# Polarimetric Data Generation through High-Fidelity Simulation with Mitsuba 3

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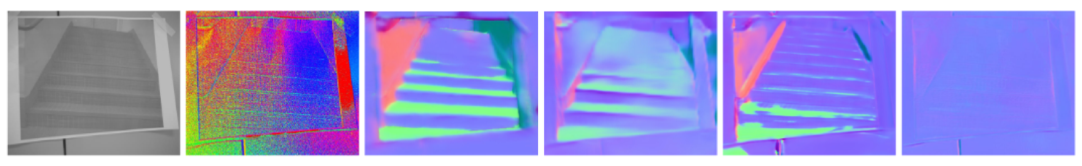
## Introduction

In this research project, we have rendered polarimetric images (images which provide additional information about the polarization state of the light) and created a dataset using controlled and uncontrolled lighting conditions, which can be used for applications like depth detection and shape estimation, which are yet to be explored completely.

## Existing Research and Gaps

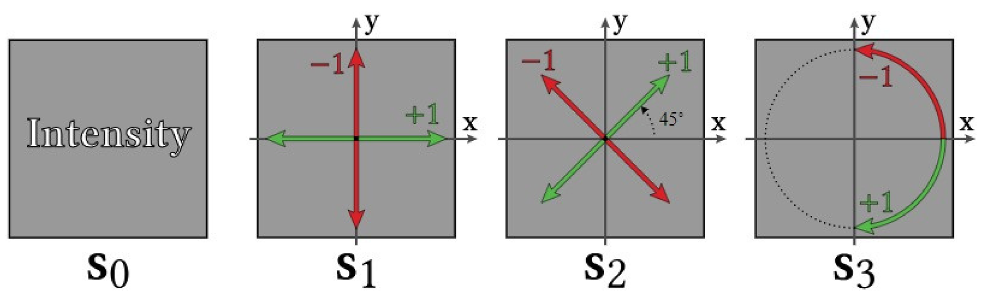
- Currently, many imaging algorithms, like 3D shape detection, surface normal and depth estimation, rely on RGB rendering and data obtained from such RGB sensor cameras without using physical phenomena like polarization.
- However, these RGB methods aren't entirely reliable, as shown below;



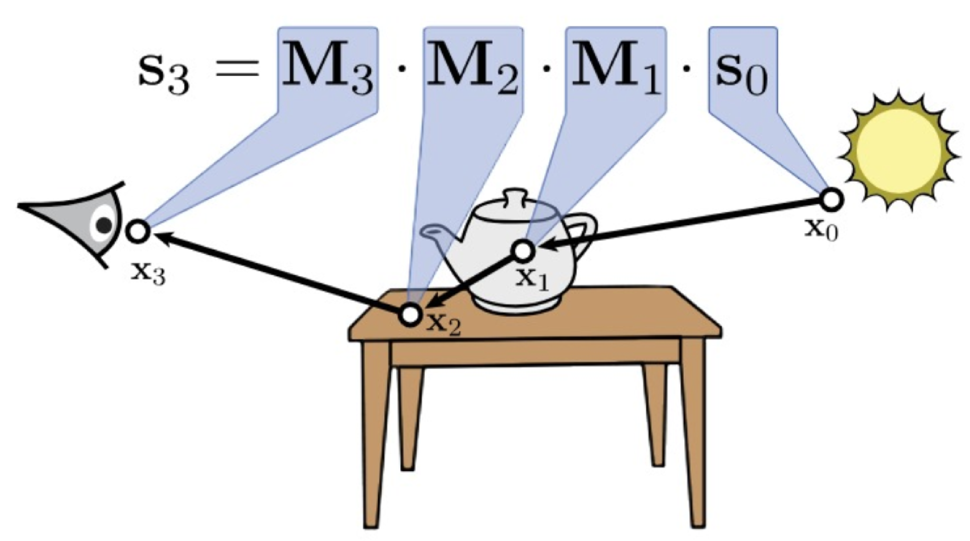
- Polarization conveys the underlying physical shape, while RGB-based methods are distracted by the semantics of a printed picture attached to a wall.
- Polarization contains helpful cues about physical 3D information of objects based on real-world reflection.
- Thus, polarization can improve estimated normals' fidelity and provide dense surface orientation cues from the polarized light perceived at each pixel, especially in areas with rare or misleading information.
- Also, compared with the active sensors and object-level normal estimation techniques (e.g., photometric stereo), the polarization camera is a passive sensor not constrained to a specific depth range. Thus, polarization images are promising data sources for accurate normal estimation in the wild.
- Considering only three models that use Polarization data, thus it is necessary to create data with polarized information so that we can robustly use and apply the physical cues in the 3D world obtained from polarization.

