3D Surface Reconstruction Using Photometric Stereo Approach

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Some slides were adapted from the course CS718 at UWM by Professor, Dr. Zeyun Yu.

Outlines

- Problem Statement
- Motivation
- Taxonomy of the 3D surface Reconstruction Approaches
- Photometric Stereo Key Concepts
- Photometric Stereo and It's Algorithm
- Our Proposed Contributions
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Problem Statement

- The human vision structure obtains information about the real world through planar images that are formed on the retina.

- Depth and 3D shape model of an object are perceived by the analysis of the stereo images captured from the left and right eyes.

- The major aim of computer vision is to provide human's ability in analyzing visual information and to enable computers to see like we do.

This presentation focuses on one of the many challenges in computer vision, the process of reconstructing a three-dimensional (3D) surface and the recovery of the depth information given a set of images under the different light directions.

Motivation

The 3D reconstruction of a surface from images alone has many useful applications:

1) In the entertainment industry, it has been widely applied in the process of movie making.
2) Without the aid of 3D reconstruction, computer graphics artists would need to spend many hours of CAD-modelling while often faced with the problem of a lack of photo-realism when the objects are rendered.
3) 3D reconstruction from images is also widely applied in the medical industry. It has been used to create models of a wide range of organs, as well as brains and cells.
4) Other application areas include robot navigation, body motion modelling, teleconferencing, remote surgery, object recognition, and VRML.

(R. Hartley, 2004)

Taxonomy of the 3D Reconstruction Approaches

3D Reconstruction Methods

Active Methods

The light sources are specially controlled, as part of the strategy to arrive at the 3D information. Active lighting incorporates some form of temporal or spatial modulation of the illumination.
Photometric Stereo is an Active approach to 3D surface reconstruction.

Passive Methods

The light is not controlled or only with respect to image quality. Typically passive techniques work with whichever reasonable, ambient light available.

Figure 1: 3D reconstruction methods. (Hansen, 2012)

Photometric Stereo Key Concepts (Contd.)

- Photometric Stereo is an approach to reconstruct a **3D surface** from a series of images of a diffuse object under **different point light sources**.
- The surface reflectance obeys **Lambert's** law: **Light is reflected by a surface equally in every direction.**
- Photometric stereo recovers **depth information** from multiple images under **different lighting conditions**.
- The Mathematics of Photometric Stereo Include:
  1) Vector Analysis.
  2) Advanced Calculus.
  3) Differential Equations.

(Woodham, 1980)
(Ikeuchi, 1981)

