Exploration of Photometric Stereo Technology Applies to 3D Model Reconstruction

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Abstract

An efficient method has been presented to achieve an accurate dense 3D reconstruction of objects using photometric stereo technology. The task of recovering three-dimensional geometry from two dimensional views of a scene is called 3D reconstruction. Photometric Stereo is a powerful image based 3D reconstruction technique that has recently been used to obtain very high quality reconstructions. The Photometric Stereo (PS) technique uses several images of the same surface taken from the same viewpoint but under illuminations with different directions. The illumination conditions refer to the light source direction and intensity, and reflectance properties mean what type of surface is under consideration i.e. Lambertian or non-Lambertian. . The algorithm has been tested on synthetic as well as real datasets and very encouraging results have been obtained.

Keywords: *3D reconstruction, photometric stereo, shape-from-shading, synthetic and real datasets.*

1. Introduction

Photometric stereo is an important research field in computer vision, which is used to recover the shape of a static object under varying illuminations. Its first application was proposed by Woodham [10] in 1980's. The photometric stereo (PS) technique [3] uses several images of the same surface taken from the same viewpoint but under illuminations with different directions. Thus the changes of the intensities in the images depend only on the local surface orientation, which can be recovered by combining the information from all images. When imaged under a particular illumination, it produces a camera intensity value which depends on the properties of the illumination configuration, the surface reflectance and the surface orientation, according to some photometric equation (hence the term "photometric stereo").

The photometric algorithm has three advantages: (1) no surface smoothness is assumed; (2) only multiple light sources are needed when implemented; (3) diffuse parameters can also be obtained. Due to these benefits, photometric stereo is widely used to reconstruct surface shape. In traditional photometric stereo algorithms, ideal imaging conditions are generally assumed, i.e., Lambertian surface, distant light sources and orthographic camera projection.

2. Photometric Stereo Technology

Photometric stereo is a computer vision technique which is based upon the estimation of local surface orientation using images of the same surface captured from a fixed viewpoint by changing the illumination settings (e.g. by changing the position of light source). It is therefore an active method as light is projected onto the scene or object. There are some factors which affects the appearance of a surface in an image. These include the illumination conditions, shape and reflectance properties of surface. The illumination conditions refer to the light source direction and intensity, and reflectance properties mean what type of surface is under consideration i.e. Lambertian or non-Lambertian. In case of a Lambertian object, the surface luminance is isotropic which means that light falling on it is scattered in such a way that its appearance or intensity to an observer is the same regardless of the viewing angle.

Once photometric images are taken, the local orientations are obtained by computing the surface normal at each pixel and the required depth map of surface is recovered.

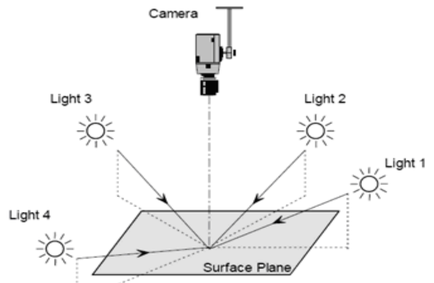

Figure 1. Illustration of Photometric Stereo Geometry

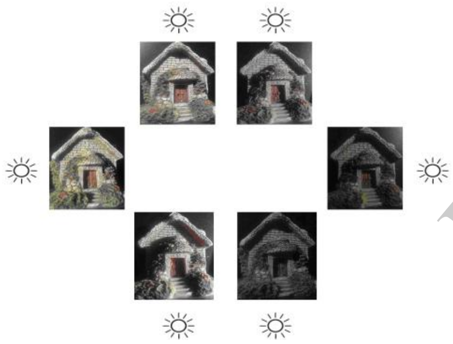

Figure 2. Photometric images taken from fixed viewpoint under different illumination directions

3. Lambertian Reflectance Theory

Lambertian reflectance is the property that defines an ideal diffusely reflecting surface. The apparent brightness of such a surface to an observer is the same regardless of the observer's angle of view. Brightness of the surface as seen from camera is linearly correlated to the amount of light falling on the surface. More technically, the surface's luminance is isotropic, and the luminous intensity obeys Lambert's cosine law.

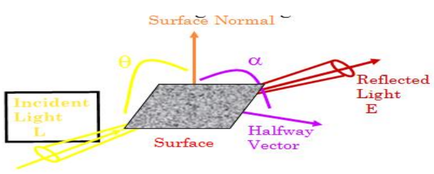

Figure 3. Lambertian Reflectance Theory

Lambert's Cosine law states that the radiant intensity or luminous intensity observed from an ideal diffusely reflecting surface or ideal diffuse radiator is directly proportional to the cosine of the angle θ between the observer's line of sight and the surface normal. The law is also known as the cosine emission law or Lambert's emission law. A surface which obeys Lambert's law is said to be Lambertian, and exhibits Lambertian reflectance. Such a surface has the same radiance when viewed from any angle.