## Polarization

Components of Stokes vector-




- $S_0$ measures the intensity of light.
- $S_1$ distinguishes horizontal vs. vertical linear polarization, where $S_1$ = ±1 stands for completely horizontally or vertically polarized light, respectively.
- $S_2$ distinguishes diagonal linear polarization at ±45° angles, as measured from the horizontal axis.
- $S_3$ distinguishes right vs. left circular polarization, where $S_3$ = ±1 stands for full right or left circularly polarized light respectively.




Emitters return emission in form of Stokes vectors and polarized bidirectional scattering distribution functions (pBSDFs) will return Mueller matrices that are multiplied with the emission.

$$p = \sqrt{\frac{S_1^2 + S_2^2 + S_3^2}{S_0^2}}$$

$$I_{pol} = I_{un}\left(1 + p\cos(2\phi - 2\phi_{pol})\right)$$

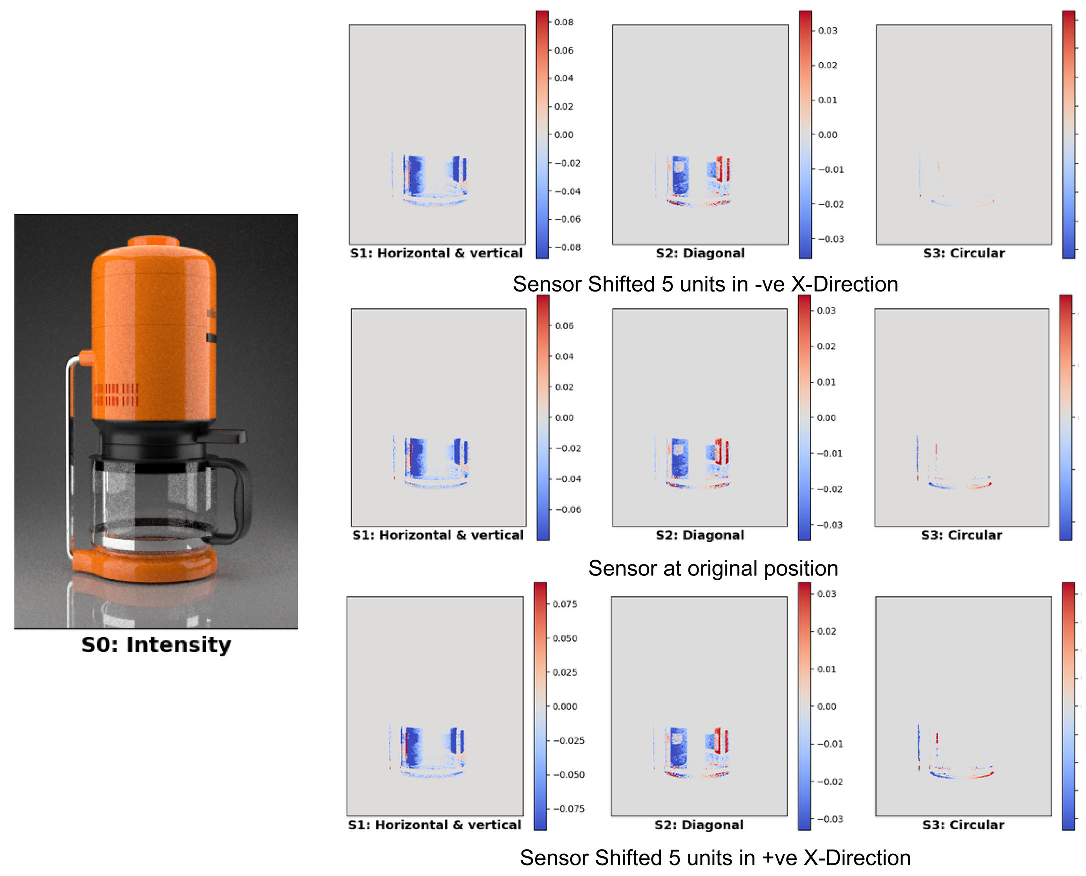
where ϕ is the angle of polarization (AoP), p is the degree of polarization (DoP), $I_{un}$ is the unpolarized intensity of light. ϕ, p, and $I_{un}$ can be computed from images with different polarizer angles. p contains cues for the viewing angle θ between surface normal and viewing direction.