Photometric Stereo Key Concepts

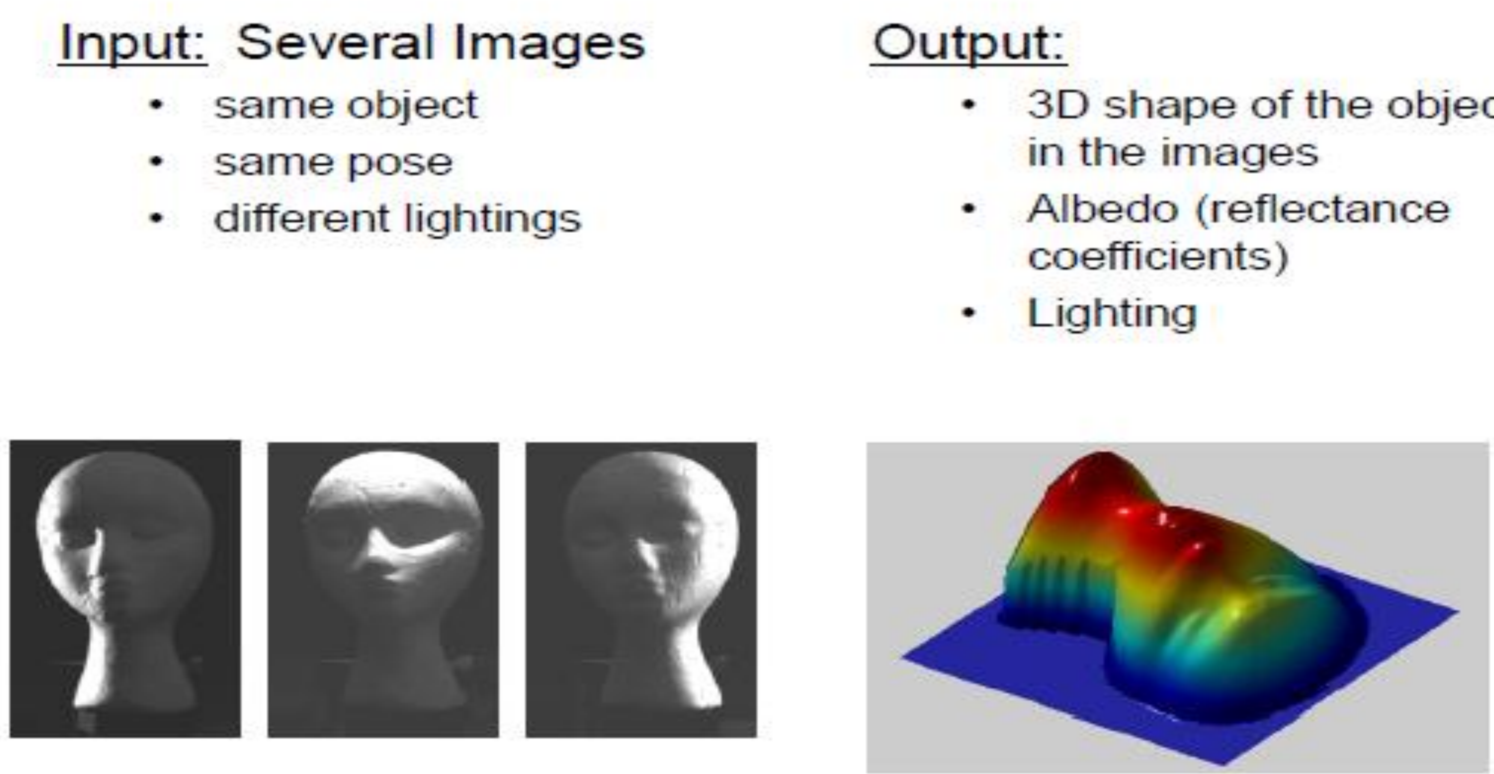


Figure 2: Applying Photometric Stereo.

Photometric Stereo and It’s Algorithm (Contd.)

Input: **2D Image, under different light sources.**

Determine Light Direction — 1

↓

Determine Surface Normal — 2

↓

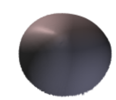
Determine Albedo — 3

↓

Determine Depth — 4

↓

Output: **3D Image.**



(Woodham, 1980)
(Ikeuchi, 1981)
(Hayakawa, 1994)
(Longuet, 1981)

Figure 3: Block Diagram for Photometric Stereo Algorithm.

Photometric Stereo and It's Algorithm (Contd.)

Step 1 **Determine Light Direction**

By changing the location of light and using a chrome sample as our case study in the same location as all the other objects, we can get the location of the light source.

Outcome	Light Vector.
Algorithm	1- Compute Centroid and Radius of our case study. 2- Compute center of reflected light on the case study. 3- The normal, **N**, at that point in the direction of the line extending to the Centroid. Viewing angle **X** has a constant direction for all pixels. 4- Light direction → **L** = **2*(N*X)*N-X**
Notes	Some preprocessing steps may/must be needed before this step.

Table 1: Step(1) Determine Light Direction; Algorithm and Outcome.

(Woodham, 1980)
(Ikeuchi, 1981)
(Hayakawa, 1994)
(Longuet, 1981)

Photometric Stereo and It's Algorithm (Contd.)

Step 2 Determine Surface Normal

Once we know the light directions, we can recover the normals at each pixel.

Outcome	Surface Normal Vector.
Algorithm	1- For Lambertian surfaces, intensity at any point on the surface can be given as $\mathbf{I}=\mathbf{K_d L n^T}$, where $\mathbf{I}$ is pixel intensity, $\mathbf{K_d}$ is albedo, $\mathbf{L}$ is the reflected light direction (a unit vector), and $\mathbf{n}$ is a unit surface normal. 2- $\mathbf{I}= \mathbf{L(K_d n^T)}$, put unknowns together. 3- In order to determine n, we need at least three light sources which are not in the same plane. We can solve for the product $\mathbf{g}= \mathbf{K_d n}$ by solving a linear least squares problem. 4- Once we have the vector $\mathbf{g}= \mathbf{K_d n}$, the length of the vector is $\mathbf{K_d}$ and the normalized direction gives $\mathbf{n}$.
Notes	An objective function definition is needed in this step.

Table 2: Step(2) Determine Surface Normal; Algorithm and Outcome.

Photometric Stereo and It's Algorithm (Contd.)

Step 3 **Determine Albedo**

Albedo step solves the parameter $\mathbf{K}$ for each pixel. Since we have already computed Normals for each pixel, using the following equations we can get $\mathbf{K}$. Where $\mathbf{J} = \mathbf{Ln}$ in previous equations.

Outcome	Albedo per light channel.
Algorithm	**1)** $\mathbf{I}_R = k_{dR}\mathbf{J}$ **2)** $\mathbf{J}\cdot\mathbf{I}_R = k_{dR}\mathbf{J}\cdot\mathbf{J}$ **3)** $k_{dR} = \dfrac{\mathbf{J}\cdot\mathbf{I}_R}{\mathbf{J}\cdot\mathbf{J}}$
Notes	Objective function and differentiation with respect to $\mathbf{K_d}$ is needed in this step.

Table 3: Step(3) Determine Albedo; Algorithm and Outcome.

Photometric Stereo and It’s Algorithm

Step 4 **Determine Depth**

For each pixel, we have the following equations.

Outcome	Depth for each pixel
Algorithm	$$n_z z_{xy} - n_z z_{x+1,y} = n_x$$ $$n_z z_{xy} - n_z z_{x,y+1} = n_y$$
Notes	Group all the equations for every pixels, we can solve the depth z for every pixel.

Table 4: Step(4) Determine Pixel Depth; Algorithm and Outcome.

(Woodham, 1980)
(Ikeuchi, 1981)
(Hayakawa, 1994)
(Longuet, 1981)

Our Proposed Contributions

1) General implementation of Photometric Stereo algorithm with Matlab.

   It's already done.

Matlab Implementation including the source code exists at:

http://ahmadpahlavantafti.com/researchprojects.html

2) Exploring a way to reduce 3D reconstruction errors.

