Journal (AAM), Vol. 17, Iss. 3, Article 3.
Available at: <https://digitalcommons.pvamu.edu/aam/vol17/iss3/3>

This Article is brought to you for free and open access by Digital Commons @PVAMU. It has been accepted for inclusion in Applications and Applied Mathematics: An International Journal (AAM) by an authorized editor of Digital Commons @PVAMU. For more information, please contact hvkoshy@pvamu.edu.



Inverse Reconstruction Methodologies: A Review

*Deepika Saini

Department of Mathematics
Graphic Era Deemed to be University
Dehradun, India
deepikasaini@geu.ac.in

Received: November 20, 2021; Accepted: August 13, 2022

Abstract

The three-dimensional reconstruction problem is a longstanding ill-posed problem, which has made enormous progress in the field of computer vision. This field has attracted increasing interest and demonstrated an impressive performance. Due to a long era of increasing evolution, this paper presents an extensive review of the developments made in this field. For the three dimensional visualization, researchers have focused on the developments of three dimensional information and acquisition methodologies from two dimensional scenes or objects. These acquisition methodologies require a complex calibration procedure which is not practical in general. Hence, the requirement of flexibility was much needed in all these methods. Due to this emerging factors, many techniques were presented. The methodologies are organized on the basis of different aspects of the three dimensional reconstruction like active method, passive method, different geometrical shapes etc. A brief analysis and comparison of the performance of these methodologies are also presented.

Keywords: Three dimensional reconstruction; Two dimensional images; Multiple Views; Camera calibration; Depth perception

MSC 2020 No.: 68Q32, 68U05, 68U07, 68U10

1. Introduction

The fundamental part in the field of computer vision is very well known for creating or reconstructing the three dimensional models using the two dimensional images. The main and foremost

goal in the image-based modeling may be treated as inferring the geometrical structure of three dimensional models from the given two dimensional images. The given two dimensional images and some viewing geometry parameters are the input for the image based three dimensional modeling whereas the structural parameters which constitute the required model in three dimensional space are considered as the output of these reconstruction algorithms. From the last few decades (Ham et al. (2019)), a large number of methods and techniques were reported in this area to solve this difficult but quiet interesting and challenging problem. In this paper, we have tried to present a set of existing three dimensional reconstruction algorithms from the two dimensional images. This review contains the basic definition, domain, uses and comparison also.

2. Inverse Reconstruction Process: Overview

2.1. What is Inverse Reconstruction Problem

Inverse reconstruction problem is the process of modeling or creating the three dimensional object using the two dimensional images. It is just the inverse process of capturing the two dimensional images of a three dimensional structure. For a human, it is usually a very easy task to have an idea of any three dimensional structure belonging to an image. But any image does not contain enough information to model any three dimensional structure. It may be due to the loss of some nature (depth, camera parameters, etc.) of the image in the process of projection of a three dimensional structure onto the projection/two dimensional planes. Due to which, it is usually very difficult to get the true and actual geometry of three dimensional structure. Hence, infinitely many different three dimensional structure may represent the same set of images. This is the main reason to name this inverse reconstruction problem as ill-posed problem.

2.2. Basic Requirements for Inverse Reconstruction

For any method involving in three dimensional reconstruction from two dimensional images, there are three basic steps:

- (1) **Camera Calibration:** This is the most essential step or part of any reconstruction algorithm, without it no algorithm can even work. It involves internal and external the parameters of the optical instrument which are used in the reconstruction process. The internal parameters illustrates the inner geometric and optical features of the camera (like focal length, center of an image, etc). And the external parameters define the location and inclination of the camera in a general optical system.
- (2) **Establishing Correspondence:** This step gives the information about the corresponding features in all different images. Or simply it can be thought as to find the solution of this sub-problem with searching that which pixels or features in one image plane correspond to which pixels or features in the other image planes. The correspondence problem may be formulated as: Given different projections in the different image planes of a three dimensional structure,

find different features or points in one image plane which may be taken as the same features or points in other image planes.

The correspondence algorithms may be divided into two types based on Area and Feature. The algorithm based on area solve the matching problem for every single point or pixel in the image which result in a dense depth map. Whereas feature based algorithms solve select the feature from the one image and try to match or find these features in the other images. These features may be edges, holes, geometric figures, lines, corners, etc. Comparatively feature based algorithms give more accurate results due to the detailed information hence result in more exact depth maps.

- (3) **Three Dimensional Modeling:** Once the depth maps are calculated for all the matched points we have to combine them to model a final three dimensional object by obtaining the coordinates in space from the adopted connections and the camera calibration framework. After finding the coordinates of certain number of points in space, it is required to obtain the corresponding surface to which these points belong to a three dimensional model. Otherwise, the reconstruction may be sparse due to a large cloud of points.

