Projector Camera System for Realtime 3 D Scanning

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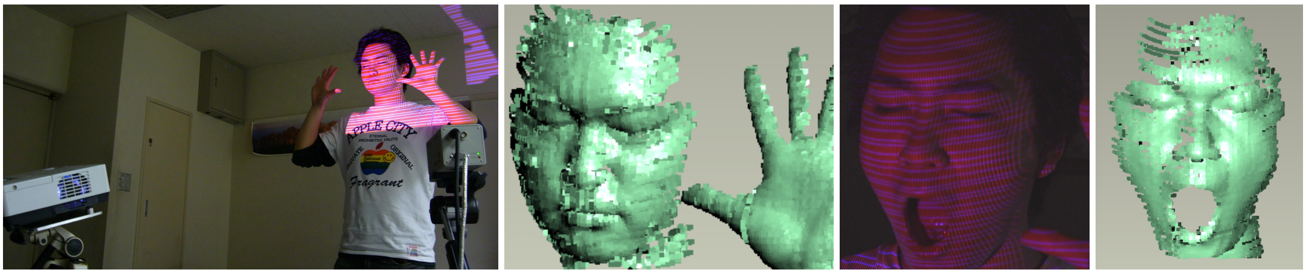

Abstract

An active 3D scanning device which can capture a sequential motion in realtime is strongly demanded for 3D display and other VR systems. Since most previous and commercial products basically recover the shape with a point or a line for each scan, fast motion can not be captured in principle. One solution for the purpose is to use a single pattern (one shot scan). However, they often have stability problems and their result tend to have low resolution. In our recent study, we have developed a system which achieved dense and accurate 3D reconstruction from only a single image. The proposed system also had the advantage of being robust in terms of image processing. In this presentation, we introduce outline of our system, several applications and results.

CR Categories: I.3.5 [Computational Geometry and Object Modeling]: Hierarchy and geometric transformations— Modeling packages ; I.3.7 [Three-Dimensional Graphics and Realism]: Virtual reality—Visible line/surface algorithms ;

Keywords: radiosity, global illumination, constant time

1 Introduction

Nowadays active 3D scanners are widely used for actual 3D model acquisition process. Especially, structured light based systems [Inokuchi et al. 1984] have been intensively researched and commercialized, because systems of this type are relatively simple and realize high accuracy. To scan a 3D shape with fast motion, 3D scanners using high-speed structured light systems have been studied in recent years [Hall-Holt and Rusinkiewicz 2001]. However, the system still require a several frames for reconstruction and it is difficult to scan a moving object sequentially and in realtime.

On the other hand, 'one-shot' structured light systems which use only single images have been also proposed. Widely used methods in this category are embedding positional information of the projectors' pixels into spatial patterns of the projected images [Je et al. 2004]. Although the techniques can resolve the issues of rapid motions and synchronization, they typically use patterns of complex intensities or colors to encode positional information into local areas. Because of the complex patterns, they often require assumptions of smooth surface or reflectance, and the image processing tends to be difficult. If the assumptions do not hold, the decoding process of the patterns may be easily affected and leads to unstable reconstruction.

Although it does not strictly involve a structured light system, methods of shape reconstruction to include objects' motion by spatio-temporal stereo matching are proposed [Zhang et al. 2004].With these techniques, a projector is only used to provide a texture that changes over time for a pair of stereo cameras. However, since they assume spatio-temporal smoothness, it is difficult to apply for realtime 3D scannings.

This paper presents a single scanning technique resolving the aforementioned problems . The proposed technique uses a simple grid pattern formed by straight lines distinguishable only as vertical or horizontal lines so that image processing is simple and stable. In addition, there is no need to encode particular information for the local grid pattern itself, so the pattern can be dense as long as it is extractable. Usually, a shape cannot be reconstructed from such a pattern. Thus, a new technique that reconstructs the grid pattern using coplanarity constraints [Furukawa and Kawasaki 2006] is presented.

2 System outline

The 3D measurement system proposed consists of a camera and a projector as shown in Fig.1(left). Two types of straight line patterns, which are vertical and horizontal stripes, are projected from the projector and captured by the camera. The vertical and horizontal patterns are assumed to be distinguishable by color.

The straight pattern projected by the projector defines planes in 3D space. Planes defined by a vertical pattern and a horizontal pattern are respectively referred to as a vertical pattern plane (VPP) and a horizontal pattern plane (HPP).

The projector is assumed to have been calibrated. That is, all parameters for the VPPs and HPPs in 3D space are known. A VPP

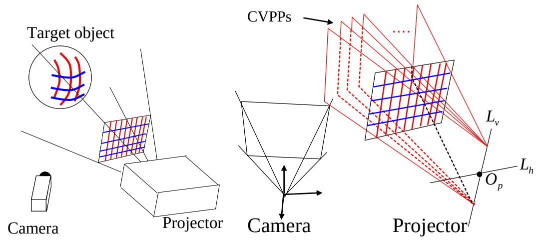

Figure 1: *Scanning system:(left) the system configuration, and (right) CVPPs.*

and a HPP with known parameters are referred to as a calibrated VPP (CVPP) and a calibrated HPP (CHPP). All the CVPPs contain a single line, as in the figure 1(right). The same assumption holds for all CHPPs. These lines are denoted as L_v and L_h and the optical center of the projector O_p is the intersection of these lines. The point O_p and the direction vectors for L_v and L_h are given by calibration.