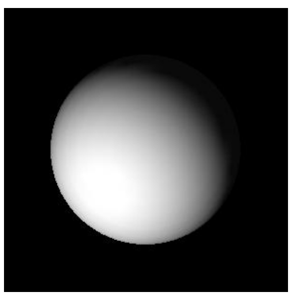
   We obtained some experimental results (Distance of the light sources and number of images).

3) Working on different depth and real sample.

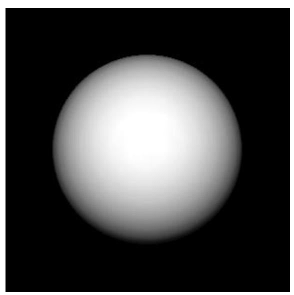
   We have faced with lack of real data.

Dataset

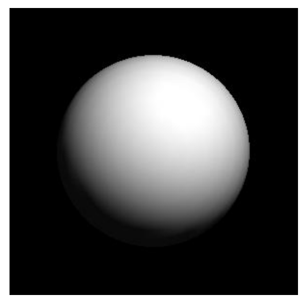
We used OpenGL for creating synthetic image (Sphere), under different light directions.



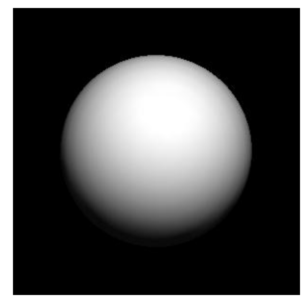
-0.4, -0.4, 0.7



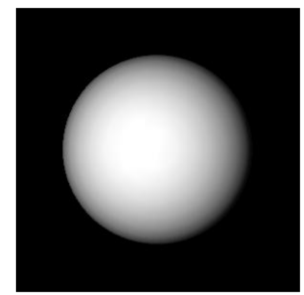
-0.03, 0.17, 0.98



0.31, 0.51, 081



0.11, 0.43, 0.89



-0.21, 0.04, 0.99

Implementation

Matlab is used to develop the algorithm and approach.

Main.m	It contains light directions and parameter initialization.
PS.m	It sets some parameters and calls Normals.m, Albedos.m and Depth.m respectively.
Loadimages.m	Loading synthetic images from our Dataset.
Normals.m	Creating normal map.
Albedos.m	Creating albedo map.
Depth.m	Estimating depth and surface reconstruction.

Matlab Implementation including the source code exists at:

http://ahmadpahlavantafti.com/researchprojects.html

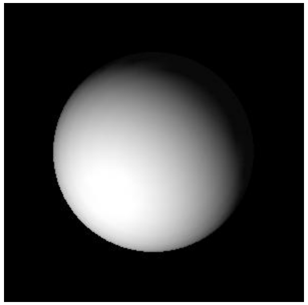
Experimental Results (Contd.)

1. Four different light sources (Close to the object)
2. Six different light sources (Close to the object)
3. Four different light sources (Far from the object)
4. Six different light sources (Far from the object)
5. Normal map comparison
6. 3D model comparison

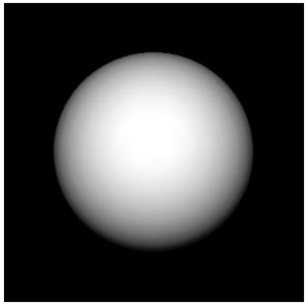
Experimental Results (Contd.)

1. Four different light sources (Close to the object)

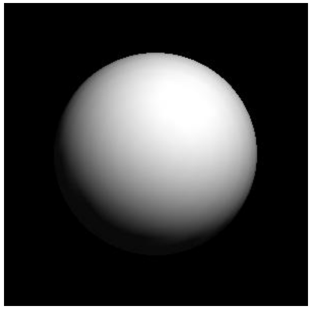
Dataset



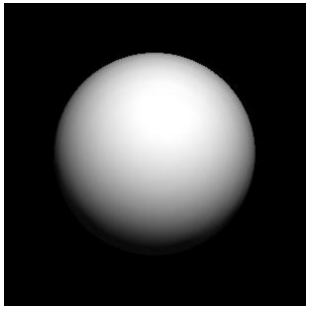
-0.4, -0.4, 0.7



-0.03, 0.17, 0.98



0.31, 0.51, 081

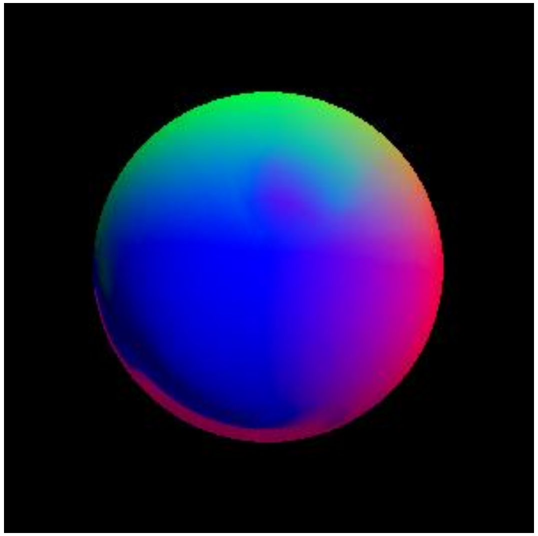


0.11, 0.43, 0.89

Experimental Results (Contd.)

