3D Reconstruction of Intricate Objects using Planar Cast Shadows

Tzung-Han Lin, Hao-Teng Chang, Shang-Jen Hu
National Taiwan University of Science and Technology*

Figure 1: *(a) the proposed 3D capture system with a translucent checkerboard. The 3D reconstruction results compared to their original objects are shown in (b) a translucent acrylic hand model, (c) a wood cage having 15cm height, and (d) a metal pen holder.*

1. Introduction

3D reconstruction for intricate objects such as mesh structures or translucent materials is a challenging task. One way to form the shape of an intricate object is to probe its silhouette. We propose a 3D reconstruction system based on planar cast shadows and the shape from silhouette algorithm. Our work focuses on simplifying the calibration procedure and equalizing the numbers of effective pixels of shadows in all captured images. With this design, the spatial resolution is improved and it is able to carve intricate shapes.

2. Our Approach

Our objective is to reconstruct intricate objects from the silhouettes of their cast shadows. It is a topic regarding visual hull and calibration, which has been addressed in [Yamazaki et al. 2007] and [Mitra and Pauly 2009]. Our setup follows the works in [Savarese et al. 2005] and [Lanman et al. 2008] including a point light source, a turntable, a projection screen and a digital camera. We use a light emitting diode (LED) as a point light source due to its high luminance and good uniformity. The turntable, which is driven by a computer-controlled servo motor, carries the objects. It is used to generate a circular arrangement for captured images. Because the servo motor has a position encoder, the positions of the calibrated checkerboards and their corresponding images are repeatable. The projection screen, which is between the LED and a digital camera, consists of a translucent acrylic flatbed and a thin sheet on one side. On the other side of this projection screen, four markers forming a square are used for calibration. And, one 16M-pixel Nikon D5100 with 55mm lens is setup in the rear side for capturing shadow images. The setup is shown Figure 1 (a).

Our calibration method consists of two procedures. It can be readily carried out by openCV library. The first procedure is a homography operation to transfer the pixels within four markers into a square image. We consider the square image as the film of the virtual camera which is formed by the LED. Then, the cast shadows of the calibration patterns are used for determining intrinsic and extrinsic parameters of this virtual camera. Mathematically, the point light emission represents a perspective projection. Its intrinsic parameter is dominated by the distance between the projection screen and the LED. The intrinsic parameter also depends on how large the square image is. In practice, we print a checker pattern on a thin translucent film. There are two reasons: the first one is to avoid light deflections. The second reason is to keep this checker pattern visible on its rear side. When the light passes through this translucent film, the corners of this checker pattern are clearly cast on the projection screen. After collecting all corners, the parameters for the LED are determined. Here, the extrinsic parameters of rear views are corrected again by a coordinate transformation. However, some corner features in the lateral views are not recognizable. Their extrinsic parameters are extrapolated by at least two extrinsic parameters of its neighboring images. Regarding the radial distortion, it is very likely to happen due to the combination of optical lenses and the translucent acrylic flatbed of the projection screen. Nevertheless, the radial distortion can be corrected by a high order polynomial equation.

In the background subtraction procedure, we use K-means clustering for automatically retrieving shadows in images. It also can be readily carried out by specifying a threshold. For capturing translucent objects, such as crystal or translucent acrylic objects, the light deflection will occur. Nevertheless, the silhouette of the cast shadow of the 3D object is the same. In these cases, manual selection for determining silhouettes is needed.

For the shadow carving procedure, we use a voxel-based visual hull algorithm. Then, the marching cube algorithm is also considered for converting all voxels into isosurfaces. The reconstructed 3D model will be a mirrored shape compared to the real object. Finally, we apply Gaussian filter on objects for smoothing their surfaces. Our average re-projection error is 0.85 pixel for a 4M pixel image, which occupies less than 0.1^2 mm^2 area on the projection plane. So, we select the $0.25^3 \sim 0.5^3$ mm^3 voxel as the basis when executing visual hull algorithm. With regard of the limitation, our method is not able to carve a self-occluded shape due to the native problem of visual hull algorithm. The results in Figure (b), (c) and (d) show that intricate objects are properly carved.

Reference

YAMAZAKI, S., NARASIMHAN, S., BAKER, S. AND KANADE, T. 2007. Coplanar shadowgrams for acquiring visual hulls of intricate objects. In *Proc. of IEEE International Conference on Computer Vision*, 1–8.

MITRA, N. J. AND PAULY, M. 2009. Shadow art. In *ACM Siggraph Asia*.

SAVARESE, S. AND ANDREETTO, M. 2005. 3D reconstruction by shadow carving: Theory and practical evaluation. *International Journal of Computer Vision*. 71, 3, 305–336.

LANMAN, D., RASKAR, R., AGRAWAL, A. AND TAUBIN, G. 2008. Shield fields: modeling and capturing 3D occluders. *ACM Transactions on Graphics (TOG)*. 27, 5, 131.

* e-mail: {thl, m10025014, m10025010}@mail.ntust.edu.tw

SIGGRAPH 2013, July 21 – 25, 2013, Anaheim, California.

ACM 978-1-4503-2261-4/13/07