2.3. Application of Inverse Reconstruction in Different Fields

The area of inverse reconstruction has wide range of application in several different fields like Medical field, Robot navigation, electronic tracking of ball trajectory (Hawk eye in cricket, Line in tennis, etc.), Path planning of missiles, Reverse engineering, Posture recognition, Motion detection, Landslide inventory mapping, Archaeology, Breast cancer detection, Object detection, Object recognition, Object tracking, Automobile industries, Image Coding and Segmentation, Entertainment, Information Transfer and Security etc. From the above mentioned field, some are described as follows:

One of the applications of reverse techniques may be seen in the field of ball tracking. It is indeed a very difficult task to find the trajectory of a fast moving object (ball) in sports (Miyata et al. (2017)). For that, first of all the cameras must be fully coordinated and the location and direction must be calibrated which is not feasible in every case. The basic idea for the tracking is to capture the ball by multiple cameras and which are to be used further as corresponding points. With this method, first the ball is detected and then it finds the temporal differences between cameras. Now the ball positions are taken as the corresponding points for camera calibration. A great revolution has been noticed in medical field after the emergence of inverse reconstruction. Three dimensional models are very well used for planning of operations and has more reliability in orthopedics. For the three dimensional modeling of images from two dimensional images, the most commonly used methods are MRI and CT scan (1). These methods are highly expensive and they also induce high risk for the patients. Another methods which are comparatively safe for the patients are based on stereo correspondence and non-stereo correspondence of points or contour. First approach starts with finding the points in different radiographs and then reconstruct the three dimensional model using multi-view radiographs. While in second approach, first of all an initial solution is to be obtained from the different radiographs. After that some physical regions are identified from the

object. In those radiographs, two dimensional contours are detected. At last, initial solution is to be optimized by using some state of the art algorithms.

In robotic navigation field, an autonomous robot uses its camera to capture the images of its surroundings. Now it creates a three dimensional map of its surrounding with the help of captured images (Fazakas and Fekete (2010)). The obtained three dimensional map is used in performing the real time processing such as to avoid obstacles as well as making measurements of the current location. Another application may be seen in order to create landslide inventory mapping (Sharad and Dericks (2018)). In the preparation of landslide inventory map, the correct estimation of landslide dimension is a difficult task. From the several years, satellite arial data photography is used for the landslide estimation but it is very expensive. To resolve this issue, drones may be very useful. Drones may take several images which may be further used in combination with three dimensional scene reconstruction algorithm to estimate or map the landslide dimension. The obtained results of three dimensional reconstruction from two dimensional images are very fast, exact and provide the possibility of accurate measurements.

3. Inverse Reconstruction Algorithms

The ultimate goal of inverse reconstruction is to model the shape of an object in space from multiple two-dimensional scenes. Many researchers have contributed their sincere effort to solve this reconstruction problem. Several ways to model the three dimensional shape from the different views may be depth (range), surface gradient, surface normal, etc. Most commonly and globally seen recovering cue is “depth”. Depth is considered as the distance from the baseline of the cameras to the three dimensional points.

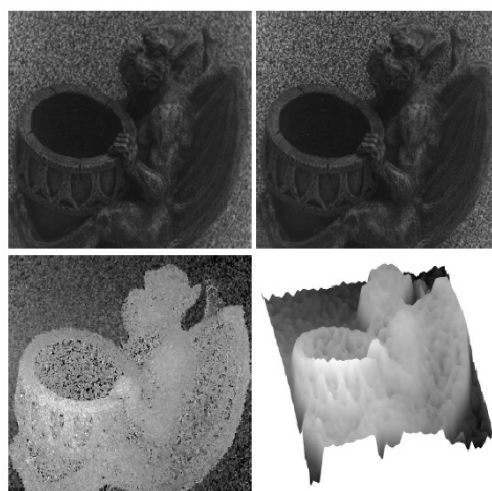
3.1. Active and Passive Methods

In the active methods, energy in the form of radio/light is projected onto the target scene by the mean of a device in an ordered way. Then, shape can be determined by measuring the reflections from the target. Active methods use light/laser projectors and achieve high accuracy in 3D reconstruction. Dense 3D reconstruction is easily achievable in active methods by controlling the projecting devices. Structured light based devices are widely used due to their scanning efficiency and less cost production. However active methods require some pre-calibration steps (Martinel et al. (2014)) between camera and projector with the changes in the system conditions. This limitation becomes the major drawback of these kind of approaches.

In contrast to active methods, passive methods use the already presented visible radiation of the scene. Passive methods are usually based on the reconstruction of object geometry. Here, the reflected radiance from the object is measured without any change in its appearance. Input of these methods are purely images taken from the camera sensors. Hence, the goal is to estimate the geometry of the object based on the analysis of input images of object or scene. Table 1 is the collection of reconstruction algorithms which are simply grouped based on active and passive methods.

Table 1. Three Dimensional Reconstruction Taxonomy

Active Methods	Depth from defocus Light properties based Atmosphere Scattering
Passive Methods	Shape from shading Shape from silhouette Shape from texture Shape from contour Passive stereo Structure from motion

**Figure 1.** Explanatory figure of depth from defocus (Favaro and Soatto (2002))

Depth from defocus. Shape from defocus methods (Favaro and Soatto (2002)) take more than one image which were captured from same locations with different optical settings. These methods can also be known for recovering the depth of the an object by measuring the amount of image blur. The three dimensional structure can be determined by using the relative defocus in the input images (as shown in Figure 1 (Favaro and Soatto (2002))). The optical settings for these input images can be changed by varying the interval between the sensors and the lens. Despite the capability of estimating relative dense depth map (Kumar et al. (2013)), shape from defocus methods were proven computationally expensive because of the highly unpredictable nature of frequencies of the scene texture. Another major drawback of these methods is that the depth estimation was more accurate only for the near objects whereas approximate solution was predicted for the far objects.

