Simulating Two-Dimensional Scattering Patterns of Particles for Use in Holography

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Abstract

Holography is not a new field, but it has not yet been sufficiently applied to small particles. Traditionally, a hologram is a photographic recording of a light field, produced from a laser and recorded onto a film. Then, the same laser is shown back through the developed film to recreate the particle.

However, this process is very impractical and time-consuming. Digitally creating the scattering pattern from the silhouette of the particle and the rules of light scattering is much more efficient. This project focuses on creating an algorithm to produce two-dimensional scattering patterns using the Huygens-Fresnel Equation and the Babinet Principle, and applying them to small particles such as different types of pollen. Ultimately, this algorithm will be used in conjunction with a drone that will generate holograms of airborne particulate matter for use in agricultural research.

Theory

Light travels in a straight line, unless it is deflected by something in its path, such as a particle. The resulting phenomenon is called a scattering pattern, because it shows how the light systematically scatters off the particle. For example, light scatters off in each direction equally for a spherical particle, so the pattern looks like several concentric circles. The rings themselves are caused by constructive interference of the light waves, and the spaces between the rings are from complete destructive interference.

Different shaped particles have different scattering patterns, and will still feature effects from interference, but will most likely not be circular because the light will scatter unequally. However, the patterns will be symmetrical along the same axes as the particle.

It is possible to simulate the behavior of the light by simply knowing the geometry and transparency of the particle, which are easily deduced from a silhouette of the particle. Thicker or more opaque particles fully scatter light, whereas more transparent particles only partially scatter the light.

The Babinet principle states that an opaque body scatters light the same way a hole of the same size and shape would. Using this idea to predict the behavior of light, as well as the Huygens-Fresnel equation to calculate a light field, a two-dimensional scattering pattern can be produced.

