A stereo system with adaptive pattern projection for the determination of object geometries

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Abstract

This paper presents a practical projector-camera based 3D object modelling system developed in our laboratories. The hardware consists of a computer, a video projector and at least two digital cameras. The 3D modelling of a real object is realized automatically by applying an adaptive spot projection technique. For each spot in the first image, an algorithm is applied to find its correspondence in the second one, thus a cloud of 3D points is finally generated by triangulation, which is necessary for the calculation of the geometry of the object. In the case that the surface of the object is irregular, an iterative optimization process is lanced to improve the 3D reconstruction speed and the precision of the reconstructed model.

Keywords: object geometry, 3D reconstruction, projector-camera system, adaptive pattern projection, iterative optimization process.

Introduction

3D reconstruction and modelling of objects is one of the main objectives of computer vision and attracts a lot of attention in recent years [1]. It has various applications such as quality control, industrial inspection and auto-navigation. Among various 3D model reconstruction techniques, the projector-camera based method (also called structured light approach) is widely utilized because of its simplicity and high accuracy [1].

In general, the reconstruction of a 3D model primarily needs to determine a geometrical and morphological precise point cloud, which then could be used for a triangulation allowing the calculation of a contiguous surface and a final texture mapping. The two latter steps are well investigated and solved. The determination of the geometrical base however is still under development, especially when the point cloud should be adapted to the morphological structure of the object. For this step we propose a hierarchical process consisting of pattern projection, image capture, image analysis and point determination which is iterated as long as the quality of the point cloud does not fit optimal to the object surface.

General conception

Our system uses a video projector, two digital cameras and some processing tools. Initially the video projector generates a certain powerful coloured light pattern (actually: spots) allowing to clearly identify individual points on the object's surface. This pattern is imaged from two (or more) positions. Then these images are analysed to get the 3D co-ordinates of each spot in the pattern. This point cloud serves as the base for a morphological analysis, which indicates those surface regions having a complex geometrical structure not being sufficiently represented in the 3D model. For these regions the pattern projection is modified in order to better adapt the pattern to the geometrical structure. This step will be repeated until the surface is captured correctly.

In the case that the surface to be determined cannot be captured with a single stereo view, additional stereo views have to be added. Adding further views needs to join the individual models. This might be achieved by geometrical processing or by preparations using common object points which have to be identified in adjacent 3D models.

Finally, the 3D model can be rendered on the screen.

Image processing technique

The main task is the determination of each projected object point in the image pairs. In order to simplify this task it is necessary to calibrate the images (see [3,4] for stereovision sensor calibration techniques, [5] for orientation of multiple images). This allows the establishment of geometrical constraints during the following analysis.

Image processing has two steps. Firstly, an image analysis is used to identify the elements of the pattern and then the correspondence problem has to be solved.

At this moment a point pattern is used, that's why the image processing has to identify individual spots representing an object point. As spots usually look like filled colourful ellipses, we apply some filtering, threshold techniques and contour recognition techniques in order to get the boundary of the spot. All pixels within the boundary are elements for a weighted calculation of the center, which is assumed to be the precise imaged object point.

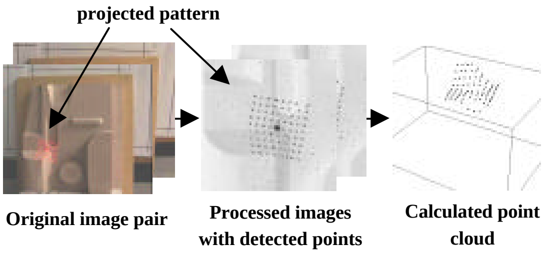

Figure 1. From a projected pattern to a point cloud

The next step is to solve the correspondence problem, i.e., to identify, for a given point in one image, its respective correspondence in the partner image. If a point does not have a correspondence, it will not be kept for the later surface reconstruction step. Since the images are calibrated and oriented in space, we can simplify the correspondence problem by applying some geometrical constraints. The most important one is based on the fact, that corresponding points are imaged on epipolar lines. Other constraints come from, for example, the relative position of two adjacent object points, or the probability of having major changes in the distance from the image to object.

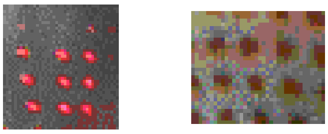

Figure 2. Pattern samples (left: laser, right: video)

If more than two images are used, which is interesting in that it increases accuracy, then a further powerful geometrical constraint can be established. This uses the fact that all epipolar lines calculated from corresponding points in other images have to intersect at one position representing the same object point.

Result

For test purposes, different types of objects have been used in order to verify aspects like overall success rate, precision, influence of surface roughness and reflectivity. The results show that the most critical effect is the clarity of the imaged points, as it affects the efficiency of the point detection and their success rate. Using a laser beam as projection source, color values and intensity are significant enough to achieve success rates of 100% (cf. Fig. 2, left). If image quality is weak (cf. Fig. 2, right), however, the process gets sensitive to his control parameters and success may be lower.

The precision achieved depends on several effects such as number of images, image quality and image scale, for example. For a test configuration of 5 images, an accuracy of 0.2~0.3 Pixel for the position a point in an image has been found.. This value has still some potential for improvements. For a stereo configuration they are a bit weaker (by factor 1.5~2).

Other effects contribute differently as function of the type of projection. Laser beams give better results on polished surfaces due to speckle induced degradations on rough surfaces. Conventional video projections, however, give superior results on such rough surfaces.

Conclusion

This paper describes a system for determination of 3D-point clouds on object surfaces based on pattern projection and two digital cameras. By using an iterative approach and controllable pattern structure, the system is able to adapt the point density to the object surface until the precise 3D model is constructed. The image processing technique gives high success rates for good image quality, and the correspondence problem is solved with several geometrical constraints. For the future, the algorithms have to be improved for lower image quality and the solution for the iterative approach will be introduced.

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Biography

Wanjing LI received a B.S. degree in Computer Sciences from the Nanjing University of Aeronautics & Astronautics in Nanjing (China) in 1995 and a master degree in Image Processing from University of Burgundy in Dijon (France) in 2004. She is now preparing her PhD diploma at the University of Burgundy and the University of Applied Sciences in Mainz (Germany). Her work focuses on the stereovision system, 3D scene reconstruction and structured light.