OPTICAL METHODS Back to Basics *by Gary Cloud*

Optical Methods in Experimental Mechanics
Part 25: Objective Speckle

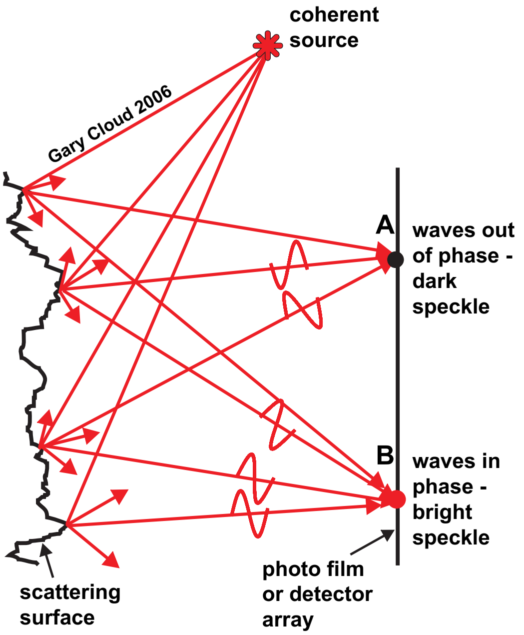
REVIEW AND PURPOSE

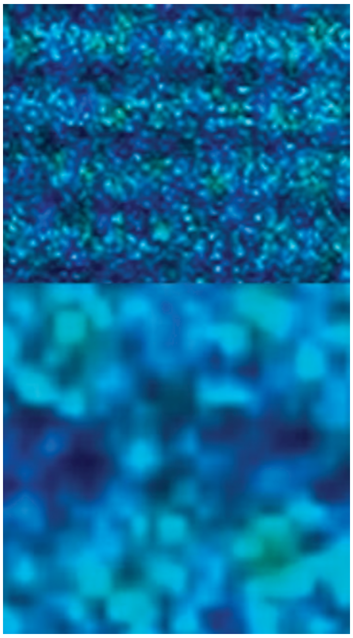
The previous article described simple experiments that demonstrate the creation of coherent light speckle and illustrate some important speckle phenomena that are useful in measurement applications.

This article describes one of the two fundamental types of speckle, the so-called objective speckle that is created when there is no imaging lens in the system. This speckle species is difficult to observe and is of little practical use in measurement. Why then study it? The reason is that it helps us understand the formation of the more complex and highly useful second type of speckle, that being subjective speckle; and it provides the foundation for estimating speckle size and brightness distributions for various types of speckle fields.

FORMATION OF OBJECTIVE SPECKLE

The sketch below illustrates in an exaggerated way the formation of speckle for the simplest case. Note that there is no imaging lens in the system, which is why this setup creates what is customarily called objective speckle.





Portions of speckle pattern from Part 4 of article series recorded with digital camera using Argon laser. Top portion is roughly normal viewing size. Bottom portion is resampled at ×4. The effects of pixel size and shape on the recorded speckles are apparent. Digital photo and composite by G. Cloud, 2002–2006.

Objective coherent light speckle:
- *is so-named because a lens is not used in the system,*
- *cannot be observed directly,*
- *has little practical application,*
- *provides the basis for understanding the more useful subjective speckle,*
- *helps us estimate speckle size and brightness.*

To create objective laser speckle patterns:
- *illuminate an object having a matte scattering surface with an expanded laser beam,*
- *collect scattered waves on a screen, usually a photo film or a sensor array.*

The series, Optical Methods—Back to Basics, *is written by Prof. Gary Cloud of Michigan State University in East Lansing, Michigan. The series began by introducing the nature and description of light and will evolve, with each issue, into topics ranging from diffraction through phase shifting interferometries. The intent is to keep the series educationally focused by coupling text with illustrative photos and diagrams that can be used by practitioners in the classroom, as well as in industry. Unless otherwise noted, the graphics in this series were created by the author.*

The series author, Prof. Gary Cloud (SEM Fellow), is internationally known for his work in optical measurement methods and for his book, Optical Methods of Engineering Analysis.

If you have comments or questions about this series, please contact Jen Proulx, journals@sem1.com.

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Light waves from a coherent source such as a laser are spread out and directed onto an object that will scatter the incoming waves in all directions. The object can be about anything from a brick building to a gumball, but it cannot have a polished specular reflective surface. A screen, a photographic film, or a detector array is set up at some distance away so as to receive the scattered waves. Now, the important fact is that each and every point on the screen receives light waves that are scattered from each and every point of the illuminated object. Thus, there will be a multitude of scattered waves coming to any single point of the screen. Furthermore, these converging scattered waves have traveled different path lengths, and they arrive with a multitude of different phases. They interfere with one another to produce a particular brightness at the meeting point. Consider screen point A in the sketch. If the phase relationships arriving here are such that predominately destructive interferences take place, then point A will be dark. At point B, the waves might be arriving more or less in-phase, so constructive interferences occur, and that point will appear bright. Adjacent points of the screen will see various mixtures of phase relationships, and the resultant brightnesses will lie between totally black and maximum brightness.