1. Four different light sources (Close to the object)

Normal and Albedo



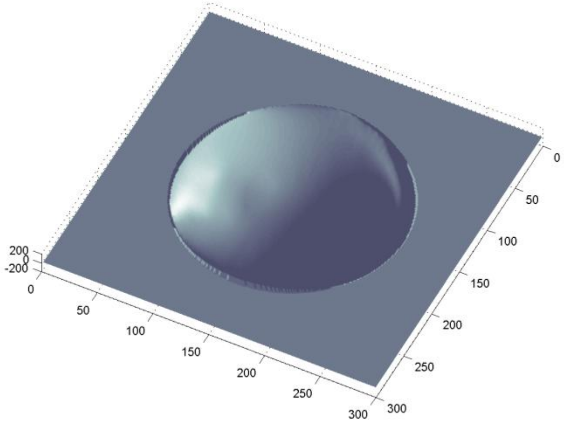
Normal map

Albedo map

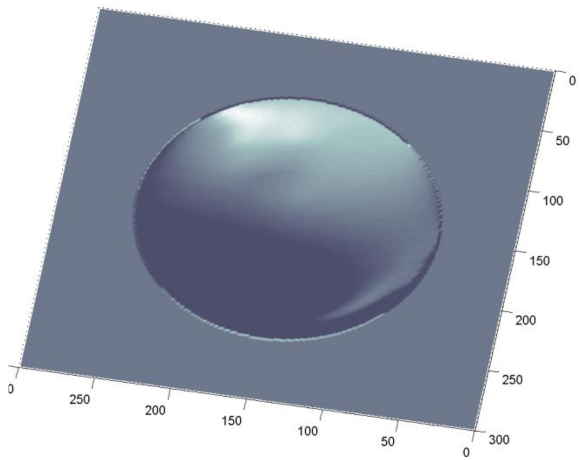
Experimental Results (Contd.)

1. Four different light sources (Close to the object)

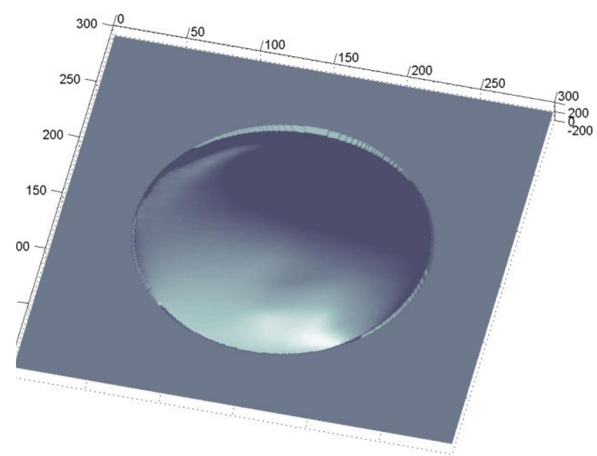
3D Model



View 1



View 2

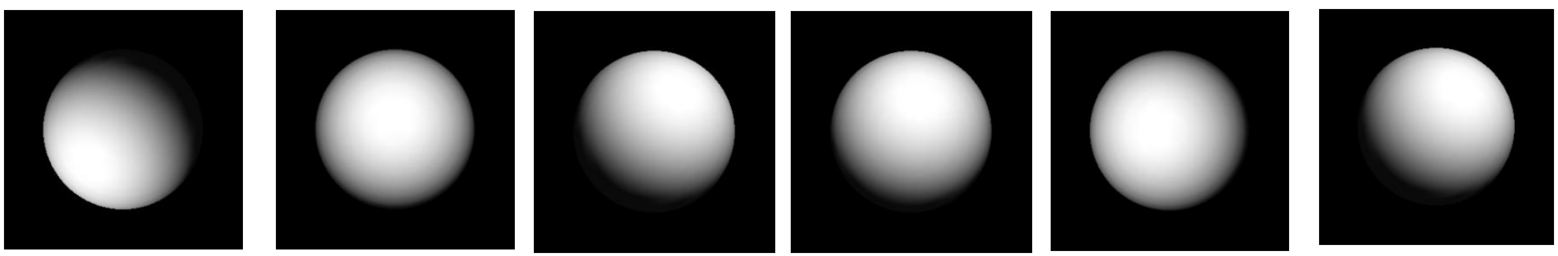


View 3

Experimental Results (Contd.)

2. Six different light sources (Close to the object)

Dataset

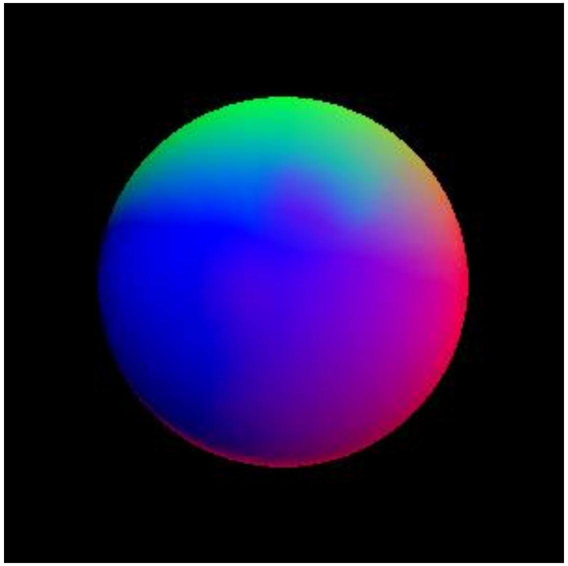


-0.4, -0.4, 0.7 | -0.03, 0.17, 0.98 | 0.31, 0.51, 081 | 0.11, 0.43, 0.89 | -0.21, 0.04, 0.99 | 0.17, 0.45, 0.79

