Shape from Distortion: 3D Range Scanning of Mirroring Objects

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Objects with mirroring surfaces are left out of the scope of most recent 3D scanning methods. We developed a new acquisition approach, shape-from-distortion, that focuses on that category of objects, requires only a still camera and a monitor, and generates high quality range scans (plus a normal field). Our contributions are a novel acquisition technique based on environment matting [Chuang et al. 2000] and corresponding geometry reconstruction method that recovers a very precise geometry model for mirroring objects.

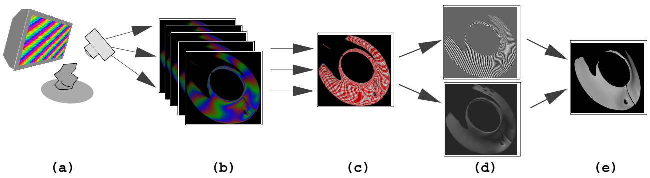

Figure 1: Acquisition Pipeline: Four images of reflected patterns are captured (a+b) and the matte (c) is extracted. A depth and a normal field are calculated (d) and combined to the final range scan (e).

Data Acquisition

In order to obtain a range scan, we display a stripe patterns four times (each rotated by 45 degree resulting in different frequencies along the axes) on a monitor and capture the reflection of the monitor on the object's surface with a digital camera. From the captured images, we compute with subpixel accuracy which pixel on the monitor is reflected at each position.

The projected stripe pattern consists of linear ramps in the RGB color channels which add up to 1 at each position making the system robust to different albedo. Furthermore, appropriate calibration steps ensure that the whole optical system has a linear response. We can thus compute for a single captured image an offset value in the periodic stripe pattern that corresponds to each color triple. Given four images, we compute the exact monitor position that is reflected in each pixel using the interference properties of the patterns. The system is overdetermined and the redundancy is used to improve the accuracy of our approach.

In contrast to other spatio-temporal modulation approaches (e.g., [Rocchini et al. 2001]), this method does not rely on progressively lower frequency patterns and coherency between neighboring pixels so that even fast changing signals can be captured. The fact that the high frequency information from all captured images is used, increases the stability of the technique.

Geometry Reconstruction

Given the captured matte, the internal camera parameters, and the position of the monitor relative to the camera, we can convert a normal directions into a depth values and vice versa by two methods: Using only local information of a single pixel, we can trace a ray trough each pixel on the image plane and reflect it of the surface so that it hits the corresponding pixel on the monitor (according to the matte). This constraint allows to directly calculate a depth value from a given normal and the other way around. Furthermore, given the normal and a depth value at a pixel and under the assumption of surface continuity depth values can be calculated for neighboring pixels by following the slope determined by the normal.

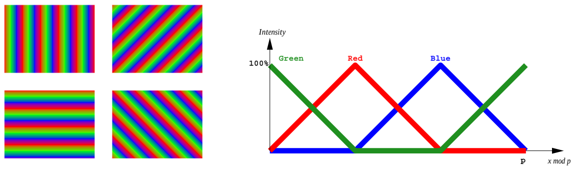

Figure 2: Projected Patterns: the patterns (left) and their basic structure.

We start with an arbitrary depth value at one pixel and calculate its corresponding normal. Then depth values in the neighborhood are computed following the slope determined by the normal; normals can then be determined at these points via the matte. This way we propagate an initial depth value through the whole field. The resulting depth and normal fields are then globally optimized following the slope along all directions (not only the direction of propagation).

Still, the depth of an initial point must be determined. To recover this value, we measure the (in)coherence of the resulting normal field i.e., the error made when a normal field is integrated along different paths. Incoherent normal fields are not justified by any depth field. In all test cases, the function relating initial depth values to the incoherence had a pronounced minimum corresponding to the correct depth value at the starting point. That minimum is quickly found using a golden section search.

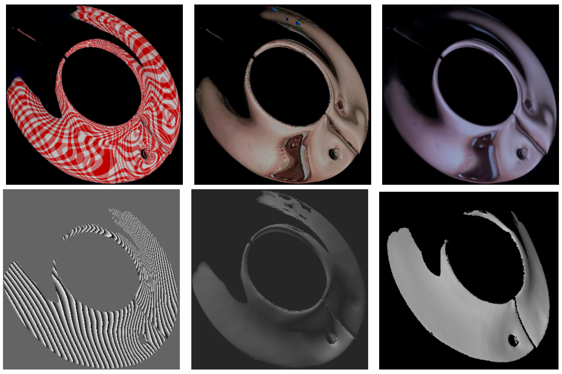

Figure 3: An Example: A matte captured over a plumbery object. Above: The images show the simulated reflection of checker pattern and an image of a face; the real reflection of the same image is on the right. Below: the resulting depth map (isovalue lines) and normal map calculates from the matte, and the final 3D range scan.

Results

We successfully applied our technique to acquire a number of mirroring objects. As can be seen in Figure 3, even tiny features of the objects can be captured well. To quantify the accuracy of the system, we scanned a mirroring sphere of 60 mm diameter resulting in an error of less than 0.02 mm.

References

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