## Mitsuba 3

- It is an open-source API that has forward and inverse light-transport simulation. It consists of a wide variety of plugins that implement functionality ranging from materials and light sources to complete rendering algorithms, which we require for polarization to simulate actual physical world phenomena and gather information about the physical characteristics of light.
- With the use of Mitsuba, we have used three sensors to ensure three viewpoints to include a binocular view and tackle the problems and limitations of a single viewpoint (like no depth Information).
- Also, we have rendered images in different controlled and uncontrolled lightings to see the effect of polarization.

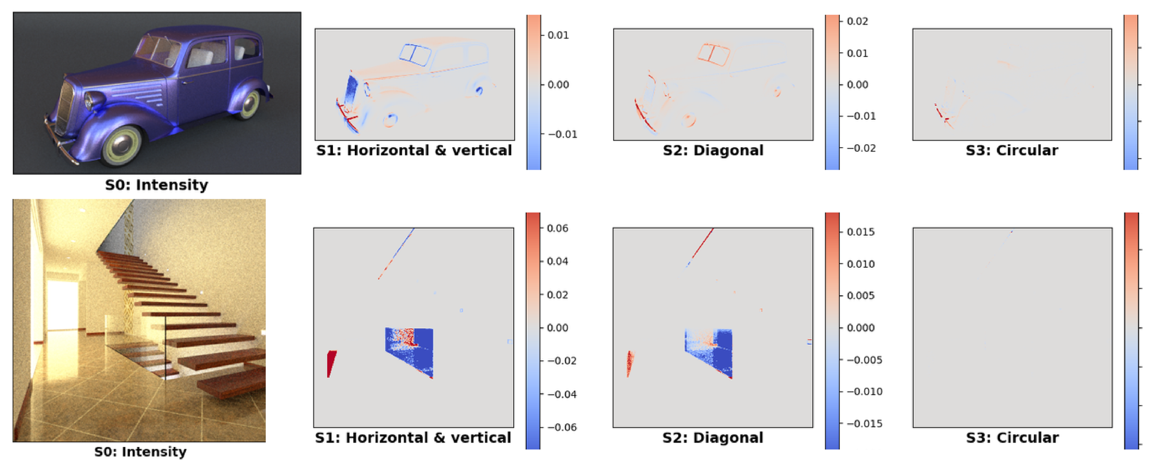
## Dataset Generation

In the following figure, we have rendered images from three different view points, keeping other factors same, and we can see the difference in the polarization states of light.

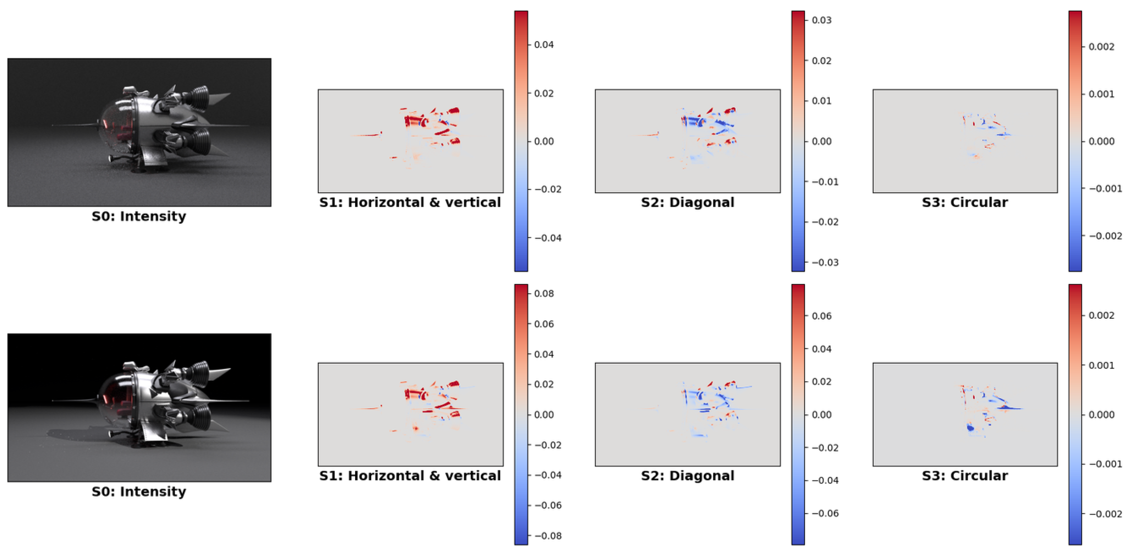



Now, this is how different components of stokes vector for a scene actually looks like.