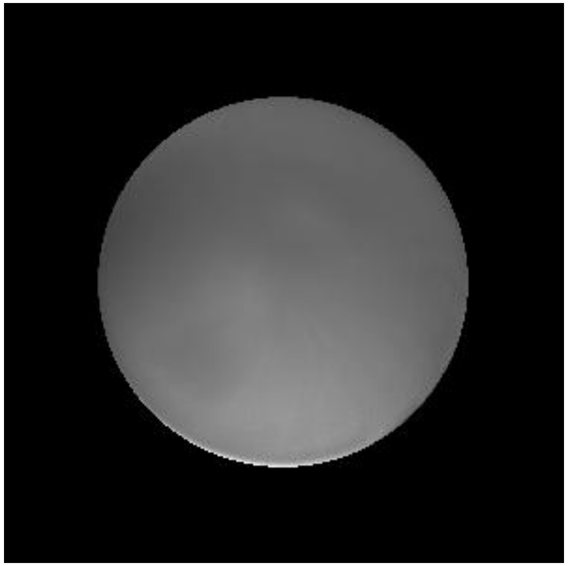
Experimental Results (Contd.)

2. Six different light sources (Close to the object)

Normal and Albedo



Normal map

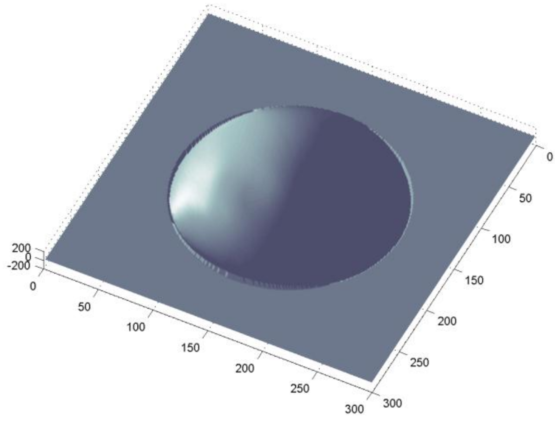


Albedo map

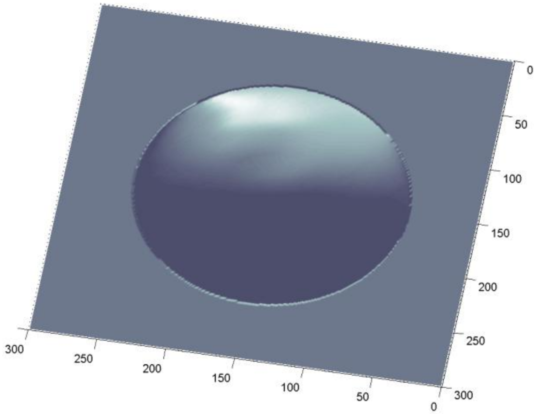
Experimental Results (Contd.)

2. Six different light sources (Close to the object)

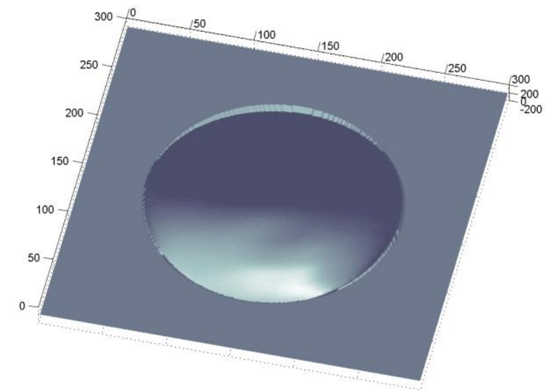
3D Model



View 1



View 2

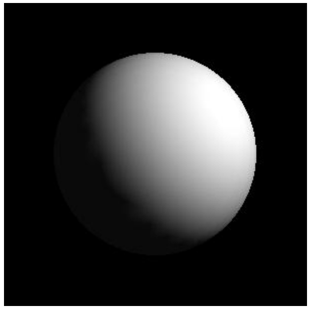


View 3

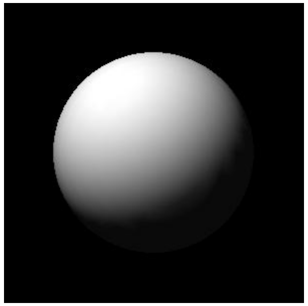
Experimental Results (Contd.)