Light property based. Light properties based methods are simply known as time-of-flight (Cui et al. (2010)). The concept behind time-of-flight methods is based on the measurement of the time which a light beam takes in traveling from the target to the sensors. The measured time usually describes the distance to the object. Different types of waves were used for this purpose, e.g., radar, sonar or optical radar. The most commonly used waves work on the principle of measuring the

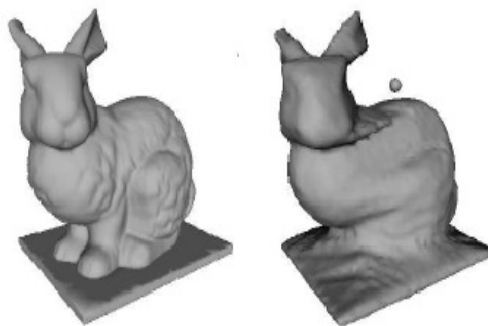


Figure 2. Explanatory figure of shape from shading (Birkbeck et al. (2006))

delay between the transmitted and received waves. Generally, the light property based techniques were found very accurate and efficient but again the development of these technologies are limited due to high implementation and equipment costs (Dai et al. (2013)).

Atmosphere scattering. There are lots of small particles, presented in atmosphere, which are responsible for the change in direction of power and light. When a beam of ray passes through the atmosphere, it changes its direction due to the scattered particles presented in atmosphere. It can be thought as the objects which are closer to the camera will be more clearer as compared to the objects which are very near (appear blurred). This concept is called atmosphere scattering. It has been used in Cozman and Krotkov (1997) for evaluating the depth of certain outdoor images. But due to the complex properties of dynamic scattering particles, it is generally very hard to estimate the absolute depth map.

Shape from shading. Human perception of shape of any object is based on the role of shading. It was proved that our eyes and brain combine the information of shading to reconstruct any three dimensional shape. For the solution of any shape from shading algorithm, first of all the study of the formation of images are important. The simplest form of image formation is Lambertian form (Zhang et al. (1999)) where intensity of the grey level at each pixel in the image rely on the direction of light source and surface normals. Hence, shape from shading (Figure 2 (Birkbeck et al. (2006))) is a process that deals with the surface normals by the mean of reflectance factor. By measuring the emitted lights from different angles, the three dimensional shape of an object can be successfully evolved. But the Lambertian model for the image formation is not always true in case of real images. That means even if we know the light source directions and surface normals, the reconstruction problem involved some non-linear equations from where it is hard to find the unique solution.

Shape from silhouette. A silhouette may be defined as an image of an object (person/animal/scene), represented by a solid shape of a single color. In shape from silhouettes method (Prakoonwit and Benjamin (2012)), an acquisition step has to be performed first in which the images of an object have to be captured from different view points around it. It may be assumed that an object is put on a turntable, and images are captured at regular intervals. Now, silhouette is extracted for each of these images (Figure 3 (Prakoonwit and Benjamin (2012))). As a result, the

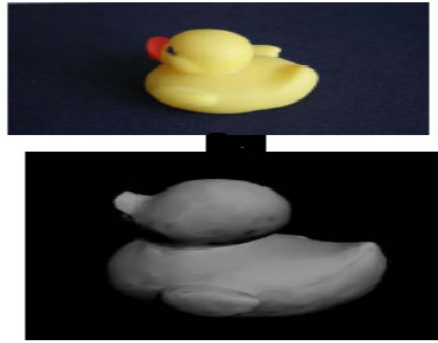


Figure 3. Explanatory figure of shape from silhouette (Prakoonwit and Benjamin (2012))

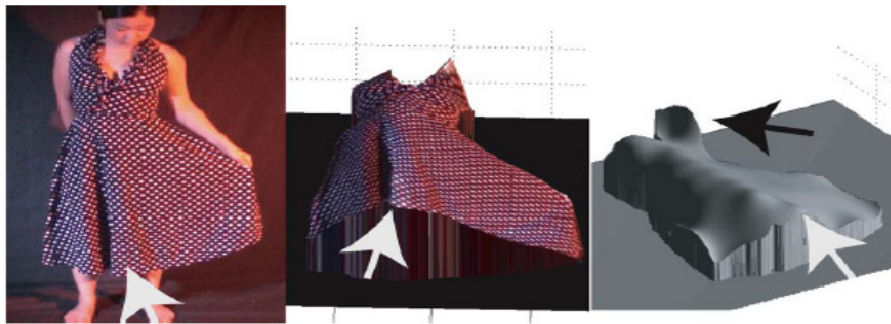


Figure 4. Explanatory figure of shape from texture (Lobay and Forsyth (2006))

entire 3D object shape can be extracted by examining every possible position of the voxels. Thus, the three dimensional shape of the object can now be evolved as the intersection of all silhouette cones. However, the method seems to be very easy and suitable for all types of static and non-static objects, but the resulting visual hull generated by all the intersecting cones is not a good approximation of the required shape. It may be get more worsen if the number of involved cameras is lessen.