Intersections of the vertical and horizontal patterns projected onto the surface of the target scene are extracted from images captured by the camera. Here, these points are referred to as captured intersections.

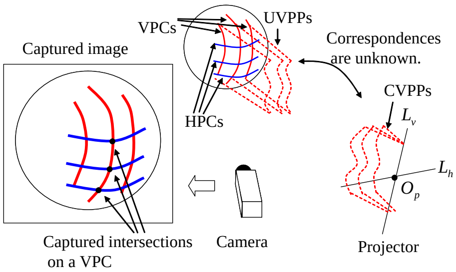

Figure 2: *CVPPs and UVPPs.*

The goal of the problem is to identify all the UVPPs and UHPPs to CVPP or CHPP. As a result, 3D positions of all the captured intersections become known.

The proposed method derives linear equations based on conditions of coplanarity of UVPPs and UHPPs and an intersection of observed curves in a captured image. Then, simultaneous equations are constructed from the equations which have general solution with one free parameter. The free parameter can be determined by assuming a correspondence between specific UVPP and CVPP. Then, the positions of all the UVPPs and UHPPs can be determined. Then, by comparing the positions with the CVPPs and CHPPs, each UVPP or UHPP is corresponded to the nearest CVPP or CHPP. Then, the differences between the UVPPs (or UHPP) and the corresponding CVPPs (or CHPP) are calculated. By regarding these differences as "errors", the correspondence with the minimum sum of squared errors are searched.

For stable searching, adding irregularities to the arrangement of the CVPPs (CHPPs) are desirable. In this paper, combined patterns of dense vertical lines with uniform intervals and horizontal lines with random intervals as shown in Fig.3(left) are used. Here, vertical and horizontal patterns were respectively colored red and blue so that they were distinguishable. Because of the simplicity of the projected pattern, this method is less affected by noise, surface texture and color, or object shape.

3 Application and Results

Our method can be applied to scan a fast moving object sequentially and in realtime. Fig.4 (a)-(d) are the captured image and reconstruction results of our scanning system. All 3D shape are scanned and reconstructed in realtime with average 1.5 frame/sec.

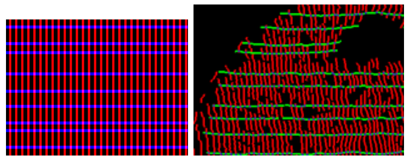

Figure 3: *A projected pattern (left) and detected lines(right). In the right figure, red curves are horizontal patterns, green curves are vertical, and intersection points are blue dots.*

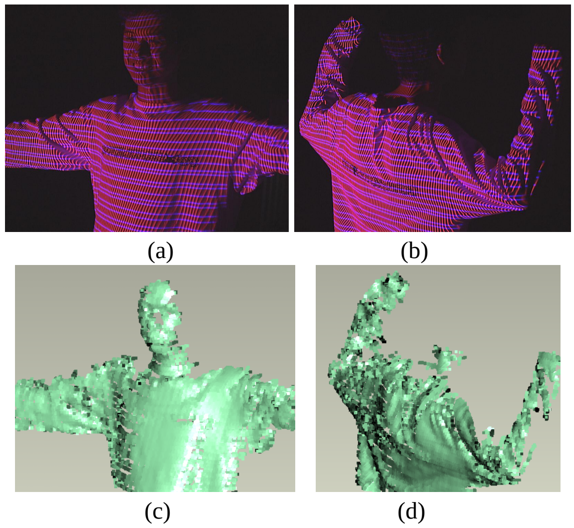

Figure 4: *Human motion capturing results of our system.*

4 Conclusion

This paper proposes a technique to densely measure shapes of dynamic scenes using a single projection of structured light. Since the proposed technique does not involve encoding positional information into multiple pixels or color spaces, as often used in conventional one-shot 3D measurement methods; but into a grid pattern instead, the technique is affected little by an object's texture or shape, providing robust shape reconstruction.

Acknowledgements

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References

FURUKAWA, R., AND KAWASAKI, H. 2006. Self-calibration of multiple laser planes for 3D scene reconstruction. In *3DPVT*, 200–207.

HALL-HOLT, O., AND RUSINKIEWICZ, S. 2001. Stripe boundary codes for real-time structured-light range scanning of moving objects. In *ICCV*, vol. 2, 359–366.

INOKUCHI, S., SATO, K., AND MATSUDA, F. 1984. Range imaging system for 3-D object recognition. In *ICPR*, 806–808.

JE, C., LEE, S. W., AND PARK, R.-H. 2004. High-contrast color-stripe pattern for rapid structured-light range imaging. In *ECCV*, vol. 1, 95–107.

ZHANG, L., SNAVELY, N., CURLESS, B., AND SEITZ, S. M. 2004. Spacetime faces: High-resolution capture for modeling and animation. In *ACM Annual Conference on Computer Graphics*, 548–558.