3D Shapes from 2D Curve Fitting – A Survey and Analysis

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*Abstract*—This technical document is a survey and analysis of existing algorithms used to reconstruct 3D objects from multiple surfaces.

Keywords—Surface registration, mesh alignment

# Introduction

The alignment of 2D surfaces to reconstruct 3D shapes is a technique in computer vision that has many applications. One of these applications is stitching together point cloud data obtained through LiDAR scans. This technology is used for creating terrain maps or 3D models of objects and locations. Another application of this technology is in the medical field. Often times, imagery of organs, cells or genetic materials are collected from multiple sensors or on multiple passes and must be aggregated to one image for proper analysis. One last example of the many applications of 3D construction is in Aerospace. Space vehicles will collect imagery from various mission and the transmission of that data back to earth is segmented due to transmission limitations and this data is reconstructed on the back end. Shape description and surface registration is not an easy problem to solve and there is ongoing research to create new algorithms and make old ones more efficient and effective. This paper presents the summary of five techniques in this domain.

# Summaries

## Solution 1

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## Solution 2

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## Solution 7

Research laid out in this publication [1] propose a method to locate all of the points on a non-rigid surface by identifying a geodesic coordinate system and a geodesic distance. The first step in this process is the initial feature extraction where graphs are built to match critical points. These graphs are high level shape descriptors that are used for shape matching in large datasets. Once the graph is constructed, global geodesic distance and coordinates are determined for matching points. One issue identified by the authors is the ambiguity of points local to a surface. The solution to this is a mapping process that recursively populates sets of points to calculate a geodesic map. Finally, for the surface alignment, Markov Random Field (MRF) energy formation is used with a divide and conquer methodology.

## Solution 8

In this paper [2], the authors present a framework based on Game-Theoretic Matching (GTM). GTM as applied in this research is based on two underlying conditions. The first condition is that there must exist the capability of modeling a matching feature as a strategy in a non-cooperative game. The second condition is that there must exist a reward function that is satisfactory in measuring the compatibility between two matches. If these two conditions are met, ideal strategies can be isolated. Once the strategies are identified the author lend the approach that now the matches can compete with each other in an isometry-enforcing alignment game. Since the goal in the registration of two different surfaces. Strategies then match points from one surface to points in another surface using the nearest descriptor in Euclidean space. The payoff function is then used in conjunction with the competing strategies to undergo an evolutionary matching process.

## Solution 9

The authors of this paper [3] propose methodologies that are based on a framework composed of three elements. The first method in this framework, the basis, is key point detection. The input data, objects from a dataset represented by a point cloud is first analyzed point by point. For every point, a neighborhood is defined as a sphere around that point with some defined radius and center. Using some methods proposed by other research, the authors extract a local reference frame (LRF) from each neighborhood and then use principal component analysis to transform each point from a given neighborhood into a locally aligned neighborhood. They then provide the mathematical equations in the next steps then describe the calculations of the surface variation index that indicated how much variation there is around each point in a local neighborhood. Then, the covariance matrix is calculated which is then used to find the eigen values. The second part of the algorithm is the core, feature descriptor generation. First a feature selection function is defined for a point in the point cloud a covariance matrix descriptor is defined. This is a “description” of the information about a neighborhood for each point. Finally, the description of a key point is enhanced by defining a multi-scale covariance matrix descriptor. The third and final step in this methodology is the feature matching where two multi-scale covariance matrices are compared to fins the similarity. Several sub-methods are mentioned for finding these similarities such as nearest neighbor distance ratio, either way, the comparison of these matrices will identify feature matching pairs that will be used for surface matching.

## Solution 10

The authors of this research [4] claim that they employ a novel method for obtaining LRF, using feature transformation for their creation. The process that they identify for this strategy is to first calculate a spherical neighborhood for each point in a model and selected orthogonal vectors x, y, and z. A covariance matrix is calculated and the eigen value that is smallest is set as the z-axis. The x-axis is constructed from a combination of seven weights that are derived from a weighting function. Finally, the y-axis is calculated from the cross product of the z-axis and the x-axis. The authors then describe the method of scale strategy for computing a scale factor for when the two surfaces are obtained at different stages. Once the scale factor is found, the LRF and feature descriptors are used for feature matching.

## Solution 11

The research presented in this document [5] proposes an algorithm for 3D surface reconstruction from stereo matching. During the first stage of the algorithm matching cost computation (MCC) is used to calculate the matching differences for every pixel. This is accomplished by using the Sum of Gradient Magnitude (SG) to find the direction along the pixel values. The second stage is the cost aggregation (CA) used for noise reduction, cleaning output from the first stage. Stage three represents a location with a grayscale pixel value encoding 3D data through a process called disparity selection and optimization (DSO). The final step is for post processing and refinement where invalid disparity values are located and filled in. Finally, triangulation is used for the surface reconstruction.

# Assessment

The solutions from section II have been evaluated by assessing their strength in seven key metrics (Table 2). Each metric is associated with a letter code for ease of reference, and which were assigned to the areas of assessment in no particular order. For each assessment, a paper scores on a scale from one to ten and these scores are aggregated into an overall measurement.

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| TABLE 1: Code Description for Assessment Metrics | |
| **Code** | **Description** |
| A | The level of success presented in the experimentation and/or results section of the paper. Was the full solution implemented as outlined in the paper? Were the results produced as expected? A high score indicates a high level of success. |
| B | The level of robustness in the solution. Does the algorithm generate acceptable results under abnormal conditions? How does it handle atypical input? A high score indicates a high level of robustness. |
| C | The level of reliability in the solution. Does the algorithm perform well under normal conditions? Does it generate expected results from typical input? A high score indicates high reliability. |
| D | The level of difficulty for implementing the solution. Is there sufficient material provided in the form of mathematical equations, pseudo code, or low-level algorithmic steps? A low score indicates a high level of difficulty. |
| E | The level of novelty. Is the algorithm original to the authors? Are the equations borrowed from other works? A high score indicates a completely novel idea. |
| F | The level of prospective future work. Do the authors lay out how to improve the solution? Are there obvious open ends to the research? A high score indicates a high prospect. |
| G | The level of complexity of the solution. How many steps are in the algorithms? Do they rely on other complex algorithms from previous work? How much computational resources does the implementation require? A low score indicates high complexity |

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| TABLE 2: Assessment Scores for Each Solution | | | | | | | |
| Solution | A | B | C | D | E | F | G |
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