3D Photography using Shadows

Iyengar, Vikram
Clemson University
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Abstract: 3D photography means recreating a 3 dimensional model of the real world objects. 3D worlds find application in varying fields like Animation, Medical surgeries and visualization, Virtual reality training simulators and preserving ancient artifacts. Modeling the world is the basic necessity but is just the first step. In this paper, I have presented a simple technique to generate a 3D model of objects using shadows generated by using a projector and a turn table to rotate the object precisely while mapping its contour.

Keywords: 3D Reconstruction, 3D Photography, Shadow Depth Map

Introduction: The aim of this project is to reconstruct in 3D a model of given objects. The motivation behind the project is to build an automated procedure to generate 3D objects. Previous work on 3D reconstruction have been done by many researchers. In "3D Photography on your desk "by Jean-Yves Bouguet and Pietro Perona, they have used a lamp and a pencil is moved between the object and the lamp to cast a shadow and calculate the depth map of the object. When I took a picture of a checkered board pattern, I found out that the webcam used by me was linear near the center but highly warped towards the periphery. In my device of using a turn table most of the measurements are made near the central region of the image which helps reducing errors caused due to non linearity of the CCD

Experimental Setup and geometry:

Fig a) Front View

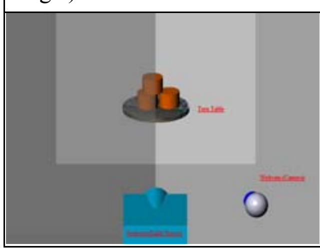
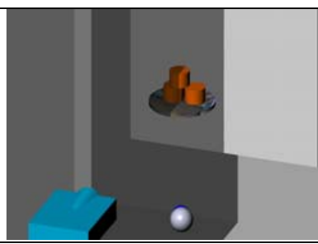


Fig b) Tilted view



To ensure accuracy of the model, we need to have a focused source of light, a sharp shadow over the objects, and the algorithm should work in the presence of other moderate ambient lighting conditions.

Source of Structured Light: To get a highly focused beam of light, with minimum soft shadows and to have the pattern of light easily changeable, I chose a Projector emitting a black and white pattern generated by Matlab.
For this setup, I have used a simple pattern *(Fig c)*. The projector emits a shadow as shown in the *(Fig d).*

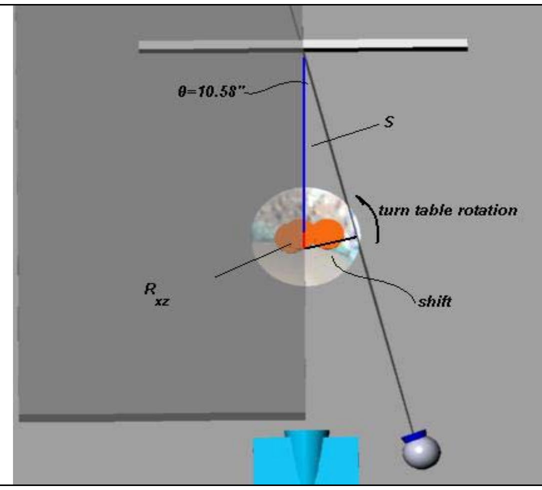


Fig e) Geometry of the setup

Fig c) Structured Light Pattern

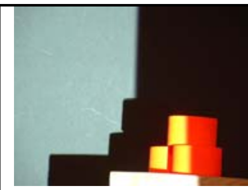


Fig d)) shadow over the objects

Camera, and Geometry: The camera is placed with its vertical plane at an angle with the central axis of the projector and the edge of the shadow as seen in *(Fig a)*
From the geometry of the setup, we see that the shadow of the pattern in displaced off the central axis of the camera by a measure proportional to the depth from the reference board which is assumed to be zero depth plane as the camera is centered according to the edge of the shadow generated.

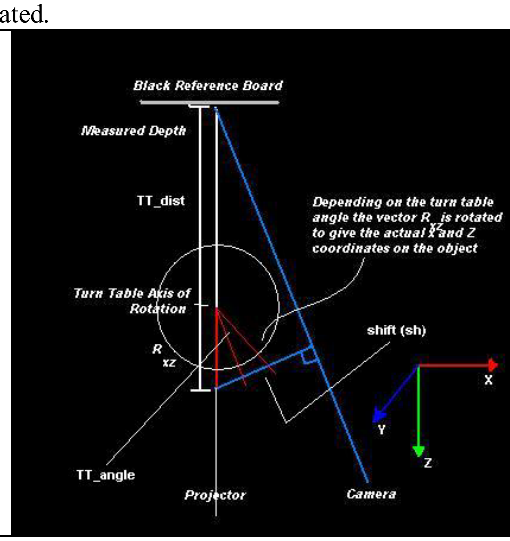


Fig e) Geometry for depth measurement and reconstruction

Here,
1) TT_dist = perpendicular distance between Black Board and the Turn Table axis of rotation
2) TT_angle= Angle of rotation of the turn table from initial position
3) Measured Depth = is the perpendicular distance from the black board to the point on the object

Measured Depth = shift* x cosine*(Theta)
R_{xz} = ***Measured Depth – TT_dist'***
X_{object} = R_{xz} x ***cos(TT_angle)***
Z_{object} = R_{xz} x ***sin(TT_angle)***

TT_dist is the real world measurement while *Measured depth* is with respect to the image obtained. So we have to calculate the value of *TT_dist'* as seen by the camera. It is done by measuring the shift of the turn table axis from the edge of the shadow as seen by the camera and using the above formula for depth calculation.

