# Assignment 2: Polarization-based Imaging - Lab session 2 -

## 1 Introduction

This assignment involves the implementation and analysis of a simple polarization-based imaging method to separate diffuse and specular reflectance components of an object by capturing it from a single point of view under polarized illumination. To evaluate your implementation, you can find the datasets Remote and Apple in the folder linked in Moodle. Additionally, you will have to capture polarization images on other objects using the equipment available in the lab session, and evaluate your algorithm on those.

## 2 Reflectance separation in available datasets

In this first task you will work with the datasets available in the folder to implement, evaluate and validate your algorithm.

### 2.1 Read and display polarization images (1 points)

Each dataset contains 9 images that follow numbered sequences `_DSC****.TIF`.

1. The first image in the sequence $L$ represents the intensity image, with no polarization effects involved. This is the first component $\mathbf{s}_0 \equiv L$ of the Stokes vector $[\mathbf{s}_0 \mathbf{s}_1 \mathbf{s}_2 \mathbf{s}_3]^\intercal$.
2. The next four images in the sequence $\mathbf{i}_0^h, \mathbf{i}_{90}^h, \mathbf{i}_{45}^h, \mathbf{i}_{135}^h$ are captured always under horizontally ($h$) polarized light. Each image is captured under a different orientation $\theta$ of the filter in front of the camera: 0°, 90°, 45°, 135°, respectively.
3. The last four images in the sequence $\mathbf{i}_0^v, \mathbf{i}_{90}^v, \mathbf{i}_{45}^v, \mathbf{i}_{135}^v$ are captured always under vertically ($v$) polarized light. Each image is captured under a different orientation $\theta$ of the filter in front of the camera: 0°, 90°, 45°, 135°, respectively.

Read, display, and label these images in the report using $\mathbf{i}_\theta^{[h|v]}$ notation. Use the same labeling in subsequent sections when necessary. TIP: The images are in TIF high-dynamic range format. If using `imagesc` function yields over- or under-exposed visualizations, you can simply apply the same scale factor to all images. **It's very important this scale factor is the same for all images**. Do not normalize each image individually, otherwise the following steps will not work. You can see examples of these images for a plastic sphere in Figure 1 [1].

### 2.2 Second and third components of the Stokes vector (2 points)

The intensity image $L$ represents the first component $\mathbf{s}_0$ of the Stokes vector $[\mathbf{s}_0 \mathbf{s}_1 \mathbf{s}_2 \mathbf{s}_3]^\intercal$. For each light filter orientation ($h$ or $v$), you need to calculate the second $\mathbf{s}_2^{[h|v]}$ and third component $\mathbf{s}_3^{[h|v]}$

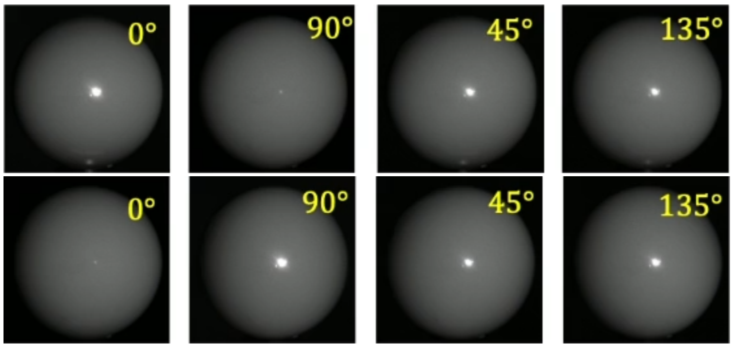


Figure 1: Polarized images of a plastic sphere under vertically-polarized light (top) and horizontally polarized light (bottom). Angles represent the orientation of the camera polarization filter. Images extracted from [1].

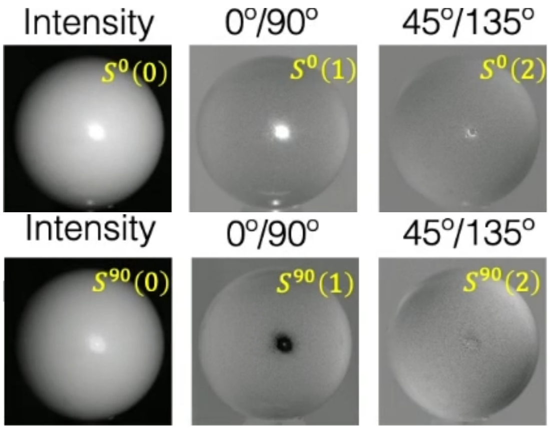


Figure 2: Stokes images (first, second and third components) of a plastic sphere under vertically-polarized light (top) and horizontally polarized light (bottom). Images extracted from [1].

of the Stokes vector. Given the polarized images $\{\mathbf{i}_0^{[h|v]}, \mathbf{i}_{90}^{[h|v]}, \mathbf{i}_{45}^{[h|v]}, \mathbf{i}_{135}^{[h|v]}\}$ for every light filter orientation, you can calculate the corresponding components of the Stokes vector as

$$\mathbf{s}_1^{[h|v]} = \mathbf{i}_0^{[h|v]} - \mathbf{i}_{90}^{[h|v]}, \quad \mathbf{s}_2^{[h|v]} = \mathbf{i}_{45}^{[h|v]} - \mathbf{i}_{135}^{[h|v]}.$$

Calculate $\mathbf{s}_1$ and $\mathbf{s}_2$ for both orientations of the light filter and display them along with the first component $\mathbf{s}_0$. You can see examples of these components for a plastic sphere in Figure 2. The0 and 90 superscripts in the image labels correspond to $v$ and $h$ superscripts in the equations, respectively. The bracketed $(k)$ numbers in the image labels correspond to the $k$ subscripts in the equations.