Algorithm

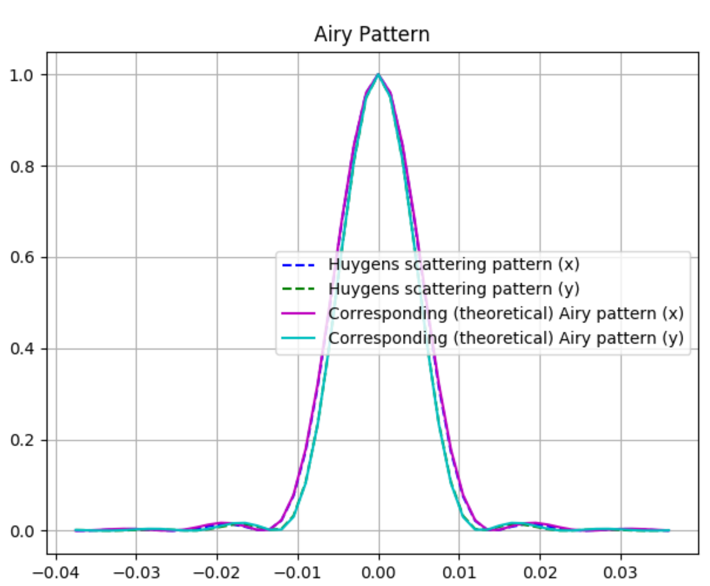
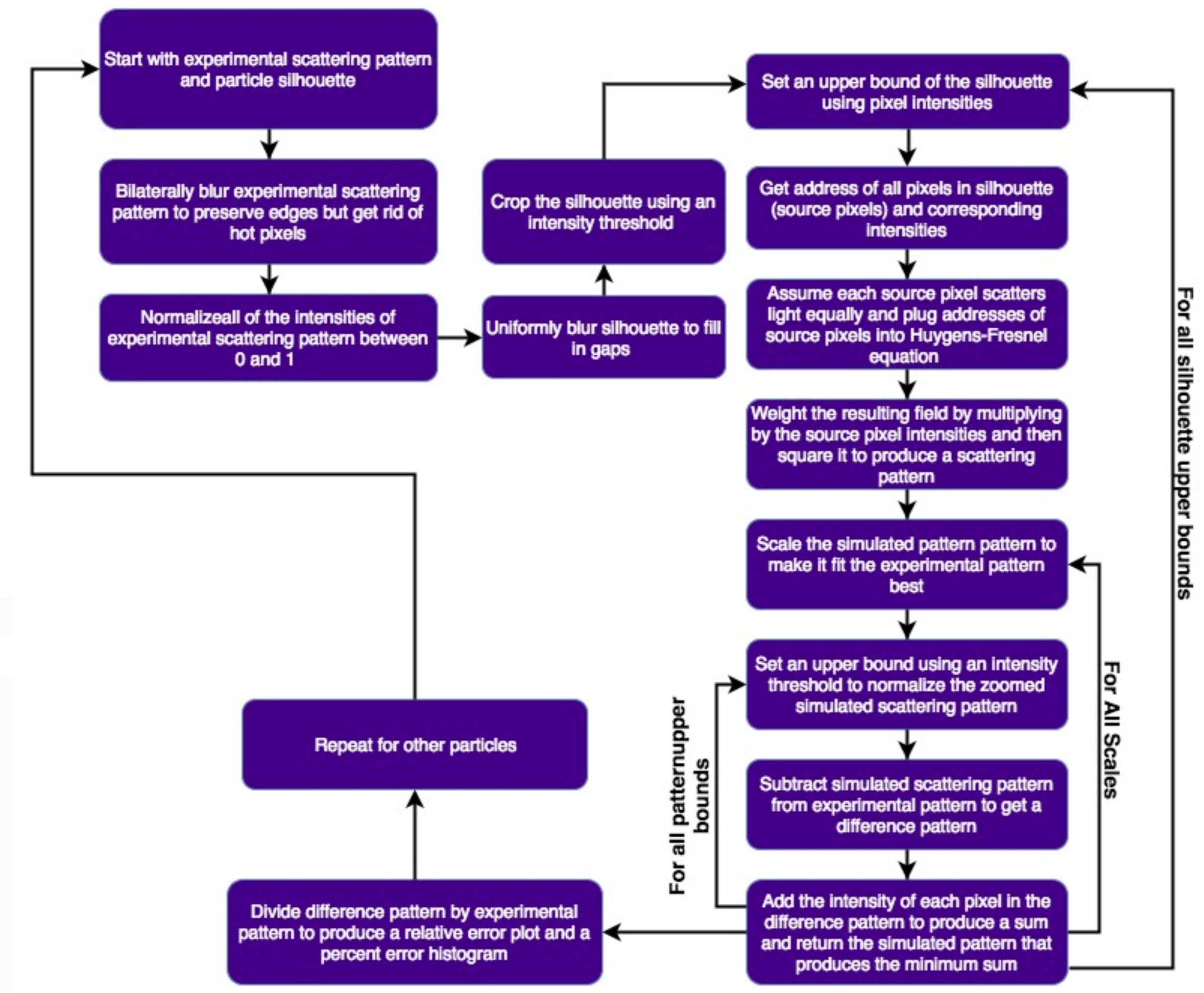


Figure 1: A one-dimensional scattering pattern in both the x and y directions of a nearly spherical particle to show that it behaves like an Airy disk, as expected. This test was to make sure that the code behaves as anticipated.