Shape from texture. Since humans can recognize patterns and objects in an image by utilizing texture as a cue (Figure 4 (Lobay and Forsyth (2006))), shape recovery from the textures (Todd et al. (2010)) was also used in computer vision. By using this method, the three dimensional model can be determined or evolved from the spatial distribution of surface marking (Bundy and Wallen (1984)). Alternate procedure of evolving the shape from texture may be taken for the cases where variations in the amount of reflectance are same in all directions. The main drawback of these techniques is the applicability which is possible only in the cases where the surface has some homogeneous texture.

Shape from contour. Another important approach for the reconstruction of three dimensional shape is shape from contour. It was demonstrated that shape from contour has some advantages over other shape cues as shading and texture. It may be described as the exposition of a single line drawing by the projection of a three dimensional object as an entity. In Solem and Kahl (2004), shape from contour was obtained as an evolving set of models whose projections best fit the input

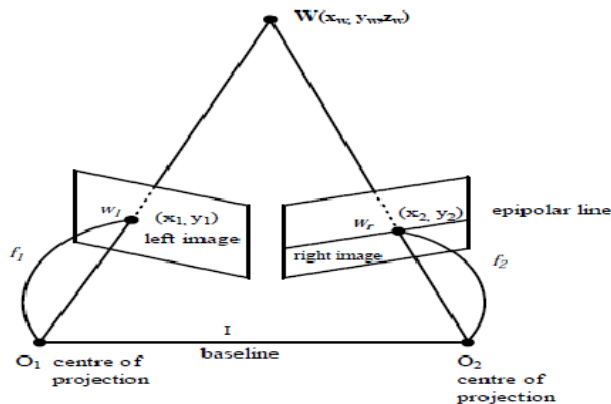


Figure 5. Passive stereo configuration (Kumar et al. (2009))

line drawing. This set of work was made a core input for further researches and then adopted in various fields because of its capability of robust reconstruction. Unfortunately, these approaches cannot be applied very effectively in case of real multi-view reconstruction problem as the assumptions which were taken at the initial steps do not hold in general.

Passive stereo. In passive stereo methods, two images captured at the same time with different view points, are used for the triangulation process (Hartley (1994); Hartley (1997)). The basic principle behind passive stereo based reconstruction method is as follows: the two projections of a three dimensional point are given in two image planes, the three dimensional position with respect to the given points can be evolved as the intersection of two rays emitted from these points. This process is called triangulation process. The configuration model can be seen in Figure 5 (Kumar et al. (2009)), where the two rays are emitted from the two image planes respectively. These rays generate the point in three dimensional space via this triangulation. The repeated process for several points will yield the shape in three dimensional space. In triangulation process, the main drawback can be thought as that one must know about the correspondence between the several image planes. This type of correspondence search is not an easy task, and proved to be the hardest part of stereo approaches.

Structure from motion Passive stereo usually uses two synchronized cameras. In case, where the scene is static, one can take the two or more images of the scene by placing the same camera at two or more different positions. This strategy is known as structure from motion (Oliensis (1999)). The same triangulation procedure may be applied here for the reconstruction process. Here, if the images are captured over a small time interval, establishing correspondence will be more easier, just by finding the feature points over the time. In Figure 6 (Yilmaz and Karakus (2013)), three images have been taken for the generation of point cloud (point x_1 is generated via the image points $p_{1,1}, p_{1,2}, p_{1,3}$. In the first part, the correspondence among all the feature points have to be established, second step deals with finding the parameters of camera configuration, and in the last step, the dense cloud points have to be obtained which will give the desired reconstructed structure. But in these approaches the question arises about the robustness of the particular theorem because generally, these approaches are considered as error-sensitive.

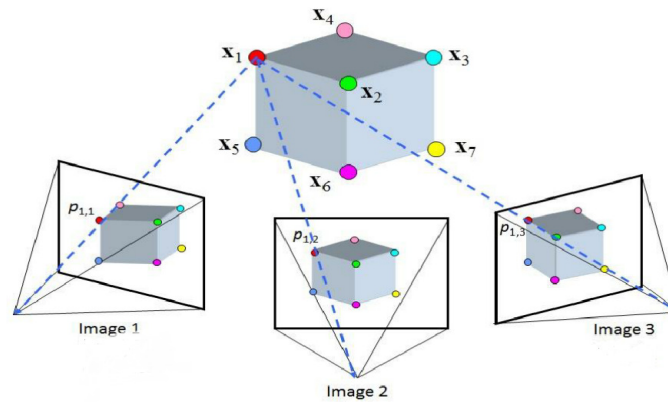


Figure 6. Explanatory configuration of structure from motion (Yilmaz and Karakus (2013))

3.2. Inverse Reconstruction Based on Geometric Properties

Feature Based. The most basic primitive which were widely used for the three dimensional reconstruction are lines. In Xie and Thonnat (1992), the three dimensional line was reconstructed by finding the three dimensional end points using its two dimensional projections. This was the basic ideal approach which was modified and presented later in Balasubramanian et al. (2000). Here, the two plane intersection approach was used to generate the three dimensional line in space.