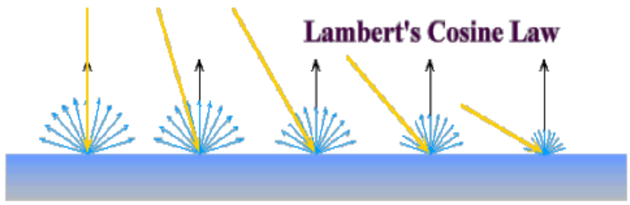

Figure 4. Lambert's Cosine Law

The reflection is calculated by taking the dot product of the surface's normalized normal vector N and a normalized light-direction vector L, pointing from the surface to the light source. This number is then multiplied by the color of the surface and the intensity of the light hitting the surface:

$$I_D = L.NCI_L$$

where I_D is the intensity of the diffusely reflected light (surface brightness), C is the color and I_L is the intensity of the incoming light. Because

$$L.N = |N||L| \cos \propto$$

Where, $\propto$ is the angle between the direction of the two vectors, the intensity will be the highest if the normal vector points in the same direction as the light vector (cos(0) = 1), the surface will be perpendicular to the direction of the light), and the lowest if the normal vector is perpendicular to the light vector (cos(π / 2) = 0), the surface runs parallel with the direction of the light).

Lambertian reflection is typically accompanied by specular reflection, where the surface luminance is highest when the observer is situated at the perfect reflection direction, and falls off sharply. The advantage of Lambertian reflectance is that if several cameras can observe the same region, the observed intensities will all be the same. This considerably simplifies the reconstruction process as the image data from different cameras can easily be compared, independent of surface angle, viewing direction, or the position of the light source.

4. Design and Implementation

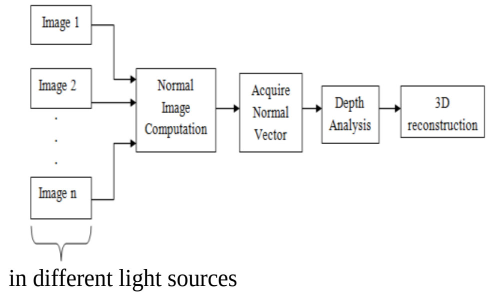

Figure 5. Block diagram of the proposed system

In above figure, the images are captured in different light source intensities. The acquired image is normalized in gray scale. The source direction is acquired and set in a matrix form. Inverse of the direction matrix is used for the calculation of the normal image magnitude. Gradient of the normal component is used for the calculation of the normal vectors for estimation of the scattering direction. Lambertian theory is used for the calculation of the same. The depth analysis is performed based on the normal component and its direction. The depth component gives the details for 3D reconstruction of the image.

5. Results and Discussions

We obtain the results of 3D reconstruction using existing Photometric Stereo Technology algorithm. Fig 6 shows the images in different light source. It shows that the proposed method produces the mask image (Fig 7) and albedo images for R, G, B components (Fig 8) almost correctly. Then the surface normal's are obtained for R, G, B components (Fig 9) and from the normal images the depth is calculated (Fig 10) and 3D reconstructed image is obtained. The quality of reconstructed 3D shape is better.

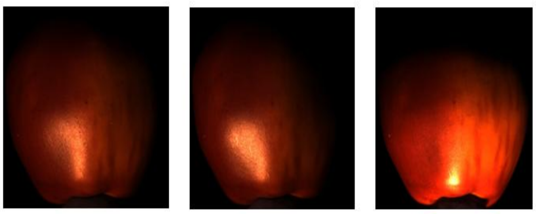

Figure 6. Images in different light sources

Figure 7. Input image and its mask image

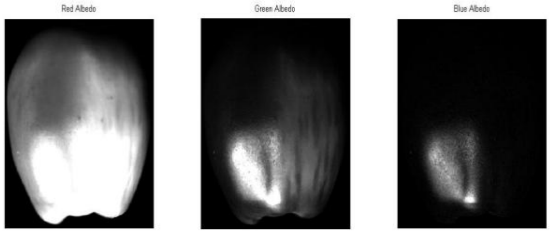

Figure 8. Albedo images for R, G, B components

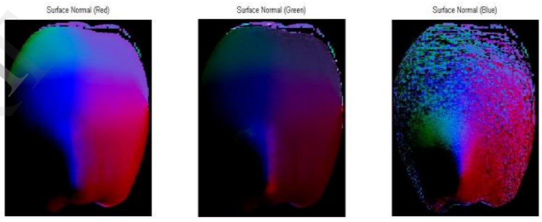

Figure 9. Surface normal's for R, G, B components

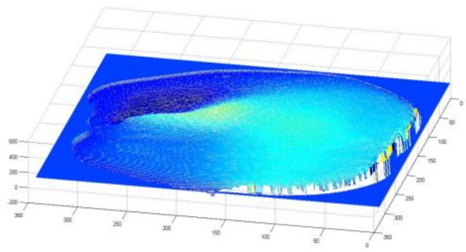

Figure 10. 3D reconstructed image

6. Conclusion

We have studied the Photometric Stereo technology and the algorithm along with the Lambertian theory that is used for 3D reconstruction. In this, images are captured in different light source intensities, calculates the normal value and based on the normal value the depth is calculated which gives us the desired result i.e. 3D reconstruction.

The 3D reconstruction method has certain theoretical significance and application value. The algorithm has been tested on sample apple datasets and quite satisfactory results have been achieved so far.

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