Resulting Patterns

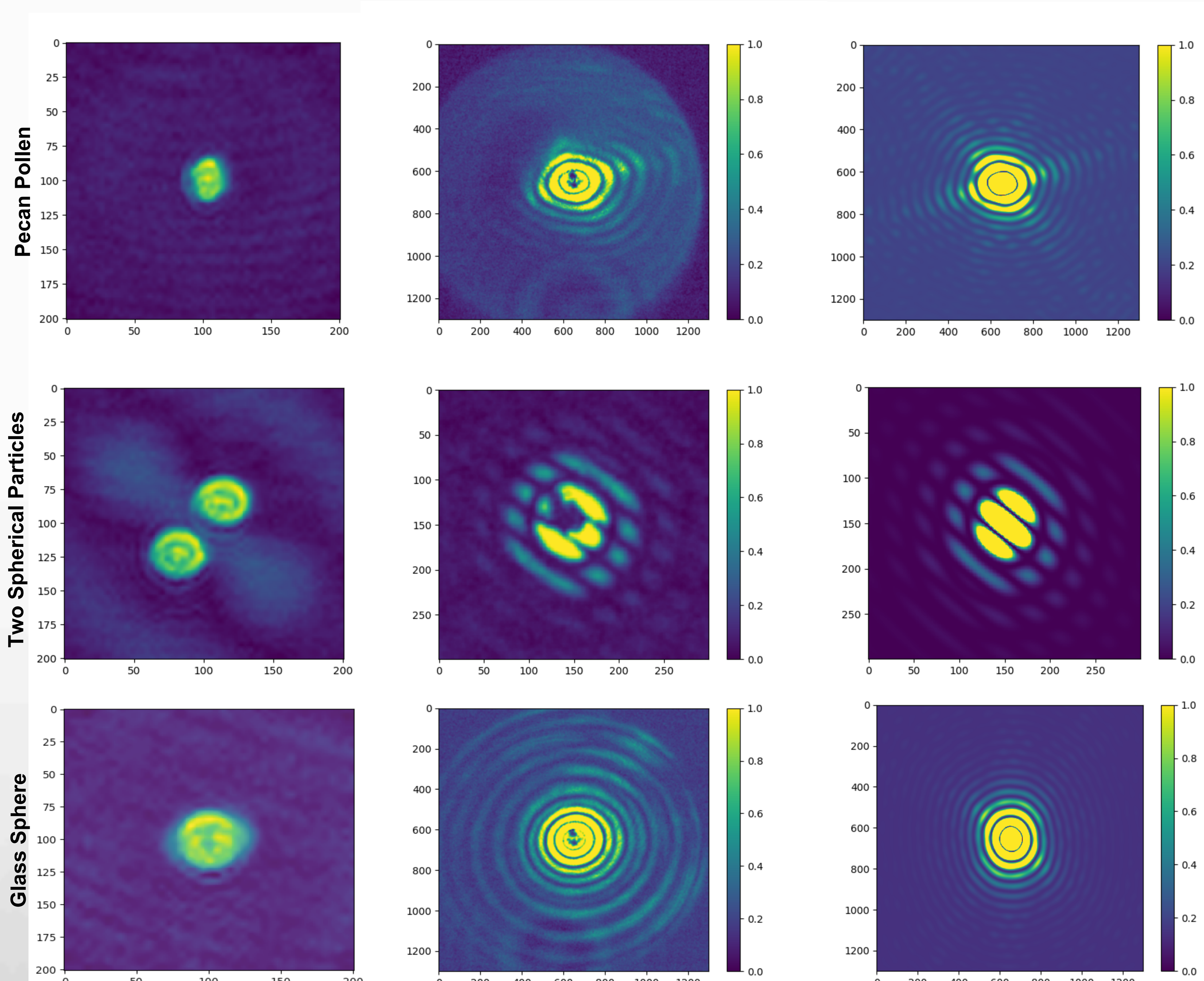


Figure 2: On the left, the silhouette is shown for three particles: a singular pecan pollen, two spherical particles, and a small glass sphere. The middle column is the experimental scattering pattern for the three particles, produced by a laser and a camera. To the right are the simulated two-dimensional scattering patterns that were deemed most similar to the corresponding experimental pattern.

Conclusion

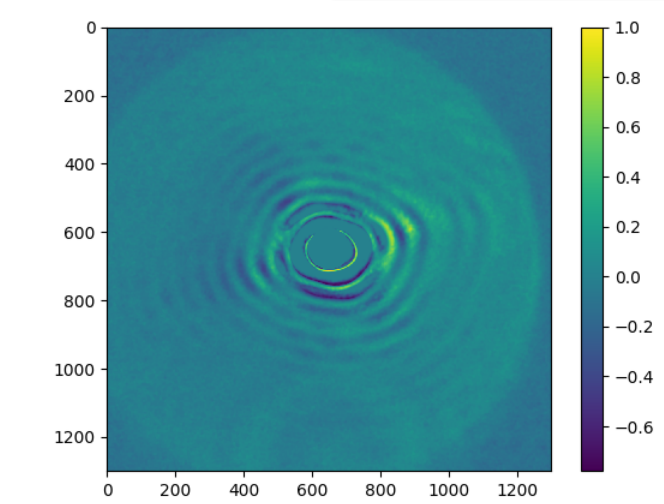


Figure 3: A difference pattern for the pecan pollen, produced by subtracting the simulated pattern from the experimental pattern.