3. Four different light sources (Far from the object)

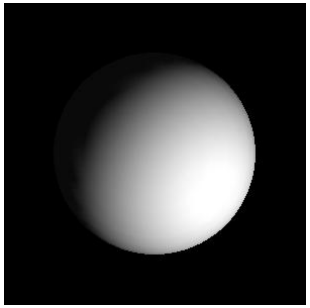
Dataset



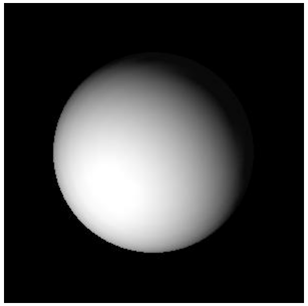
20.00, 10.00, 12.00



-15.00, 32.00, 27



7.00, -1.00, 9.00

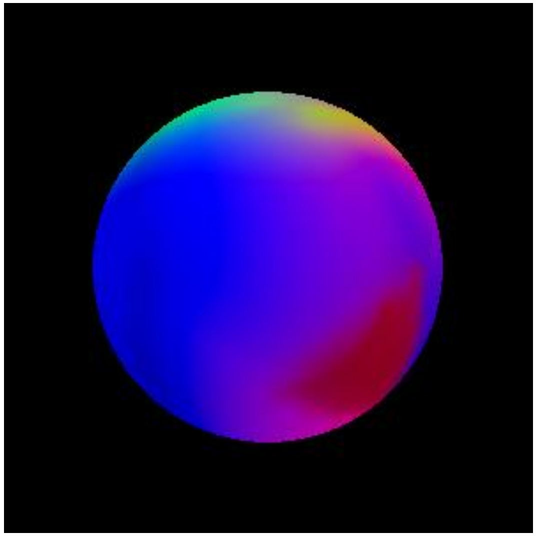


-9.00, -8.00, 17.00

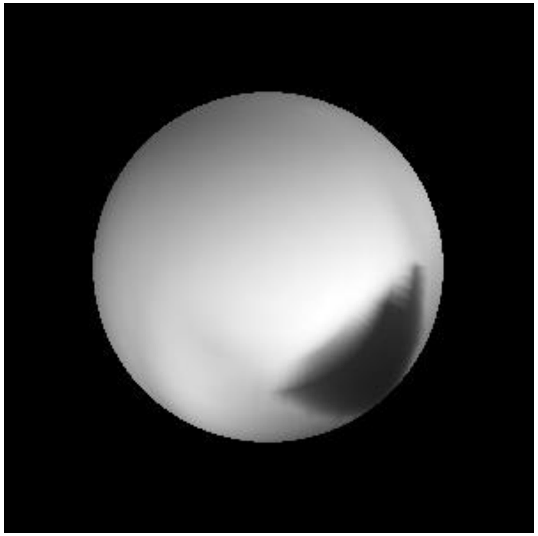
Experimental Results (Contd.)

3. Four different light sources (Far from the object)

Normal and Albedo



Normal map

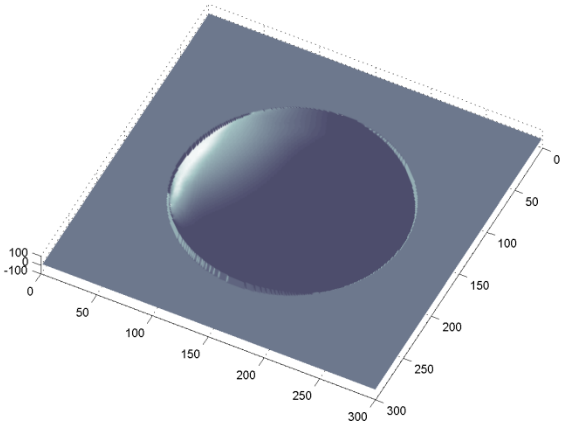


Albedo map

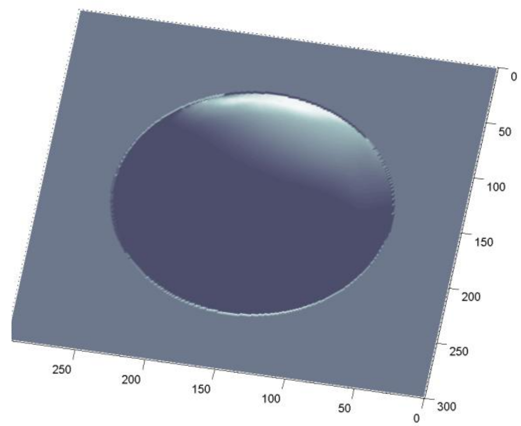
Experimental Results (Contd.)

3. Four different light sources (Far from the object)

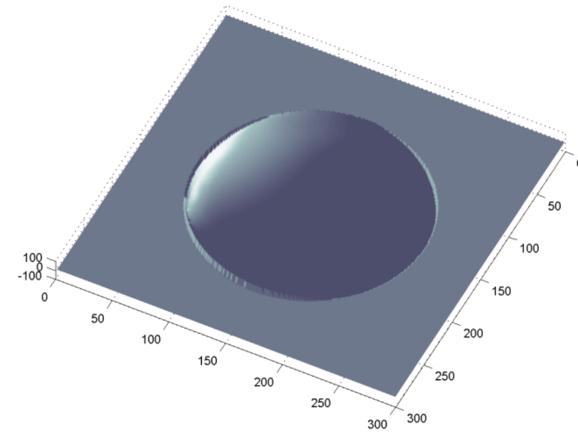
3D Model



View 1



View 2

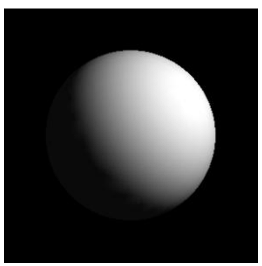


View 3

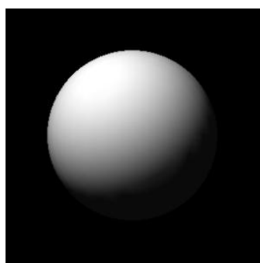
Experimental Results (Contd.)

