EXPLOITING FEATURE MATCHING IN 3D RECONSTRUCTION FROM MULTIPLE IMAGES USING GVC

Kalpana Yadav, Ankita, Megha Pahwa, Niharika Sachdeva*, Shruti Choudhary

Dept. Computer Science & Engineering, Indira Gandhi Institute of Technology, GGSIPU Kashmere Gate, Delhi-110006, India.

ARTICLE INFO

Corresponding Author:
Niharika Sachdeva*
Dept. Computer Science & Engineering, Indira Gandhi Institute of Technology, GGSIPU Kashmere Gate, Delhi-110006, India.
niharika248@gmail.com

KeyWords: Reconstruction, Voxels, Consistency, GVC, feature Matching.

INTRODUCTION

In this paper, we consider the problem of reconstructing a 3D model of a scene using multiple images taken from multiple views of the scene. There are many different available techniques to accomplish this task, but we chose generalized voxel coloring (Culbertson et al., 1999), because of its simplicity and effectiveness.

Feature matching is a concept which is used to solve the correspondence problem in computer vision. Its aim is to detect similar features in all images, so that in the final reconstruction, the desired details are present.

In this paper, we have introduced feature matching in our volumetric reconstruction method. In GVC, the consistency check used to determine if voxel under consideration is to be carved or not, it happens that many times it carves voxels because it is not able to detect features like edges, lines, corners etc. Features in a scene are those areas where large intensity variation occurs, so threshold based consistency checks are not able to detect them. To tackle the above shortcoming in GVC, feature matching was added to enhance the quality of the reconstruction.

The outline of the paper is as follows: In section 2, we discuss related work to this field, in section 3 GVC algorithm is discussed in detail, in section 4, our proposed methodology is presented, section 5, complexity analysis is done and then in section 6, conclusion is drawn.

RELATED WORK

We will have a brief overview of volumetric techniques of scene reconstruction and then we will discuss some of the popular feature matching methods.

Voxel Coloring (Seitz et al., 1999) is a novel scene reconstruction technique which discretizes scene space into a set of voxels. The voxels are traversed layer by layer, satisfying the ordinal visibility constraint, they are checked for color consistency, if not consistent, it is carved. It has complexity as O(N^3n) where N^3 represents set of voxels and n, number of images. It is a single pass algorithm, but cannot detect edges, specular surfaces, and requires high camera calibration.

Space Carving (Kutulakos et al., 2000) method finds a set of all photo-consistent shapes from the given set of input photographs and tries to compute a shape from this set, known as the photo hull, a maximal shape. The scenes are characterized using the background and a radiance constraint. The carving of an arbitrary volume is done such that it converges to the photo hull. It uses the same consistency check as voxel coloring, the only advantage it has that it does not place any constraint on camera position.

Generalized voxel coloring (Culbertson et al., 1999) will be discussed in further sections in detail as it is the focus of our paper.

Silhouettes based reconstruction (Mulayim et al., 2003) is one of the basic techniques but is very useful too. Each image is converted into a binary silhouette by differencing the image with an empty background. Then each cube in an octree volumetric 3D model is projected into the silhouette and those cubes that fall outside the silhouette are removed. If a cube falls partially on the silhouette, it is marked for later subdivision, and the process is repeated until a minimum resolution is achieved.
Combined Corner and Edge detector (Harris et al., 1988) is a feature matching and tracking technique that overcomes the limitation of lack of connectivity in features by detecting corners.

The corners are detected using Moravec operator which functions by considering a local window in the image, and determining the average changes of image intensity that result from shifting the window by a small amount in various directions. The above operator also suffers many problems which can be solved using autocorrelation function. This method helps to detect majority of the features.

There exist broadly 2 types of image or matching techniques: feature based and area based. Out of the 2, feature based are better or optimal (Babbar et al., 2010). In feature based matching, distinct points in the images are selected using an interest operator then corresponding points are obtained using a similarity measure and then out of them consistent point pairs are chosen. A popular feature matching technique is RANSAC.

Before feature matching can be done, feature extraction is an important step. This task can be done by following types of operators:

- Point operator: Moravec, Luhmann and Ehlers, Dreschler, and Hannah
- Edge operator: Canny, Sobel, Prewitt, Laplacian
- Region operator: multi patch method

**GENERALIZED VOXEL COLORING**

GVC is a volumetric scene reconstruction technique which overcomes limitations of Voxel Coloring and Space carving. It does not place any constraint on the camera placement and works on visibility of the voxel. It means that, whenever a voxel is carved, it affects the visibility of the other voxels, and hence their color consistency needs to be reevaluated.

To determine visibility, every voxel is assigned a unique ID. Then, an item buffer is constructed for each image. An item buffer, shown in contains a voxel ID for every pixel in the corresponding image. A voxel V is rendered to the item buffer, after that each pixel will contain the ID of the closest voxel that projects onto it. In figure 1, representation of an item buffer is shown.

