Observing Optically Challenging Objects with Structured Light

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Abstract: Structured light is a common tool to observe the 3D shape of objects. However, most of these sensor systems assume that the objects scatter light diffusely and that there is only a moderate amount of ambient light. They are not able to deal with specular or transparent objects or with the ambient lighting from direct sunlight. We have built a scanning laser line striper that works even in bright sunlight and is able to observe optically challenging objects. In this paper we will show how the sensor can be used to measure the 3D shape of reflective objects and objects behind a semi-transparent plane.

OCIS codes: 150.0150 Machine vision; 150.6910 Three-dimensional sensing

1. Introduction

Structured light is a common approach to measure the three-dimensional shape of objects. We developed a system [1,2], consisting of a laser based projector and a camera (Fig. 1 far left). A horizontal line is projected on the scene (Fig. 1 middle left) and scanned by shifting it vertically. At each location the line is observed by a camera and the 3D shape of the cross section is calculated by triangulation. Putting these cross sections together gives a full 3D map of the scene.

Our system is able to work outside in bright sunlight by removing almost all of the ambient light contributions (Fig. 1 middle left and middle right). By having an image which shows only the contributions from the line and none from the ambient light, one is able to analyze the image to determine the optical properties of the observed objects. Diffuse, translucent, reflective, and transparent objects show a thin line, a blurred line, multiple lines, and caustics respectively. This is discussed in detail in [1], where we detect glass, metal, and translucent objects. In this paper we want to discuss how one can do 3D reconstruction of optically difficult objects once the optical properties are determined and one is able to choose the appropriate algorithm. The two objects we will consider are a metal plate and a semi-transparent plane that obscures a second object.

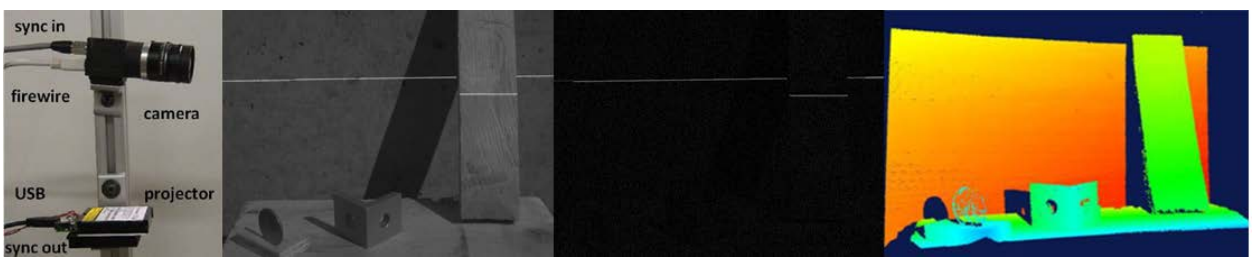

Fig. 1 Far left: The scanning laser line striper consisting of a camera and projector. Middle left: One line is projected onto a scene. Middle right: The same scene after all the background has been removed. Far right: The 3D map of the scene (color indicates depth).

2. Reflective metal plate

In general structured light sensors assume that the projected light is reflected only once. The light travels from the light source to the object where it is diffusely reflected and then it ends up at the camera. However, if there is a metal plate in the scene multiple reflections are possible.

Fig. 2 (far left) shows an example. A wood block and a metal plate are at an angle of approximately 90°. Light from the projector is first diffusely reflected off the wood block and then specularly reflected off the metal plate. One can see a blurred image of the wood block in the metal plate (Fig. 2 middle left).

One line projected onto the scene as seen by the sensor camera is shown in Fig. 2 (middle right). One can see thin lines that are all diffuse reflections of the various objects and directly observed by the camera. At the location of

the metal plate there is a second thicker line above the thin line. This thicker line is a reflection from the wood block.

The distinguishing feature between the desirable diffusely reflected lines and the spuriously reflected line is their thickness. When a hat filter is applied to the image the thick line disappears (Fig. 2 far right). The resulting image can be analyzed like before and will yield a correct 3D map of the scene.

