Image-based Fast 3D Reconstruction

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Abstract. *Image-based 3D reconstruction* has many applications, but the reconstruction process is really time-consuming. In this paper, we have discussed several existing methods which can speed up the reconstruction, but many of them have their own limitations. After the analysis of image-based 3D reconstruction procedures, we proposed several possible strategies, like preprocessing images to accelerate *image matching* and calculating a less dense point cloud to save the time of getting mesh and textures, which are supposed to quicken the process of reconstruction.

Introduction

Photogrammetry is the science of making measurements from photographs, and measuring the real 3D world via photographs has arose great interest for decades, since the word we live in is a 3D world.

Reconstructing the 3D world would make the measurement much easier, and 3D model is much more fascinating than 2D images, which is getting more and more popular in many fields. However, the process of that reconstruction of 3D world through 2D images has encountered a lot of tricky problems, like key points detection in images, image matching, calculating the motion and pose of cameras, triangulation, etc.

With the development of computer vision during past few decades, many great progresses have been made in such a short time. A way of detecting corners in images proposed by Harris [1], can be applied in key points detection; Sift key points with 128-dimension descriptors [2], can make the key points matching much more precisely; Structure from motion and multi-view stereo have facilitated image-based 3D reconstruction.

All these, especially multiple view geometry [3], make image-based 3D reconstruction possible. While how to make this construction much faster has become an issue worth studying, since 3D geometric reconstruction has many applications in VR, movie industry, and computer games and so on so forth, which means reducing certain time of the reconstruction process, will definitely cut considerable costs in those industries. And if that reconstruction can be accomplished in a very short time, it will definitely make a difference in emergency management.

To achieve that, there are several optimization jobs to do during the whole process of photograph-based 3D reconstruction. In this paper, we have discussed several possible methods to do the optimization jobs, which can speed up the process.

The process of image-based 3D reconstruction

Generally, there are several procedures in the construction process, which have been presented in Fig. 1. However, the procedures listed below don't include calibration, but it doesn't mean you need not to do it. Fig. 2 is a simple example of image-based 3D reconstruction, which has contained some of the procedures.

1. Get photographs with certain consistence, which means the adjacent images are supposed to have large part of same coverage.
2. Detect key points in the images and find the correspondence, and one of the most common ways to do that is use SIFT detector. SIFT is more precise and stable, for it is scale-invariant, and robust to local affine distortion. But it is quiet time-consuming to use SIFT to detect key points, generate the descriptors, and match them, especially when matching with brutal force.

3. Calculate the spatial relation between the photographs, like rotations and transformations, which can decide the positions and the poses of the photographs.
4. Calculate 3D positions of the corresponding points(triangulation), and get a sparse 3D point cloud.
5. Calculate a dense 3D point cloud using multi-view stereo.
6. Generate meshes and fill them with textures.

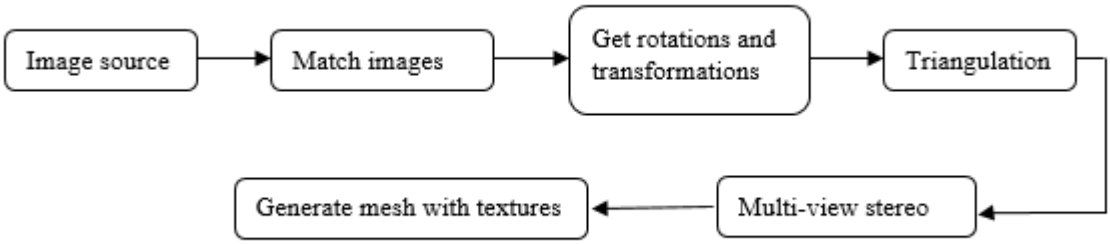

Figure 1: Main procedures of image-based 3D reconstruction

Fast 3D Reconstruction Methods

3D reconstruction involves different objects and scenes, which may vary a lot in geometric scale, illumination condition and structure complexity. It means finding a fast 3D reconstruction method that can be applied everywhere requires great efforts.

For small subject reconstruction, it is easy to control the illumination condition during the process of image capture. Macros and Alan developed a novel uncoded structured light method [4], which projects a pattern of evenly-spaced white stripes onto the subject, and records the deformation of stripes in a video camera placed in a fixed geometric relationship to the stripe projector. However, for outdoor scenes and large scale objects, it is nearly impossible to use this method.

Image matching is one of the indispensable stages in image-based 3D reconstruction, and usually occupies half of the computational cost and inaccurate matching may lead to failure of reconstruction. Consequently, fast and accurate image matching is very crucial for 3D reconstruction. One of the most common way to perform image matching is to match SIFT descriptors with brutal force. It may be easy and simple, but usually time consuming.