### 2.3 Reflectance separation (3 points)

Here you will use the Stokes images you computed to calculate different reflectance components of the captured object. Namely, you will compute its diffuse polarized reflectance, its specular polarized reflectance, and its diffuse *un*polarized reflectance.

**Polarized diffuse reflectance** To calculate polarized diffuse reflectance, you need to calculate the following intermediate images using the second and third components of the stokes vectors for both vertical and horizontal orientations of the light polarization filter as:

$$\mathbf{s}_{dp,1} = \mathbf{s}_1^h + \mathbf{s}_1^v, \tag{1}$$

$$\mathbf{s}_{dp,2} = \mathbf{s}_2^h + \mathbf{s}_2^v. \tag{2}$$

Using these images, you can calculate the polarized diffuse reflectance as

$$\mathbf{s}_{dp,0} = \mathbf{s}_{dp,1} + \mathbf{s}_{dp,2}.$$

Calculate and display these images. Do not discard the intermediate images, you will use them to calculate the polarized specular reflectance.

**Polarized specular reflectance** To calculate the polarized specular reflectance of the object, you need to use the intermediate images Equation (1) and the second and third Stokes components of vertically polarized light. First, calculate the following intermediate images:

$$\mathbf{s}_{sp,1} = \mathbf{s}_{dp,1} + \mathbf{s}_1^v, \tag{3}$$

$$\mathbf{s}_{sp,2} = \mathbf{s}_{dp,2} + \mathbf{s}_2^v. \tag{4}$$

Using these images, you can calculate the polarized specular reflectance as:

$$\mathbf{s}_{sp,0} = \mathbf{s}_{sp,1} + \mathbf{s}_{sp,2}. \tag{5}$$

**Unpolarized diffuse reflectance** $\mathbf{s}_{dp,0}$ and $\mathbf{s}_{sp,0}$ represent the diffuse and specular *polarized* reflectance of the captured scene. You can now calculate the diffuse unpolarized component by simply subtracting those from the original intensity image $\mathbf{s}_0$ as:

$$\mathbf{s}_{du,0} = \mathbf{s}_0 - \mathbf{s}_{dp,0} - \mathbf{s}_{sp,0}.$$

Calculate and display a comparison of all the components (intensity, diffuse and specular polarized, and diffuse unpolarized) for the datasets. Comment how the different images relate to the to the nature of the light transport scattered by the object and its material properties.

# 3 Reflectance separation in your own datasets

## 3.1 Capture your own datasets (3 points)

In this task you will have to capture your own datasets using the equipment available in the lab session. You will need to place one of the available items in front of the camera and the illumination source and capture nine images. First you need to capture one intensity image (without polarization filters). Then for each illumination polarization filter orientation (horizontal and vertical) you need to capture four images for each orientations of the camera polarization filter: 0°, 90°, 45°, 135°. Follow the instructions of the professors in class to capture everything correctly. To facilitate further evaluation, capture the images following the same filter sequence as we provide in the available datasets (described in Section 2.1).

The Nikon camera available in the lab saves the images in NEF format (HDR) and JPEG format (LDR). Download, display, and label these images as you did in Section 2.1. TIP: The camera captures images at 24MP resolution. To speed up computations, you can downsample these to a lower resolution using `imresize`.

## 3.2 Calculate Stokes images (1 points)

Calculate the Stokes images for the new datasets you captured by evaluating the algorithm you implemented in the previous section. Visualize the images and label them correctly.

### 3.3 Calculate reflectance images (2 points)

Calculate the images with every reflectance component (polarized diffuse, polarized specular, and unpolarized diffuse) of the newly captured datasets using the Stokes images you calculated in the previous step. Visualize these images along with the intensity image, and label them correctly. Comment on the different reflectance components observed and why some objects show stronger or weaker components of each kind.

## 4 Submission and evaluation

You will have to submit a report of up-to 3 pages maximum, plus figures. The report should include the results required for every task, and a brief discussion of what is shown on every result. The maximum score possible for this assignment is 10 points:

| | |
|---|---|
| **Available datasets (Section 2)** | |
| → Read and display datasets (Section 2.1) | 1 |
| → Calculate Stokes images (Section 2.2) | 2 |
| → Calculate reflectance components (Section 2.3) | 3 |
| **New datasets (Section 3)** | |
| → Capture datasets (Section 3.1) | 3 |
| → Calculate Stokes images (Section 3.2) | 1 |
| → Calculate reflectance components (Section 3.3) | 2 |

## References

[1] Seung-Hwan Baek et al. "Polarization-Based Visual Computing". In: ACM SIGGRAPH 2023 Courses. SIGGRAPH '23. Los Angeles, California: Association for Computing Machinery, 2023. ISBN: 9798400701450. DOI: 10.1145/3587423.3595544. URL: https://doi.org/10.1145/3587423.3595544.