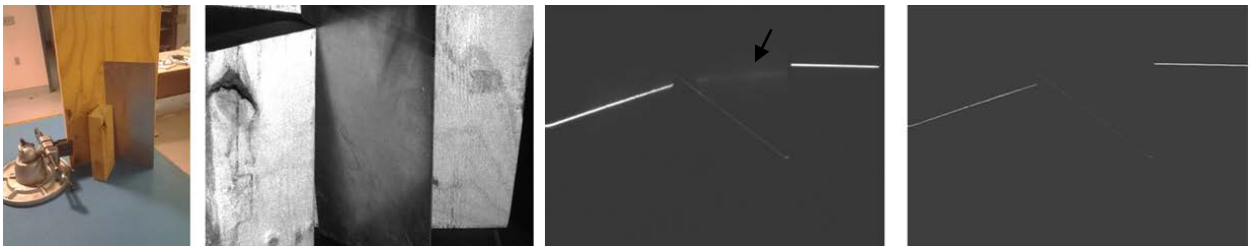

Fig. 2 Setup of metallic object. Far left: Photo of scene. Middle left: Scene observed by the scanning line striper camera. One can see the reflection of the wood block off the metallic plate. Middle right: The image from one line. The black arrow points to the reflection. Far right: Image from one line after filtering.

The uncorrected and corrected 3D reconstructions can be seen in Fig. 3. Without the hat filtering there are many spurious points close to the corner of the wood block and metal plate. With the hat filtering the spurious points are almost completely gone.

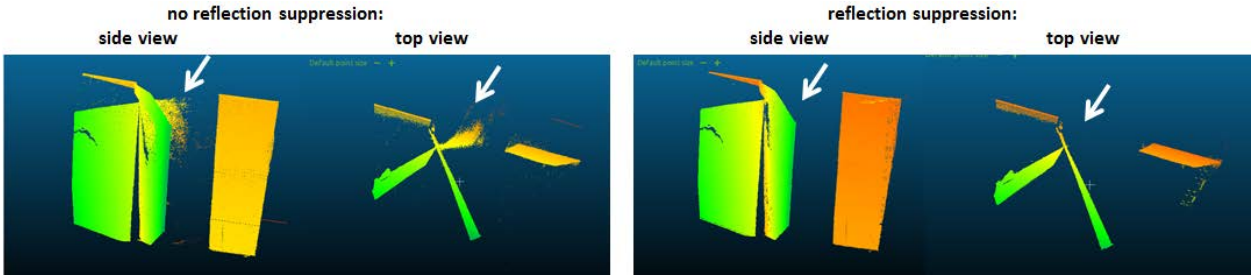

Fig. 3 3D reconstruction of the scene in Fig. 2 without (left) and with (right) reflection suppressed by applying the hat filter. Shown are front and top views of the scene. The white arrows indicate the spurious points on the left and the absence of spurious points on the right.

3. Semitransparent Objects

Semitransparent objects pose difficulties for structured light measurements. They reflect sufficient light that they can be detected, but they also transmit enough light so that other objects behind them are visible. Additionally, the scattering of light inside the semitransparent object diffuses the return from the second object. An example is shown in Fig. 4 where a wood block is placed inside a plastic bin.

