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A Low-Cost Solution for 3D Reconstruction of Large-Scale Specular Objects

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Abstract: In this paper, we present a low-cost 3D reconstruction method for large-scale specular objects based on deflectometry. Experiments show that our system reaches high accuracy and meets requirements of the target applications in the cultural heritage preservation.

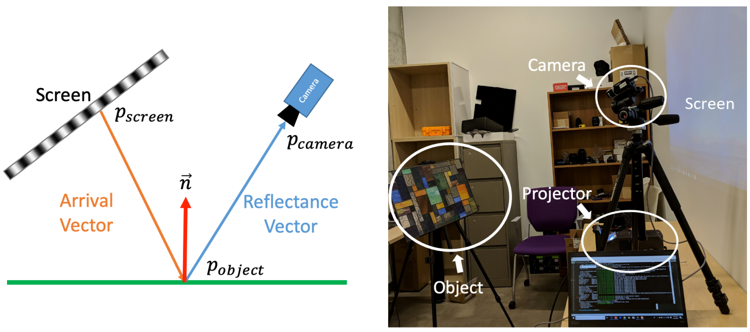
1. Introduction

3D measurements of objects are an important part of documenting their state of preservation [1]. However, 3D reconstruction of large scale specular objects, in particular, stained glass windows, has been a challenge for years because of the large specular surface areas, large angular range, and high-frequency surface 3D information. While such stained glass windows show distinct details and 3D features, their overall shape is commonly flat.

In this conribution, we present a low-cost, portable, and high-accuracy 3D reconstruction method for large-scale specular objects. We utilize deflectometry [2] [3], an active 3D reconstruction technique for specular surface recovery. In a deflectometry setup, the screen projects fringe patterns to the specular surface. Eventually the system computes surface gradient information (in the form of surface normal vectors $[n_x, n_y, n_z]^T$) from the pattern deformation in the camera images. By replacing the LCD screen commonly used in conventional deflectometry setups with a projector and an entire wall, our system can create an effective screen large enough to “cover” the angular range and surface area of large scale specular objects with high surface frequencies. This system can be assembled/disassembled within 5 minutes, and can be deployed at any place with a surface large enough to serve as ”screen”. Our evaluation shows that this system is capable of recovering 3D surface details with high accuracy and satisfies the demand of applications in the field of cultural heritage preservation.

2. Proposed Method

Fig 1(a) shows a typical deflectometry system. A deflectometry system consists of three parts: screen, camera and specular object. The screen area determines the coverage of angular range and surface area of a reconstructed object, so it is typically desirable to make it as large as possible. In our system, we use a projector and an entire wall to cover the large angular range and surface area of specular objects. The screen created by a projector is significantly larger than commercially available LCD monitors. Figure 1(b) shows our experimental setup.



(a) (b)

Fig. 1. (a) Typical deflectometry system (b) Experimental setup

In our system, we implement Phase Measuring Deflectometry [2], a variant of deflectometry method. In our approach, the normal-depth-ambiguity problem, inherent to each deflectometry method, is solved by exploiting prior information about the object under test - namely that its overall shape is flat. We place markers on the object, use our calibrated camera to detect their position in space and fit a plane between marker positions. This plane is used to approximate the depth of each object point, which in turn allows for an unambiguous calculation of the surface normal.

To compute surface normal, we need to calibrate: 1) camera intrinsic matrix and 2) position and pose of screen and object. We integrate a system calibration procedure in our system. Additionally, we add a radiometric calibration process proposed by Debevec et al. [4] to remove radiometric distortions on images.

3. Experiments

To evaluate accuracy of our system, we measured a lab-grade spherical mirror [5]. Then we compared the measured normal map to the ground truth normal map generated using manufacturer specifications. The measured normal maps of mirror (in n_x, n_y and n_z components) are shown in Figure 2(a). Figure 2(b) shows absolute angular errors. The average absolute angular error is 0.67 degree, and root mean square angular error is 0.75 degree.

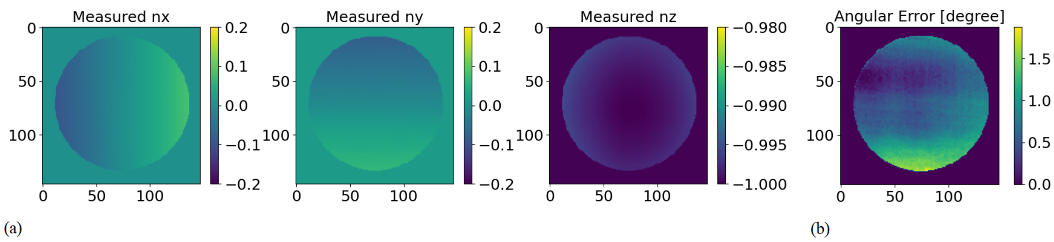


Fig. 2. (a) Measured normal map of mirror (b) Angular errors between normal maps

We also measured a 12*24 inch (30*60cm) stained glass window using our system. Figure 3 shows the normal map of the stained glass window (where n_x, n_y, n_z are encoded respectively into R, G and B channels). The 3D structures of the stained glass which are hard to observe on conventional RGB images can be easily recognized.

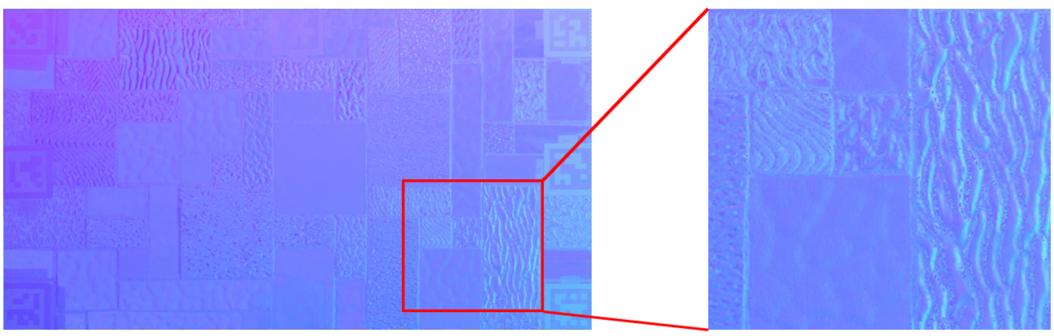


Fig. 3. Measured Normal (right) of stained glass (left) specular surface

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