Algebraic Curves/Conics/Surfaces. In Euclidean geometry, algebraic curves are the simplest objects having their own importance in the field of multi-view reconstruction. In An and Lee (1996), stereo vision system was described in order to achieve the desired result, which can effectively reconstruct the planar curves, but for the higher degree curves it failed. Reconstruction of higher degree algebraic curves is more difficult task in computer vision. A number of results for reconstructing these kind of algebraic curves were observed in Kahl and August (2003) and Kaminski and Shashua (2004) using multi-view geometry. Their approaches were relied more on a concept related to the projective depth map, i.e., corresponding to any pair of image points, depth can be comprehended as a linear factor.

The algebraic curves which can be represented by polynomials of degree 2 are defined as conics. Conics are adopted as the fundamental primitive and have more general features in comparison to lines. An analytic presentation for this kind of reconstruction problem was explored in Ma (1993) and Xie (1994). They have resolved the problem of unique reconstruction by solving the correspondence problem in a closed form. Whereas in Quan (1996), the same problem was solved for conics by using a new type of constraint called non-transparency constraint. After some time it was shown (Kahl and Heyden (1998)) that for establishing correspondence among image planes, Fundamental or Essential matrix may play a vital role. In Balasubramanian et al. (2002), the concept of third view was explained in order to achieve the unique reconstruction in case of different conics. Due to the complex nature of correspondence establishment problem, a new framework based on ray-surface intersection (Saini and Kumar (2015)) was proposed where the reconstruction was done by solving some set of equations via numerical algorithms. The presented approach

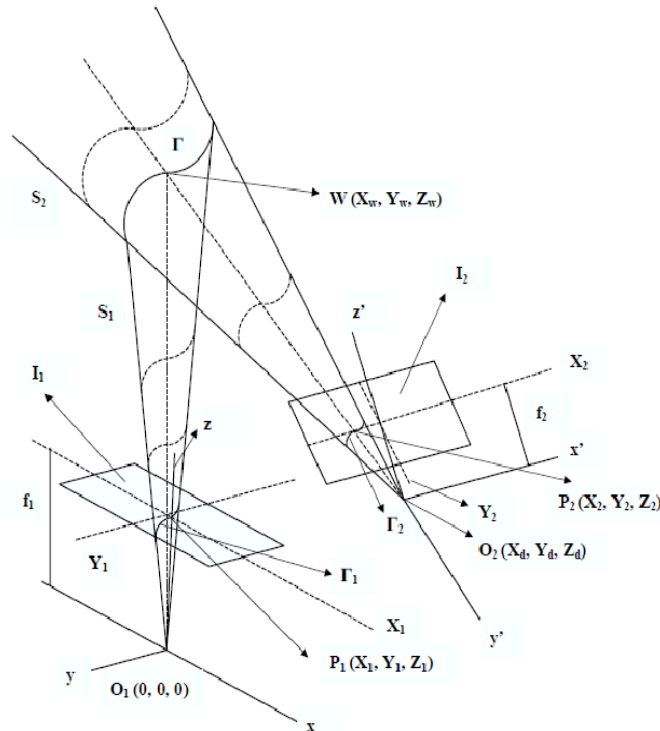


Figure 7. Reconstruction of non-planar curves from two projections (Kumar et al. (2009))

may be thought as a special case of reconstruction via intersection of two cones or surfaces. This approach was already successfully applied in case of unique reconstruction of planar curves as an intersection of two cones (Sukavanam et al. (2007)). However, the same approach was used in Kumar et al. (2009) for planar as well as non-planar curves of higher degrees. The reconstruction of non-planar curve is shown in Figure 7 (Kumar et al. (2009)) as the intersection of two cones respectively. Various fields of engineering use surface reconstruction techniques in various models such as CAD models, computer animation, surface rendering, etc. Usually, the field investigate the inverse reconstruction techniques to generate the three dimensional surface model from their physical models. In Koch (1995) and Koch et al. (2000), the three-dimensional object surface were modeled or recovered using a number of sequenced images. The proposed method did not use any kind of prior knowledge of three dimensional surface. This was a purely automatic approach for the surface modeling. Whereas in Zeng et al. (2004), the sparse three dimensional points as well as two dimensional synchronized views, both were used for the reconstruction of a dense surface.

Free-Form Shapes. The reconstruction of free-form shape in three dimensional space is not an easy task since free-form structures cannot be represented by any of the algebraic structure. To remove this ambiguity, Non-uniform Rational B-spline or NURBS (Piegel (1991); Farin (1992)) is a very effective tool. NURBS are mathematical representations of 3D geometry that can accurately describe any shape from a simple 2D line, circle, arc, or curve to the most complex 3D organic free-form surface or solid. Because of their flexibility and accuracy, NURBS models can be used in any process, from illustration and animation to manufacturing. One can use NURBS in two ways: (i) Construct 3D models from NURBS primitives. Primitives are simple 3D objects created in the

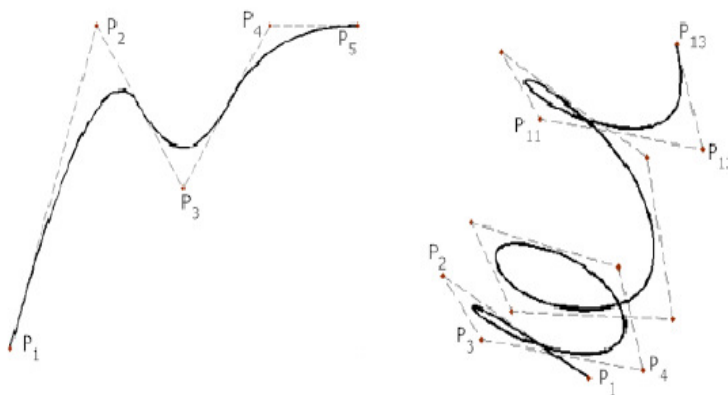


Figure 8. NURBS representation of free-form shapes (Saini et al. (2015))

shape of common geometric forms such as cubes, spheres, cones, and so on. Primitives can be a great starting point for many 3D shapes. You can modify the attributes of NURBS primitives to modify their shape. (ii) Construct NURBS curves that define the basic outline of the 3D form you want to construct, then use the curves as a basis for constructing NURBS surfaces.