Instead, there are several other ways to perform that matching. K-d tree is much faster and also very accurate. A library called FLANN, can perform fast approximate nearest neighbor searches in high dimensional spaces, which works quite well in image matching. A substitution of SIFT is SURF [5], whose descriptor has only 64 dimensions, only half of SIFT descriptors, which can reduce the matching time.

Except those strategies to boost image matching, some new methods have been developed. A Cascade Hashing strategy has been proposed to speed up the process of image matching. It has a three-layer structure: hashing lookup, hashing remapping, and hashing ranking [6]. Each layer adopts different measures and filtering strategies, which is less sensitive to noises. But this method is a little cumbersome. Another method that uses Grab Cut algorithm [7] to eliminate some parts of images that do not have their prominence in 3D reconstruction, can extract the most paramount key points, which leads to the reduction of the key points numbers and the time of image matching. It may sound like a very promising strategy, but we have to say it is a challenge to control which part of image to cut and eliminate. For example, if too many of image parts have been cut or the wrong parts of image have been cut, the left parts may not have enough information for matching, which could lead to the failure of the reconstruction.

The Optimization Strategies

There may be several strategies we can take to optimize those procedures.

1. Before we take pictures of the subject that we are about to reconstruct, we need to do the plan about how to minimize the numbers of the pictures you plan to take, without impairing the result of the reconstruction. Less number of pictures for reconstruction, less time will take. For instance, you can control the percentage of coverage between two pictures. It would be better, if the order of the pictures can be recorded.

2. Before image matching, we can preprocess pictures, like to make their size smaller, or use some graph cuts method to eliminate certain parts of the pictures, only make the most paramount key points left. We can even select and limit the number of key points in each image, as long as it meets the need of reconstruction and can boost the process of image matching.

3. During the reconstruction, the dense points cloud contains excessive information for calculating the mesh and texture, which means a less dense points cloud would cost less time, but is enough for reconstruction. However, the best parameters are supposed to be decided through some experiments that are designed to optimize the process.

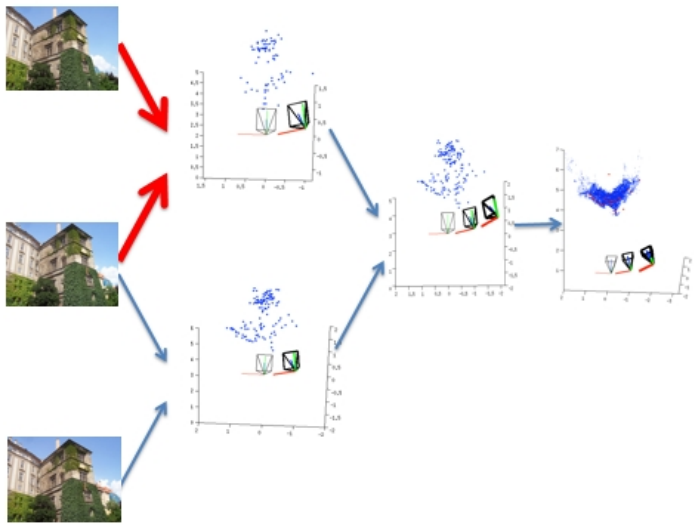

Figure 2: image-based pair wise 3D reconstruction process

Conclusions and future work

Image-based 3D reconstruction has enjoyed enormous popularity in many industries, like movie industry, virtual reality, and video games. But this kind of reconstruction process usually takes a long time which makes real-time reconstruction very difficult. Therefore, if the methods to speed up that reconstruction process can be developed, the time costs of the reconstruction will be reduced accordingly, and the costs of those industries that apply this technique will definitely be cut down dramatically.

To build 3D model from 2D images, the depth information of the subject is always miss, which makes the reconstruction quite difficult. The method to project white stripes onto images, simplifies the process of getting depth information, but depends heavily on illumination condition.

Several methods about fast 3D reconstruction have been proposed to boost the reconstruction, but many of them have their own limitations, which prevent them from being applied widely. However, there are certain general strategies we can take during the process of 3D reconstruction to promote its speed: control the input images to make sure there are not many excessive images; preprocess the images to speed up image matching; optimize the multi-view stereo algorithm to calculate a less dense points cloud which is less time consuming but enough for reconstruction.

In our future work, we will design some experiments to test our strategies about fast 3D reconstruction, and find solutions to the optimization problems of the reconstruction. For example, we will test the method to optimize MVS, which is just our hypothesis.

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