4. Six different light sources (Far from the object)

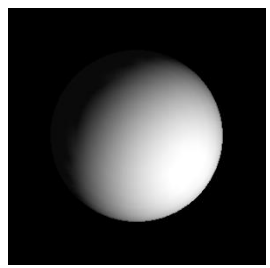
Dataset



20.00, 10.00, 12.00

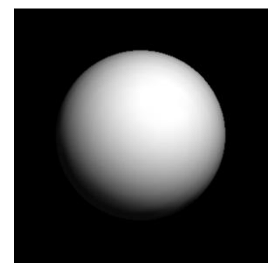


-15.00, 32.00, 27

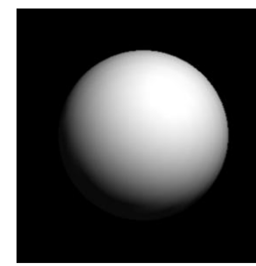


7.00, -1.00, 9.00

-9.00, -8.00, 17.00



8.00, 12.00, 26.00

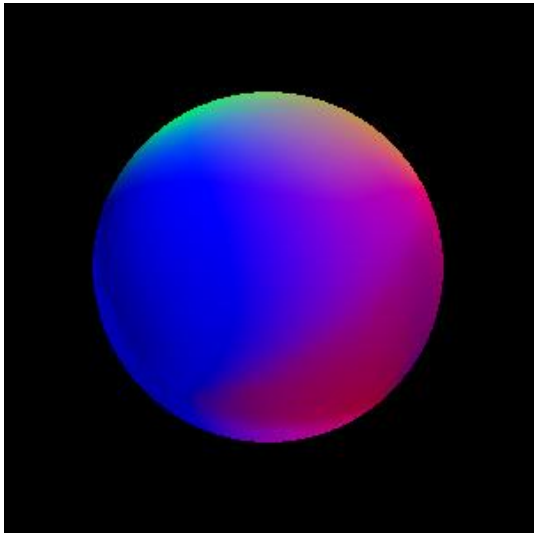


2.00, 3.00, 5.00

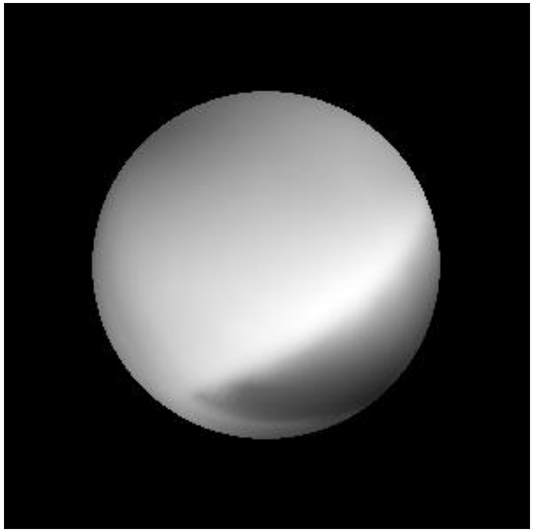
Experimental Results (Contd.)

4. Six different light sources (Far from the object)

Normal and Albedo



Normal map

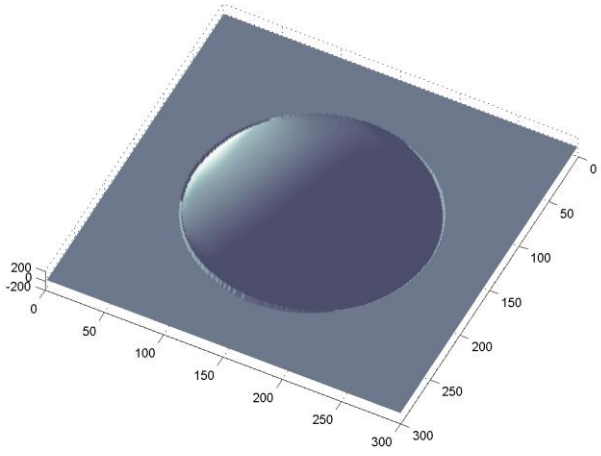


Albedo map

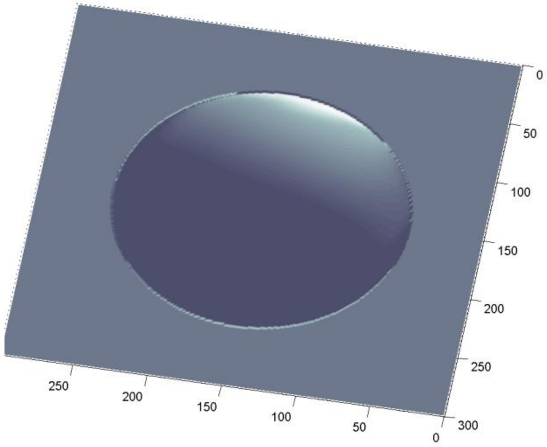
Experimental Results (Contd.)