NURBS shapes may be represented completely by the control points, hence the problem of inverse reconstruction may also be converted into finding the set of control points in three dimensional space using two dimensional control points of NURBS in different views (Figure 8 (Saini et al. (2017))). Reconstruction procedure of free-form shaped objects from their arbitrary perspective views involves a crucial step, called curve-fitting in all image planes. Usually, the curve-fitting is done by the method of error minimization of a residual function for a given set of data points. In case of NURBS-fitting, a two-step procedure was used in Saini et al. (2017) which was performed by obtaining the control points and their corresponding weight vectors. A new type of method for the correspondence establishment problem was discussed in Cai et al. (2011), which was called energy minimization based “snake” algorithm. Here, the shape of the snake was controlled by some force factors called intrinsic and extrinsic forces. In energy minimization algorithms, the energy function was made by the linear combinations of the above two forces, which was further minimized via several iterative techniques. To provide more flexibility to the snake models, a modern version named NURBS-snake was introduced by Saini et al. (2015) for the reconstruction of free-form shapes in three dimensional space.

Hybrid methods. As we can see that all the methods described above had some pros and cons in the field of inverse reconstruction individually. No single method was capable of reconstructing the object in space on its own. Hence, hybrid approaches like shape from shading with stereo (Bae and Behabib (2003)), shape from silhouette with stereo (Lin et al. (2008)), light based structure methods with stereo (Li et al. (2021)), optical flow with stereo (Roxas and Oishi (2018)), atmosphere scattering with deep learning (Sun et al. (2019)), etc., were come into the picture to overcome the difficulties of standard reconstruction algorithms.

4. Comparison Analysis

For any algorithm related to the three dimensional reconstruction, it requires a careful design of the concern criteria and data sets. Almost all the algorithms talk about their execution time and error rate, based on which we can compare them. But the main difficulty to process them is that all the algorithms have different backgrounds, characteristics and performance. Hence, we compare the performances of the algorithms based on some qualitative aspects which we are characterized as follows:

(i) **Absolute or Relative Depth:** This aspect shows that whether an algorithm provides an actual size of the object or the relative depth. In case of the actual depth, the algorithm provides the real distance between the viewing geometry and objects. While for relative depth map, the algorithm tells about the relative depth by analyzing edges, shading, contour, etc.

(ii) **Real Time Processing:** This aspect tells us that whether the given algorithm is suitable for real time execution or not. For the correct measurement of real time procession, the explicit run time (speed) and all related environment parameters must be given. However, it must be noted that run time or speed is related to their accuracy. Greater accuracy requires more processing time in general.

(iii) **Image Acquisition Method:** This aspect describes the image acquisition method. It means the used technique in the given algorithm is active or passive.

(iv) **Nature of Depth Map:** This aspect measures the density level of the depth map or reconstructed three dimensional points. Density may be dense or sparse. A dense map is generated by using the points or features of overall image as each depth level is assigned to each image pixel, whereas the sparse depth map measure the depth level only for some feature points.

(v) **Depth Range:** Depth range is the estimation of distance of, ideally, each point of the seen scene. The comparison is presented in Table 2.

Table 2. Three Dimensional Reconstruction Taxonomy

Algorithm	Abs/Rel Depth	Real Proc.	Image Acqu.	Depth Map	Range
Depth from defocus (Favaro and Soatto (2002))	Absolute/Relative	Yes	Active	Dense	< 1000m
Light properties based (Cui et al. (2010))	Absolute	Yes	Active	Dense	All
Atmosphere Scattering (Cozman and Krotkov (1997))	Relative	–	Active	Dense	1000 – 10000m
Shape from shading (Birkbeck et al. (2006))	Relative	No	Active/Passive	Dense	All
Shape from silhouette (Prakoonwit and Benjamin (2012))	Absolute	Yes	Passive	Sparse	Indoor sizes
Shape from texture (Lobay and Forsyth (2006))	Absolute	–	Passive	Dense	All
Shape from contour (Solem and Kahl (2004))	Relative	Yes	Passive	Sparse	All
Passive stereo (Hartley (1994))	Absolute	Yes	Passive	Dense/Sparse	< 30m
Structure from motion (Yilmaz and Karakus (2013))	Absolute	Yes	Passive	Sparse	< 50m
Feature Based (Balasubramanian et al. (2000))	Absolute	Yes	Passive	Sparse	All
Algebraic Curves (An and Lee (1996))	Relative	Yes	Passive	Dense/Sparse	All
Conics (Kumar et al. (2009))	Absolute	Yes	Passive	Sparse	All
Surfaces (Zeng et al. (2004))	Absolute	Yes	Passive	Dense	All
Free-Form Shapes (Saini et al. (2017))	Absolute	Yes	Passive	Dense/Sparse	All

5. Conclusion

A number of algorithms were reported in the field of three dimensional reconstruction from two or more images. In this paper, we have presented the algorithms based on different state of the arts aspects of their nature such as active/passive or geometrical shapes. Each of these algorithm has its own requirements, own importance, own limitations, etc. No algorithm is robust but can be better in order to achieve more accuracy. These algorithms may be better applied in different areas such as object detection, robot navigation, modeling etc.