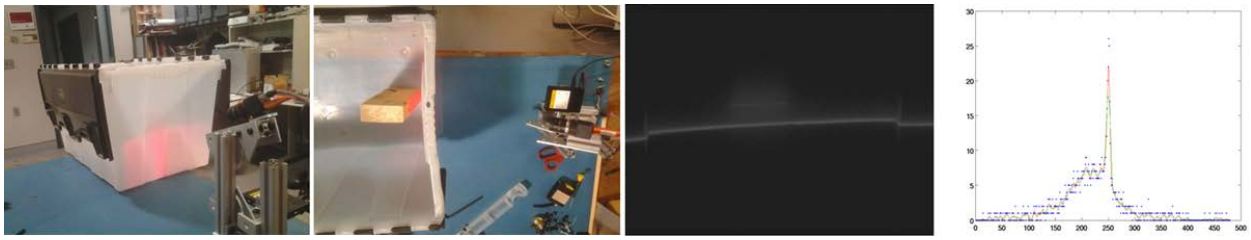

Fig. 4 The scanning laser line striper is observing a solid object (wood block) behind a semitransparent plane (wall of a plastic bin). Shown are frontal (far left) and top (middle left) views. A single line projected onto the scene by the projector as seen by the camera (middle right). One can see the return from plastic plane (long horizontal line) and the wood block (short horizontal line), as well as the diffusion. The intensity for one column in the image is shown on the far right. The sharp peak is from the plastic wall and the broad peak is from the wood block.

In the frontal view (Fig. 4 far left) it is very difficult to discern the object behind the plastic plane. It is easier to see when one looks at only one projected line (Fig. 4 middle right). The wood block shows up as a short, diffused horizontal line behind a long, sharp horizontal line from the plastic wall. In the intensity plot of one column (Fig. 4 far right) the plastic wall is a sharp peak and the wood block is a broad peak. The peak from the wood block is broadened because the incoming and outgoing rays are scattered by the plastic wall.

We want to detect both, the wood block and the plastic wall. The plastic wall creates a sharp tall peak and is detected by our usual method of finding the maximum intensity in each column of the image. Next we eliminate the sharp peak by ignoring all the pixels in a small window around the sharp peak. Then we use the maximum intensity method again to find the second peak.

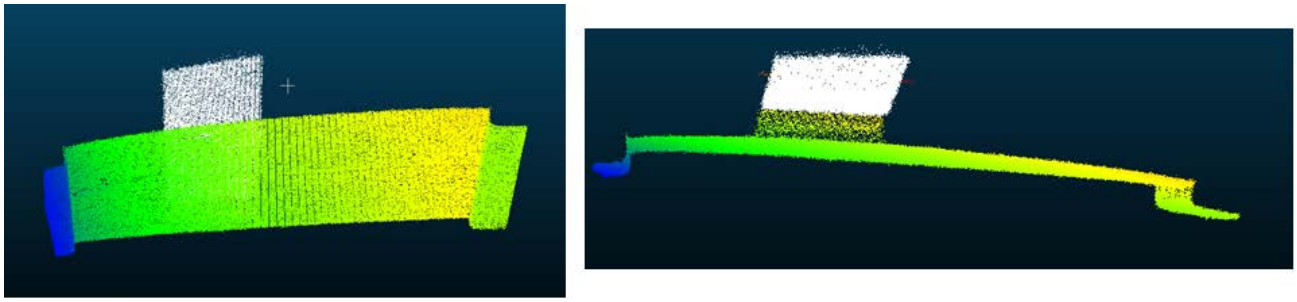

Fig. 5 The 3D map of the wood block inside the plastic bin. The plastic wall is shown in color and the wood block is shown in white. Left is a frontal view and right is a top view.

The resulting 3D map of the wood block inside the plastic bin is sown in Fig. 5. Both objects are clearly seen and they are well reconstructed. With this we have shown that it is possible to reconstruct an object that is behind a semitransparent wall.

4. Conclusion and Outlook

It is possible to extend standard structured light methods to create 3D models of optically difficult materials. In this paper we demonstrated this with two examples; one which contained a metallic object and the other contained a semi-transparent object. The algorithms that one needs to use are specific to the materials and the setup of the objects. In previous work we showed how one can detect different optical properties with the same camera and projector sensor. In the near future we want to combine the detection of optical properties, choice of appropriate algorithm, and the 3D reconstruction to have a complete system for the 3D mapping of optically difficult objects.

5. Acknowledgement

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4. References

[1] C. Mertz, S. Koppal, S. Sia, and S. Narasimhan, "A low-power structured light sensor for outdoor scene reconstruction and dominant material identification," 9th IEEE International Workshop on Projector–Camera Systems, June, 2012.

[2] C. Mertz, "Performance of a scanning laser line striper in outdoor lighting," SPIE Defense, Security, and Sensing, conference 8741, May, 2013