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Case Report

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Depth from Diffraction During a Solar Eclipse

Greg Passmore*

PassmoreLab, Austin, Texas, USA

*Corresponding Author
Greg Passmore, PassmoreLab, Austin, Texas, USA.

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For fun, we can use the Huygens-Fresnel Principle to calculate depth to a partial occluder (like a leaf on a tree), where every point on a wave front from the occlude edge can be considered as a secondary source of spherical waves. This only works in any useful sense with point emitters (solar eclipse, artificial lighting, RF emitters). These secondary waves propagate outward from their respective partial occlusion points in all directions. The sum of all these secondary wavelets at any given point and time determines the shape and behavior of the overall wave front. So guess what, we can measure that and work back to distance!

We can explicitly solve for implied distance using:

$$\Psi(x,y,t) = \iint \frac{A_0}{r} e^{i(kr-\omega t)} dS$$

where for any given point (x, y) at time t, we can calculate the complete amplitude of the wave $\Psi(x, y, t)$ as the superposition of all the secondary wavelets.

In the equation above, A_0 is the amplitude of the primary wave, r is the distance of the secondary source to the point (x, y) , k is the wave number given by $k = \frac{2\pi}{\lambda}$ where λ is the wavelength, w is the angular frequency as given by $w = 2\pi f$ where F is the frequency of the wave, the double integral $\iint$ is the summation of all secondary sources and dS is the infinitesimal area element on the wavefront.

The most interesting part of this equation is the "infinitesimal area." The concept of an "infinitesimal area element" on a wavefront is a funny concept. It's a mathy way of breaking down a larger area into tiny, nearly infinitesimal pieces to analyze the contributions of each of these pieces to the overall wavefront.

In the context of the Huygens-Fresnel Principle, a wavefront is a surface in space where all points on that surface are in phase. This region can be considered a tiny piece of the larger wavefront. This tiny piece is so small that we can approximate it as flat or planar over this small region.

The "infinitesimal area element" (denoted above a dS) represents this tiny, flat piece of the wavefront. It is an incredibly small area within the wavefront, so small that it's basically treated as a point by many math geeks. However, it still has an area, just extremely tiny.

When applying the Huygens-Fresnel Principle, we consider how the wave emanates from every point on this small area element (dS) as if it were a point source (which is really cool BTW). In essence, you break down the larger wavefront into countless such tiny point sources, each corresponding to an infinitesimal area element.

The contributions of these countless point sources (associated with infinitesimal area elements) are then all handily superimposed to calculate the wave's behavior at any specific point in space at a given time. This superposition process accounts for the interference and diffraction effects that you see in the photos.

When integrating over all these infinitesimal area elements, we effectively sum up the contributions of all these tiny portions of the wavefront to determine the wave's behavior at a particular point.

Then, we do this for every pixel in our image to get a relative depth map in the familiar expression:

$$\mathrm{f}(i,j) = \sum_{i=1}^{M} \sum_{j=1}^{N} I(i,j)$$

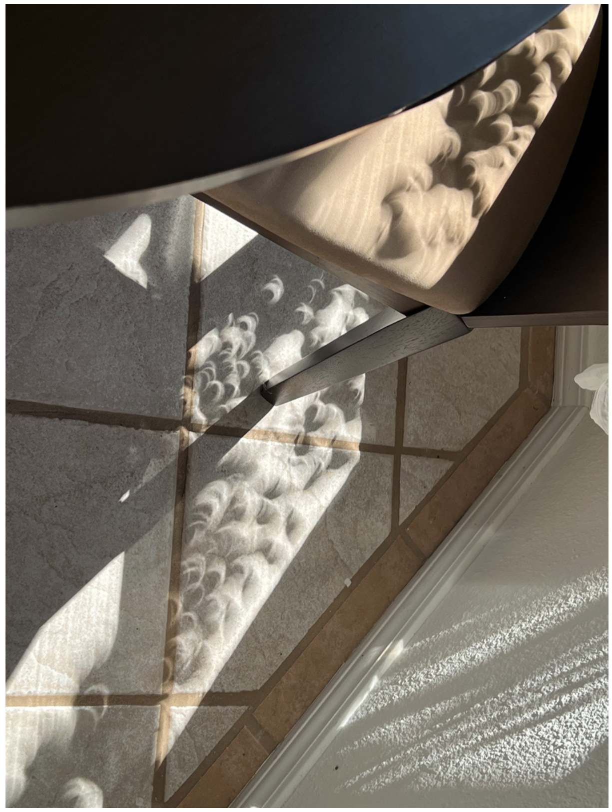
where, we do every (i, j) pixel and for each pixel we look at wave spread, derived from refracted angle and the amplitude is $A(\theta)$ so that we use the integral over the edge as:

$$A(\theta) = \int_{-\infty}^{\infty} A_0 e^{ikx} dx$$

with the only undefined value being x which is the position along the edge. This is sort of like a slit diffraction pattern.

We need the delta of the angle of course, to compute spread, so we take a shortcut and calculate $|A(\theta)|^2$ as the halfway position from maximum.

It is more complex than this, since we do not have the luxury of slits, but this method works for any refractive edge, with tuning for what our occluder is ... and yes, I hacked over the explicit depth measurement, but it is simply the spread delta $\Delta\theta \approx \frac{\lambda}{d}$ where d is edge geometry. This means if we have the distance, we can also figure out the edge geometry instead (useful or calibrations). Keep in mind, that this only works outdoors during a solar eclipse (or in controlled conditions).



Huygens-Fresnel-Kirchhoff popping up on my kitchen floor during the solar eclipse