Once valid item buffers have been computed for the images, it is then possible to compute the set Vis (V) of all pixels from which the voxel V is visible. Vis (V) is computed as follows. V is projected into each image. For every pixel P in the projection of V, if P's item buffer value equals V's ID, then P is added to Vis (V). To check the color consistency of a voxel V, a consistency function consist is applied to Vis (V) or, in other words, consist (Vis (V)). Since carving a voxel changes the visibility of the remaining uncarved voxels, the item buffers need to be updated periodically.

During the final iteration of GVC, no carving occurs so the visibility information stays up-to-date. Every voxel is checked for color consistency on the final iteration so it follows that the final model is color consistent.

As carving progresses, each voxel is in one of three categories:

- It has been found to be inconsistent and has been carved;
- It is on the surface of the set of uncarved voxels and has been found to be consistent whenever it has been evaluated; or it is surrounded by uncarved voxels, so it is visible from no images and its consistency is undefined.

**Figure 1: Item buffer used in GVC**

![Item buffer used in GVC](image)

**Generalized algorithm:**

```plaintext
initialize SVL for every voxel V on SVL {
    compute V's consistency
    if (V is inconsistent) {
        carve V
        reevaluate SVL
    }
    loop until no more voxels are carved
}
```

**PROPOSED METHODOLOGY**

Generalized voxel coloring uses a consistency check consist(vis(v)) which checks the consistency using a threshold value. Even if histogram technique is used, or any other Euclidean distance based check is used, all suffer from the problem of not being able to detect high intensity variation at features like boundaries, edges and corners.
So there is a need of feature matching or tracking to enhance the quality of the 3D reconstruction model.

The proposed methodology works in 2 passes:
- In the first pass, generalized voxel coloring is used to construct the scene, carving of voxels is done, the carved voxels are stored in a set.
- In the second set, each of the carved voxel is projected back into the images to obtain corresponding footprints. Feature matching technique is applied on the footprints to determine the features if any.

A voxel may be carved due to 2 reasons:
- It is actually inconsistent
- It has some feature elements

To tackle the second reason, the second pass was introduced. Since the number of carved voxels are not very large in number as compared to the actual set of voxels, so the computation time required to do the feature matching is not very huge. But the space complexity becomes high.

We have already discussed the first pass, where GVC is applied; we also need a set of carved voxels, which we can store in a list called CVSVL, which can be further used in the second pass.

The second pass proceeds in 2 steps:
- Feature extraction
- Feature matching

Two types of features will be extracted using a combined corner and edge detector (C. Harris et al., 1988). This operator is also called an interest operator (C. Schmid et al., 2000). Output of this operator can be seen in Figure 3a) and 3b).

Figure 3 a): Original Image

Figure 3 b): After applying combined edge operator on fig 3a)

Figure 4: Feature extraction and matching

The algorithm works as follows:
1. Select a random feature point \( p \) from the first image footprint (Image 1).
2. On the second image footprint (Image 2) search within a circle of radius \( R \) and center \( (x_C, x_C) \) for the best candidate matches.
3. Select the matches that are below certain threshold.

After the features are extracted, they need to be matched in all images considered. Feature based image matching will be used as given in (Hassan et al., 2009). Example of feature matching can be seen in Fig 4 and 5.

Feature matching:

The above algorithm can be extended to multiple image footprints where data structures like kd trees (S. Arya et al., 1998) can be used, so that the computational time is reduced and to determine the threshold, multiple times the algorithm can be run.

After the matching, normalized cross-correlation over matched footprints (2 at a time) is used as the similarity measurement of two potential matches.

If the average confidence measure derived from the normalized cross correlation is high (set up by the user), then the voxel is accepted, otherwise carved.

The flowchart of the proposed methodology is given in figure 2.

COMPLEXITY ANALYSIS

In the first pass, GVC runs, so the time complexity is approximately \( O(N^3) \) and space complexity is \( O(N^2) \).
where \( N \) is the number of voxels present in the initial volume.

In the second pass, each carved voxel is reevaluated; the reevaluation step consists of 2 steps: feature extraction and feature matching.

Feature extraction will take approx \( O(n) \) time, where \( n \) is the number of images. Feature matching will take \( O(n^2 R^2/d_{cor}^2) \) where \( R \) is radius of the circle considered for matching, \( d_{cor} \) is the feature isolation number. Now \( R^2 \) and \( d_{cor} \) are constant terms most of the times, so time complexity is equal to \( O(n^2) \).

So total time taken when both passes are completed are: \( O(N^2) + O(nN) + O(n^2N) \) i.e. approx \( O(\max(N^2, nN, n^2N)) \). (1)

**CONCLUSION**

To detect features in a scene, feature matching technique was added to the original GVC algorithm. Two passes were used to obtain a complete scene reconstruction from the given images.

The resulting time complexity is given in (1) which is more as compared to, if only single pass is used. The enhancement to the model is that more features are reconstructed i.e. more quality is obtained.

Future work in this methodology can be using more efficient interest operators, consistency checks to decrease the running time.

**REFERENCES**

7. Hassan Hajjdiab; Robert Lagani`ere; “Complexity Analysis of Featured-Based Image Matching”; World Academy of Science, Engineering and Technology 51 2009
14. Qian Chen and Gérard Medioni; “A Volumetric Stereo Matching Method: Application to Image-Based Modeling” University of South California