REFERENCES

- 3D Reconstruction from Multiple Images, Wikipedia, the free encyclopedia. https://en.wikipedia.org/wiki/3D_reconstruction_from_multiple_images
- An, H., M. and Lee, N., C. (1996). Stereo Vision Based on Algebraic Curves. In *13th International Conference on Pattern Recognition*, Vienna, Austria, August 25-30.
- Bae, K-Y and Behabib, B. (2003). A hybrid scheme incorporating stereo-matching and shape from shading for spatial object recognition, *Journal of Engineering Manufacture*, Vol. 217, pp. 1533-1542.
- Balasubramanian, R., Das, S. and Swaminathan, K. (2000). Simulation Studies for the Performance Analysis of the Reconstruction of a Line using Stereoscopic Projections. In *Proceedings of the Indian Conference on Computer Vision, Graphics and Image Processing (ICVGIP-2000)*, pp. 338-344.
- Balasubramanian, R., Das, S. and Swaminathan, K. (2002). Reconstruction of quadratic curves in 3d from two or more perspective views, *Mathematical Problems in Engineering*, Vol. 8, pp. 207-219.
- Birkbeck, N., Cobzas, D., Sturm, P. and Jagersand, M. (2006). Variational Shape and Reflectance Estimation under Changing Light and Viewpoints. In *European Conference on Computer Vision (ECCV) 2006*, Part I, LNCS, pp. 536-549.
- Bundy, A. and Wallen, L. (1984) Shape from Texture. In *Catalogue of Artificial Intelligence Tools, Symbolic Computation (Artificial Intelligence)* (A. Bundy and L. Wallen, Editors), Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-96868-6_232
- Cai, Y., Su, Z., Li, Z., Sun, R., Liu, X. and Zhao, Y. (2011). Two-view curve reconstruction based on the snake model, *Journal of Computational and Applied Mathematics*, Vol. 236, pp. 631-639.
- Cozman, F. and Krotkov, E. (1997). Depth from scattering. In *IEEE Computer Society, Conference on Computer Vision and Pattern Recognition, Proceedings*, pp. 801-806.
- Cui, Y., Schuon, S., Chan, D., Thrun, S. and Theobalt, C. (2010). 3d shape scanning with a time-of-flight camera. In *Proceedings of Computer Vision and Pattern Recognition (CVPR)*, pp. 1173-1180.
- Dai, F., Rashidi, A., Brilakis, I. and Vela, P. (2013). Comparison of image-based and time-of-

- flight-based technologies for three-dimensional reconstruction of infrastructure, *Journal of Construction Engineering and Management*, Vol. 139, No. 1, pp. 69-79.
- Farin, G. (1992). From conics to nurbs, *IEEE Computer Graphics and Applications*, Vol. 12, pp. 78-86.
- Favaro, P. and Soatto, S. (2002). Learning shape from defocus. In *Proceedings of European Conference on Computer Vision (ECCV)*.
- Fazakas, T. and Fekete, R.T. (2010). 3D reconstruction system for autonomous robot navigation, 11th International Symposium on Computational Intelligence and Informatics, Budapest (November 2010).
- Ham, H., Wesley, J. and Hendra (2019). Computer vision based 3D reconstruction: A review, *International Journal of Electrical and Computer Engineering (IJECE)*, Vol. 9, No. 4, pp. 2394-2402.
- Hartley, R.I. (1994). Projective Reconstruction from Line Correspondences. In *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, IEEE Computer Society Press, pp. 903-907.
- Hartley, R.I. (1997). Triangulation, *Computer Vision and Image Understanding*, Vol. 68, No. 2, pp.146-157.
- Kahl, F. and August, J. (2003). Multiview Reconstruction of Space Curves. In *Proceedings of IEEE International Conference on Computer Vision, Nice, France*, pp. 1017-1024.
- Kahl, F. and Heyden, A. (1998). Using Conic Correspondences in Two Images to Estimate the Epipolar Geometry. In *Proceedings of the International Conference on Computer Vision*, pp. 761-766.
- Kaminski, J.Y. and Shashua, A. (2004). Multiple view geometry of general algebraic curves, *International Journal of Computer Vision*, Vol. 56, No. 3, pp. 195-219.
- Koch, R. (1995). 3d Surface Reconstruction from Stereoscopic image sequences. In *Proceedings of the International Conference of Computer Vision*, Cambridge, USA.
- Koch, R., Pollefeys, M. and Gool, V., L. (2000). Realistic surface reconstruction of 3d scenes from uncalibrated image sequences, *The Journal of Visualization and Computer Animation*, Vol. 11, No. 3, pp. 115-127.
- Kumar, S., Micheloni, C. and Balasubramanian, R. (2013). Intelligent Multimedia Surveillance: Current Trends and Research, Multiresolution Depth Map Estimation in PTZ Camera Network, pp. 149-169.
- Kumar, S., Sukavanam, N. and Balasubramanian, R. (2009). Reconstruction of cubic curves from two or more images using geometric intersection, *International Journal of Information and System Sciences*, Vol. 5, No. 1, pp. 98-111.
- Li, M., Liu, J., Yang, H., Song, W. and Yu, Z. (2021). Structured light 3D reconstruction system based on a stereo calibration plate, *Symmetry* 2020, Vol. 12, No. 772, pp. 1-12.
- Lin, H-Y. and Wu, J-R. (2008). 3D reconstruction by combining shape from silhouette with stereo, 19th International Conference on Pattern Recognition.
- Lobay, A. and Forsyth, D., A. (2006). Shape from texture without boundaries, *International Journal of Computer Vision*, Vol. 67, No. 1, pp. 71-91.
- Ma, S.D. (1993). Conic-based stereo, motion estimation and pose determination, *International Journal of Computer Vision*, Vol. 10, No. 1, pp. 7-25.