Experimental Results:
Step I) I tested my algorithm for geometric accuracy by using an artificial 3D world generated in Rhinoceros 3D modeling API

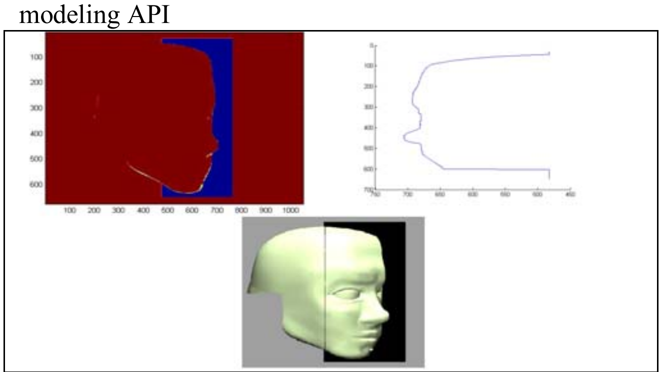


Fig f) Algorithm testing using a 3D head model resulted in a accurate contour but the shadows were sharp unlike in a natural scene

Step II) I tested the algorithm using the same setup of projectors on a plastic toy. The plastic surface emits a specular highlight whose brightness changes as per the angle between the light and the camera as well as the surface contour. Places in shadow are lit because of this highlight
It makes the reconstruction very noisy.
I could lessen this effect by reducing the light emitted by the projector by increasing the area of black as compared to the brighter region in the pattern.

Step III) Initially I took pictures using the VFM (Video for Matlab) toolbox. As the lighting in the laboratory cannot be completely switched off, I had to use contrast stretching on the images to get a sharper shadow edge. Even then, the resulting output wasn't noise free.

Step IV) In the last set of experiment, I used painted wooden pieces and used a Digital Camera to take pictures. The problem of specular highlight was avoided because of the matt finish of the paint and the wood surface.
The resulting the original objects and the 3D plots are shown in the figures below:

Fig g) Objects assembly

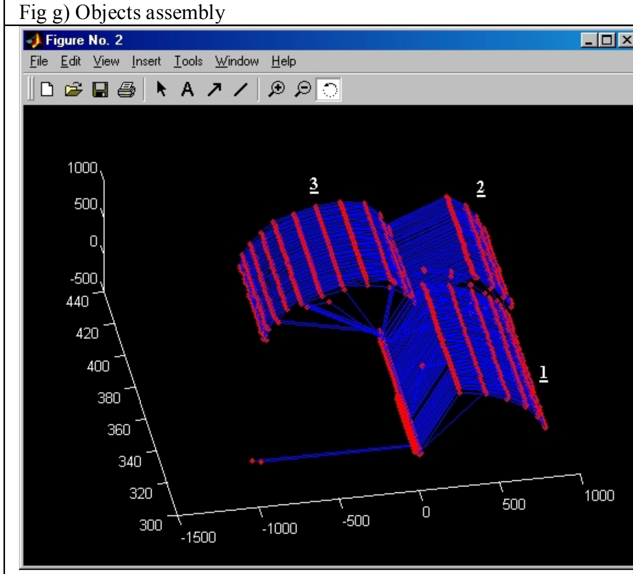


Fig h) 3D Matlab Reconstruction (for 180 degrees Rotation)

3D OBJ File format: Now the 3D points have to stored in a standard format so as to view it and modify it in Open GL based environments.

OBJ file format is the simplest of them all. It stores the 3D vertex coordinates with a tag 'v' and the faces of the object are stored with a tag 'f'. Each face is stored in terms of three or more corner points defining the plane of the face.
I generate the OBJ files using Matlab. While trying to read the files using a simple OBJ file parser that I had written while making an OpenGl based API for 3D object viewing. It does not filter out certain characters like carriage return. So I couldn't view the OBJ.

Example:

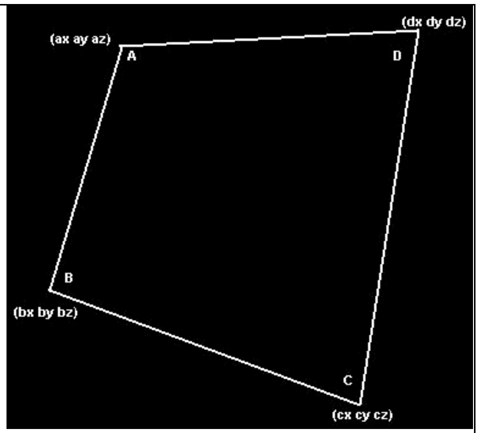
<table>
<tr>
<td>1.v ax ay az
2.v cx cy cz
3.v bx by bz
4.v dx dy dz
5.
6. f 1 3 2 4</td>
<td>
</td>
</tr>
<tr>
<td>OBJ content to represent polygon ABCD</td>
<td>A face of a 3D object ABCD(CCW)</td>
</tr>
</table>

Fig h) OBJj File Format

Conclusion: The setup and algorithm work fine for objects with lesser specular highlight.

The accuracy depends totally on the contour of the objects as some objects contour cast a shadow on regions belonging to it self which will give rise to errors in the output.

This can be reduced by adjusting the angle between the camera axis and the light source.

Accuracy can be increased by increasing the accuracy in the rotation of the turn table by using a stepper motor or a motor/encoder set up

Also the camera can be calibrated for its non linearity in case of webcams, which have a highly non linear profile which will further improve errors.

References: "3D Photography on your desk" by Jean-Yves Bouguet and Pietro Perona, ICCV 1998