4. Six different light sources (Far from the object)

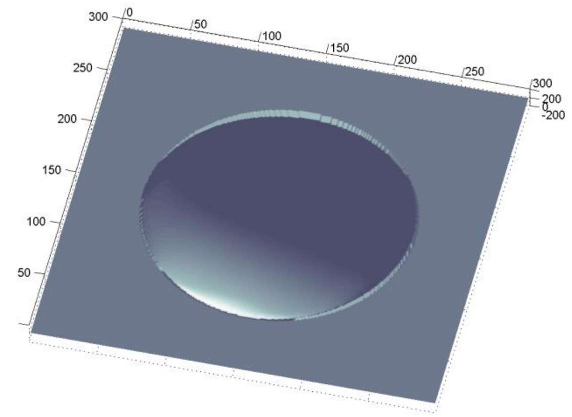
3D Model



View 1



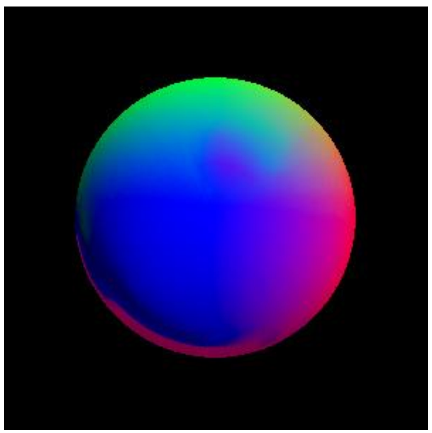
View 2



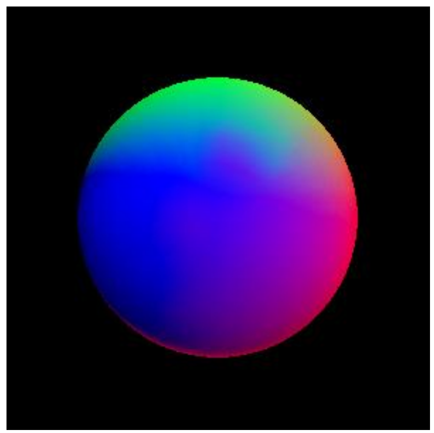
View 3

Experimental Results (Contd.)

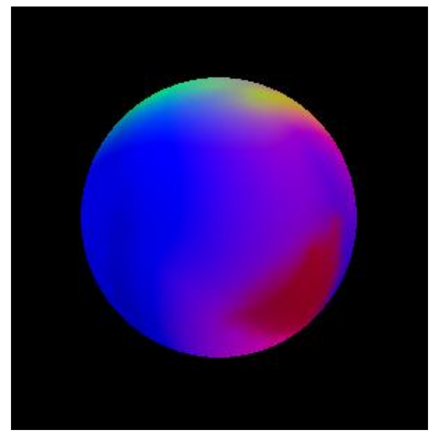
5. Normal map comparison



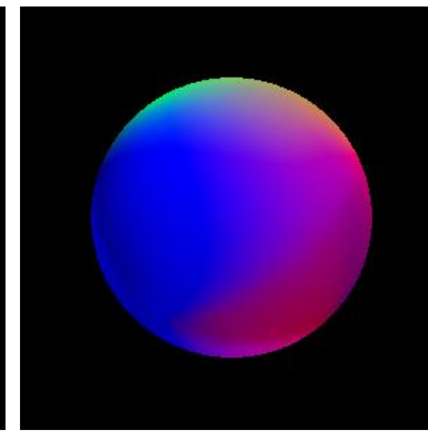
Normal map
4 light sources
(Close)



Normal map
6 light sources
(Close)



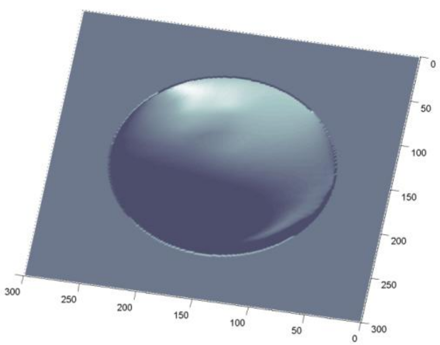
Normal map
4 light sources
(Far)



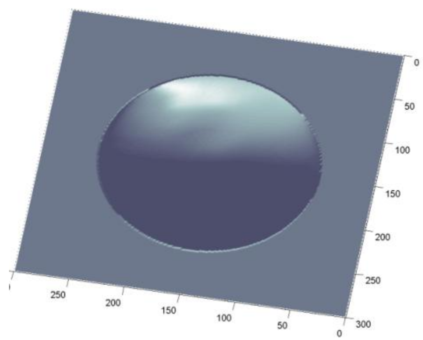
Normal map
6 light sources
(Far)

Experimental Results

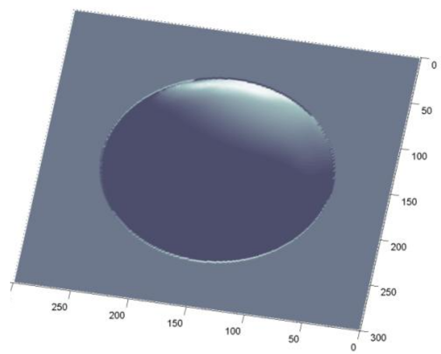
6. 3D model comparison



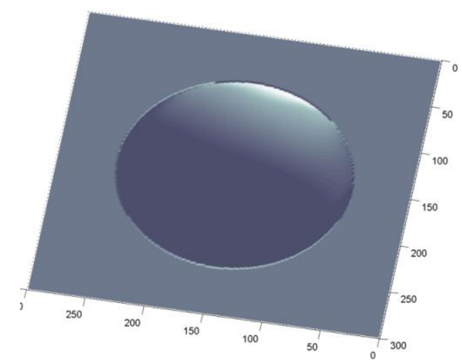
3D model
4 light sources
(Close)



3D model
6 light sources
(Close)



3D model
4 light sources
(Far)



3D model
6 light sources
(Far)

Conclusion and Future Works

- Distant light sources and larger number of images under different light directions, could result in better results.

- We will investigate on error reduction and also creating point clouds from the depth map as our future works.

References

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Thanks