- Martinel N., Prati A. and Micheloni C. (2014). Distributed Embedded Smart Cameras. In *Distributed Mobile Computer Vision: Advances, Challenges and Applications*, pp. 93-120.
- Miyata, S., Saito, H., Takahashi, K., Mikami, D., Isogawa, M. and Kimata, H. (2017). Ball 3D Trajectory Reconstruction without Preliminary Temporal and Geometrical Camera Calibration, 2017 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), pp. 164-169.
- Oliensis, J. (1999). A multi-frame structure-from-motion algorithm under perspective projection, *International Journal on Computer Vision*, Vol. 34, No. 2-3, pp. 163-192.
- Piegel, L. (1991). On Nurbs: A survey, *IEEE Computer Graphics and Applications*, Vol. 11, pp. 55-71.
- Prakoonwit, S. and Benjamin, R. (2012). 3d surface reconstruction from multiview photographic images using 2d edge contours, *3D Research*, Vol. 3, No. 4, pp. 1-12.
- Quan, L. (1996). Conic reconstruction and correspondence from two views, *IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI)*, Vol. 18, pp. 151-160.
- Roxas, M. and Oishi, T. (2018). Real-time simultaneous 3D reconstruction and optical flow estimation, *IEEE Winter Conference on Applications of Computer Vision (WACV)*.
- Saini, D. and Kumar, S. (2015). Stereo vision-based conic reconstruction using a ray-quadric intersection, *Int. J. Image Graph*, Vol. 15, No. 4, pp. 1550019:1-1550019:22.
- Saini, D., Kumar, S. and Gulati, T., R. (2015). Reconstruction of free-form space curves using NURBS-snakes and a quadratic programming approach, *Comput. Aided Geom. Des.*, Vol. 33, pp. 30-45.
- Saini, D., Kumar, S. and Gulati, T., R. (2017). NURBS-based geometric inverse reconstruction of free-form shapes, *J. King Saud Univ. Comput. Inf. Sci.*, Vol. 29, No. 1, pp. 116-133.
- Sharad, G. and Dericks, S. (2018). Application of drone for landslide map-ping, dimension estimation and its 3D reconstruction, *Journal of the Indian Society of Remote Sensing*.
- Solem, J.E. and Kahl, F. (2004). Surface Reconstruction from the Projection of Points Curves and Contours. In *Proceedings of IEEE 3DPVT*, pp. 301-307.
- Sukavanam, N., Balasubramanian, R. and Kumar, S. (2007). Error estimation in reconstruction of quadratic curves in 3d space, *International Journal of Computer Mathematics*, Vol. 84, pp. 121-132.
- Sun, Y., Shi, J., Sun, L. and Zengi, G. (2019). Image reconstruction through dynamic scattering media based on deep learning, *Optics Express*, Vol. 27, No. 11, pp. 32-46.
- Todd, J., T., Christensen, J., C. and Guckes, K., M. (2010). Are discrimination thresholds a valid measure of variance for judgments of slant from texture?, *Journal of Vision*, Vol. 10. No. 2, pp. 1-18.
- Xie, M. (1994). On 3d Reconstruction Strategy: A Case of Conics. In *Proceedings of International Conference on Pattern Recognition (ICPR), Volume A*, pp. 665-667.
- Xie, M. and Thonnat, M. (1992). A Theory of 3D Reconstruction of Heterogeneous Edge Primitives from Two Perspective Views. In *Proceedings of European Conference on Computer Vision (ECCV)*, pp. 715-719.
- Yilmaz, O. and Karakus, F. (2013). Stereo and Kinect Fusion for Continuous 3D Reconstruction and Visual Odometry. In *International Conference on Electronics, Computer and Computation (ICECCO)*.

- Zeng, G., Sylvain, P., Quan, L. and Maxime, L. (2004). Surface Reconstruction by Propagating 3D Stereo Data in Multiple 2D Images. In *European Conference on Computer Vision (ECCV)*, pp. 163-174.
- Zhang, R., Tsai, P-S., Cryer, J. E. and Shah, M. (1999). Shape-from-shading: A survey, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 21, No. 8, pp. 690-706.