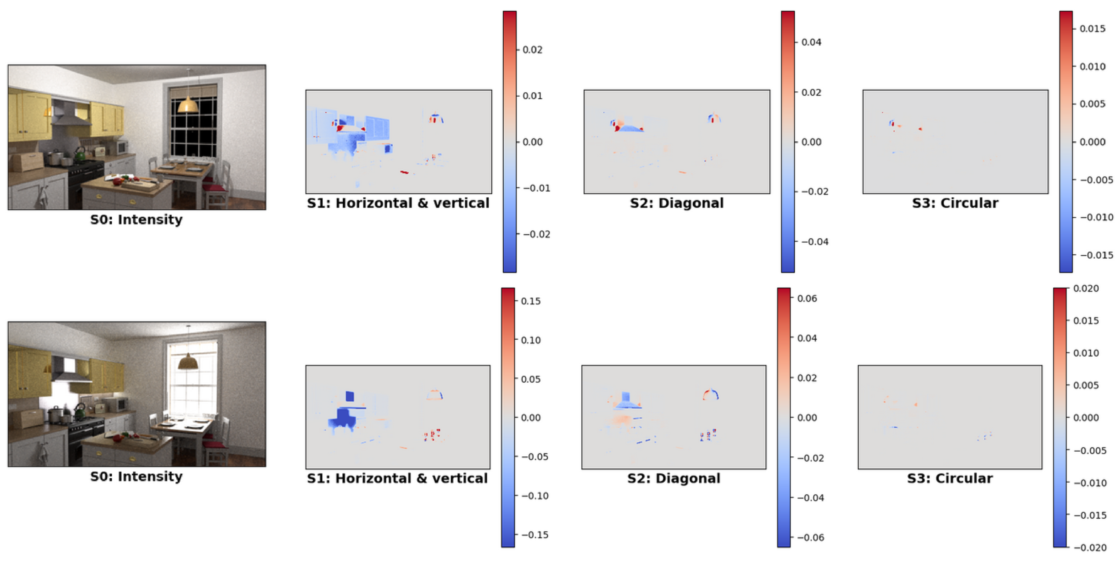

We have used a colormap to visualize the different polarization states better.




Now, we have kept camera position fixed and changed the lighting conditions from a constant emitter to a spotlight.

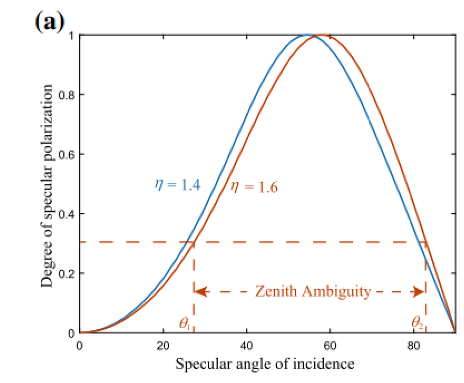



Here, we have rendered a real-life scene in controlled and uncontrolled lighting conditions.




## Limitations

- Not all BSDFs and integrators can interact with polarization. For example, rough dielectric BSDF acts as a depolarizer.
- Currently, all emitters in Mitsuba 3 emit completely unpolarized light.
- Also, there are some ambiguities related to polarization, like GBR ambiguity and Zenith ambiguity.




## Future Pursuits and Applications

- Use the ShapeNet dataset to render polarimetric images for all the components of the Stokes vector.
- Train a deep learning model on the generated dataset and test it on the real world data captured using a polarimetric camera.
- Use the polarization property of light to convert LDR images into HDR images.
- Further, it can be used in existing shape detection models for accurate predictions, depth estimations, and material detection.
- We can also use this to remove glare from images as shown in the figure below.

Effect of polarizing filter on light reflected from a water surface. (Image on right is filtered one.)

## Acknowledgements

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### References

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