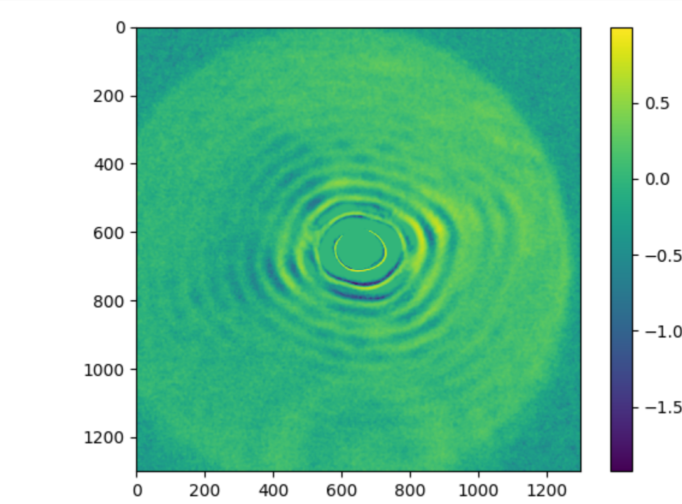


Figure 4: A relative error plot for the pecan pollen, produced by dividing the difference pattern by the experimental pattern.

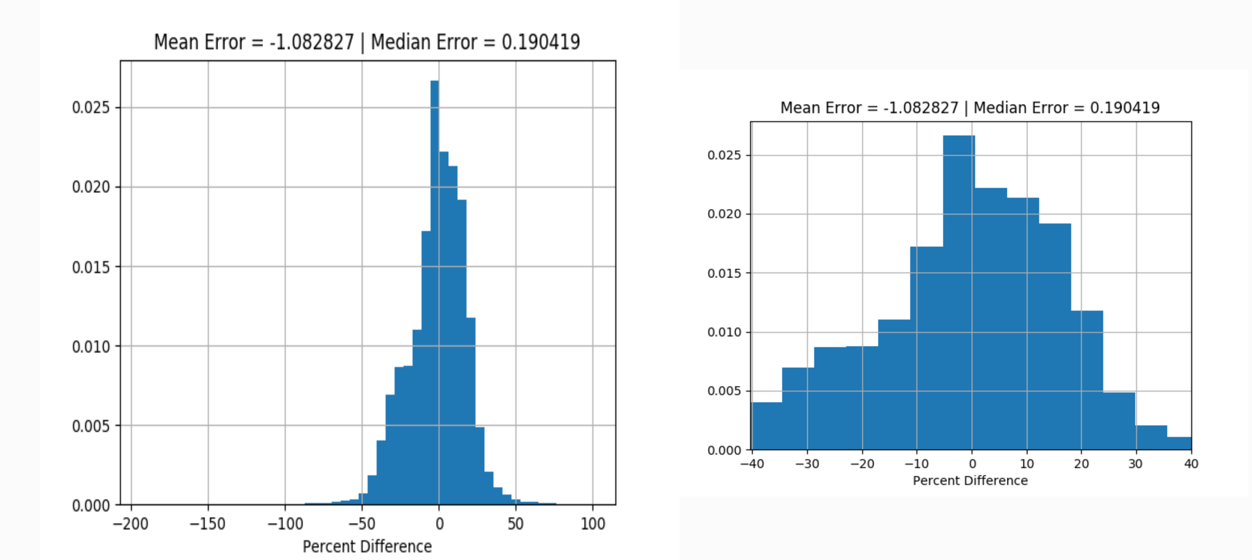


Figure 5: A percent difference histogram and corresponding subplot for the pecan pollen particle. This shows the difference per pixel between the experimental and simulated scattering patterns.

Through this project, an algorithm was developed to accurately simulate two-dimensional scattering patterns based on a particle's silhouette. Ultimately, this code will be used to create a library of scattering patterns so that a particle can be identified based on its scattering pattern alone. Further research may focus on making the simulated patterns even more accurate, or finding an algorithm to efficiently produce three-dimensional patterns.

References

[1] M. J. Berg, S. Holler (2016). Simultaneous holographic imaging and light-scattering pattern measurement of individual microparticles (pdf). Optics Letters, 41, 3363-3366.

[2] "Open-CV Python Tutorial." *Open-CV*. Open Source Computer Vision, n.d. Web. 28 Jul. 2017.

Acknowledgements

Thank you to the National Science Foundation, Jesse Laning, and Ryan Mersman.