The basic physics of objective speckle formation are that:

- *each point of the screen receives light waves from every point of the illuminated object,*
- *each wave travels its own particular path length to a screen point,*
- *the multitude of waves arrive at the point with a multitude of different phases,*
- *the waves all interfere with one another as they arrive at the point,*
- *at some points, the waves are predominately in phase so they constructively interfere to create a bright patch,*
- *at other points, the waves are predominately out of phase so they form a dark patch,*
- *many points have a mixture of phase differences, so the result is a gray patch.*

The shrewd student will be troubled by this simplified model and correctly raise the following query, "For the system shown, the waves come to the screen from a multitude of angles, so aren't the interferences between waves complicated by oblique interference?" The answer is, "Yes, indeed. But, for the moment assume that the object and screen are on the small side and that the one lies quite a distance from the other. In this case the interferences are close to the collinear type (Part 2 of this series), and the model is sufficient—for now." The oblique interference case will be taken up presently as it provides an approach for estimating speckle size.

The simple model described is sufficient if the object is small and at large distance from a small screen, in which case the interference systems are close to the collinear case.

For a large object close to the screen, the interference systems are complicated because the waves meet at significant angles. In this case, oblique interference must be considered, and this provides an approach for estimating speckle size.

RANDOM SPECKLE BRIGHTNESS

The random nature of the scattering surface at the scale of the wavelength of light causes the phase combinations at any receiving point to be random, so there is no way to predict the brightness at that point. Likewise, the brightness at one point bears no relation to the brightness at any adjacent point, so there is no ordering of the brightness into anything like a continuous interference fringe.

This situation is very different from that encountered when light is bounced from a mirror and combined with another portion of the original beam, as with Lloyd's mirror (Part 4 of this series), or when light is simply bounced from a grating. In such cases, the path length variations are predictable and related, and ordered systems of interference fringes are obtained. One can imagine creating a speckle pattern from a scattering surface where the small-scale roughness is "somewhat ordered." A machined surface or the faces of a fatigue crack come to mind. In that case, the distribution of speckle brightnesses might show evidence of systematic arrangement because some of the path lengths are related. This idea suggests ways of assessing surface characteristics or damage.

Speckle brightnesses are:

- *not predictable,*
- *random because the path length relationships for a given speckle are random,*
- *not related to one another,*
- *do not combine to form continuous fringes.*

The randomness of a speckle pattern is important in establishing brightness distribution and in measurement applications, as will be seen presently.

HOW CAN WE OBSERVE OBJECTIVE SPECKLE?

In the early days of speckle study, instructors would bounce an expanded laser beam off an object, hold a white card so as to collect the scattered waves, and pronounce that what we saw on the card was objective speckle. Well, not exactly. The problem is that the waves from a speckle point that have any brightness at all are rescattered from the card and pass through the lens of our viewing eye to form an image on the retina. This retinal image contains a speckle pattern that is different from the one on the card. The various waves that create the speckles have traveled through a new system of path lengths that depend on, among other parameters, the lens itself. The speckle pattern is thus transformed to one of the so-called subjective variety, a topic that will be studied in the next article.

One cannot see accurately an objective speckle pattern with the eye or a camera because the lens in the viewing system converts the pattern to subjective speckle.

Apparently, the only way to view objective speckle patterns is to use a photographic film, a scanning picture-sensing detector (analog TV), or a detector array (digital photo), but even these approaches are problematical. In any case, no lens is used. The scattered waves fall directly on the detector. If a film is used, it is developed and printed, and a good representation of the objective speckle pattern is then directly viewable. Its accuracy might be affected by film resolution and linearity. If an analog TV camera without a lens is employed, then the recorded speckle might be greatly modified by the raster scan. If a digital camera is used, then the recorded speckle pattern is affected by the pixel size and spacing, as illustrated by the photograph at the head of this article. Among other problems, there might be several small speckles in one pixel space; also, the boundaries between speckles will probably not line up with pixel edges. One concludes that seeing an accurate representation of a speckle pattern is actually quite difficult.

To view an objective speckle pattern:
- *expose a photographic film, using no lens, develop the negative, and print it; this image might be affected by film characteristics,*
- *use an analog TV sensor without a lens; the pattern is modified by the raster scan,*
- *allow the pattern to fall directly on the sensing array in a digital camera; the recorded pattern will be affected by the pixel size and pixel spacing.*

WHAT IS NEXT

The next article will describe the formation of subjective speckle patterns. Subsequent articles will deal with estimations of speckle size, speckle pattern brightness distributions, and, perhaps, combinations of speckle fields. ■

Speckle topics to be studied next include:
- *subjective speckle,*
- *estimates of speckle size,*
- *speckle brightness distributions,*
- *combinations of speckle fields.*