Optical Methods in Experimental Mechanics

Part 24: Demonstrations of Laser Speckle Phenomena

REVIEW AND PURPOSE

Recent articles in this series have dealt with various forms of geometric moiré, a phenomenon that does not involve optical interference.

Now begins study of the speckle effect that is observed whenever an object is illuminated with coherent light as from a laser. It is an interference phenomenon, and it is fundamentally important in many methods of experimental mechanics including electronic speckle pattern interferometry and laser speckle shearography. This short introductory article focuses on simple qualitative demonstrations of speckle phenomena that are subsequently explained quantitatively and then exploited in measurement techniques that are, in fact, closely related to moiré.

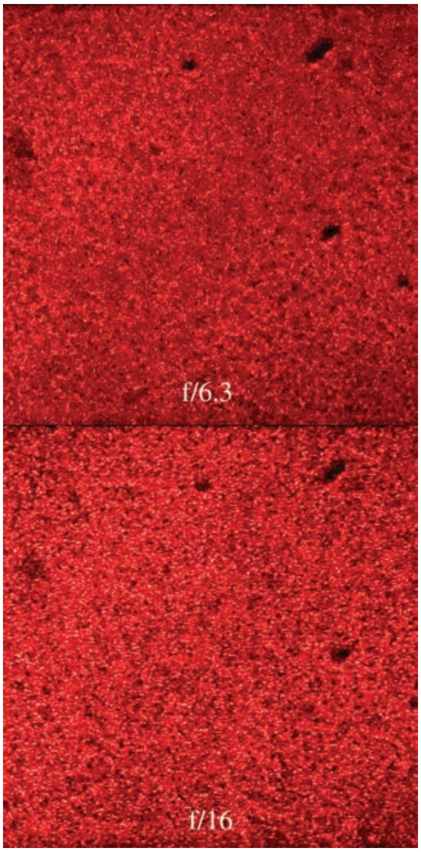
THE SPECKLE EFFECT

The invention of the laser was hailed by photographers, microscopists, artists, and other users of optical devices because it appeared to be the perfect solution to many illumination problems. Here was a source that produced a beam of light that was intense, collimated, narrow, monochromatic, and coherent. Disillusionment soon followed. Images of objects illuminated by a laser were contaminated with a grainy structure that severely limited the effective resolution. Photographs made with coherent illumination were neither attractive nor scientifically adequate, as evidenced in the photographs with this article. Laser-based photos were greatly inferior to those made with old-fashioned noncoherent light. Considerable time and effort were expended to understand this aggravation, which came to be called the “speckle effect,” with the aim of eliminating it from images taken with laser light.

This study of laser speckle was fruitful in ways that were unexpected and fortuitous. The speckle pattern was found to carry much information about the illuminated object as well as other components of the optical system. Applications were soon invented, and the formerly problematical phenomenon evolved into the basis of a whole family of measurement technologies. These new techniques, which are loosely grouped under the name “speckle methods,” use speckle fields in combinations to generate data, often in the form of fringe patterns similar to those of geometric moiré, about motion, deformation, and strain.

SIMPLE DEMONSTRATIONS OF FUNDAMENTAL SPECKLE BEHAVIORS

Before beginning inquiry into the physics of speckle, types of speckle, and relationships between speckle appearance and the optical system, consider some



Composite of two photographs taken with different apertures of speckle pattern created by projecting He–Ne laser light onto a screen. The effect of camera aperture on apparent speckle size is evident although subdued by the reduction. Digital photographs by Gabriel Isaicu of Michigan State University, Mechanical Engineering Department, September 2006.

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.

doi: 10.1111/j.1747-1567.2006.00103.x

simple but useful experiments that illustrate fundamental speckle behavior. These demonstrations are easy to do yourself or to present to large groups in classroom or lab, and they are effective in helping you see with your own eyes, and believe, the basic speckle phenomena that are important in measurement applications.

Simple experiments that demonstrate basic laser speckle phenomena are described.

Images made with laser illumination are contaminated with a "salt-pepper" pattern called "laser speckle."

The only apparatus needed for these demonstrations is a small laser, a beam expander, and a stable screen. A low-power He–Ne laser suffices; those removed from copy machines and sold on the surplus market are more than adequate. A reasonable degree of coherence is required because the light must interfere with itself over small path length differences. Some laser pointers should work, although the author has not tried them. The beam expander is easily implemented with a microscope objective lens in the range 10–50X. Try what you have on hand or can borrow from someone's lab.

Laser speckle:
- *was first viewed as a nuisance,*
- *proved to be a useful discovery,*
- *carries much information about the illuminated object,*
- *is the basis of a family of measurement techniques, including:*
  - *a. digital and electronic speckle pattern interferometry,*
  - *b. speckle photography,*
  - *c. speckle shearography.*

The lens can be attached to the front end of the laser with duct tape if you have no optical rails on hand. If tape is used, a bit of fiddling will get the lens somewhat concentric with the laser beam. The goal is to produce on a screen a nicely illuminated patch that is large enough for you and the audience to see comfortably. The screen can be a painted wall, a sheet of posterboard, drywall, or even a projection screen. The most important requirement is that both laser and screen be well fixed so that they do not move or vibrate. Support the laser on a stable platform—a stack of books on a desk works well—and illuminate the screen. If large black dots, rings, or fringe patterns appear in the patch, clean the lens or get another one. If the laser is of low power, darken the room for ease of viewing.

The demonstration experiments require only:
- *a minimal laser,*
- *a beam-expanding lens such as a microscope objective,*
- *a screen for viewing the expanded laser beam,*
- *stability of the system.*

BASIC SPECKLE OBSERVATION

Sit very still and just stare at the illuminated patch on the screen. You should see that it is filled with tiny bright and dark specks. The bright ones are sometimes called sparkles, but the whole thing is called a speckle pattern. If you do not see the speckle, then check the stability of the laser and screen and also stop talking or chewing gum. If you do not possess a definite master eye, then you might try closing one of them.

Sit quietly and stare at the illuminated patch on the screen to see the laser speckle.

SPECKLE MOTION WITH LATERAL MOVEMENT

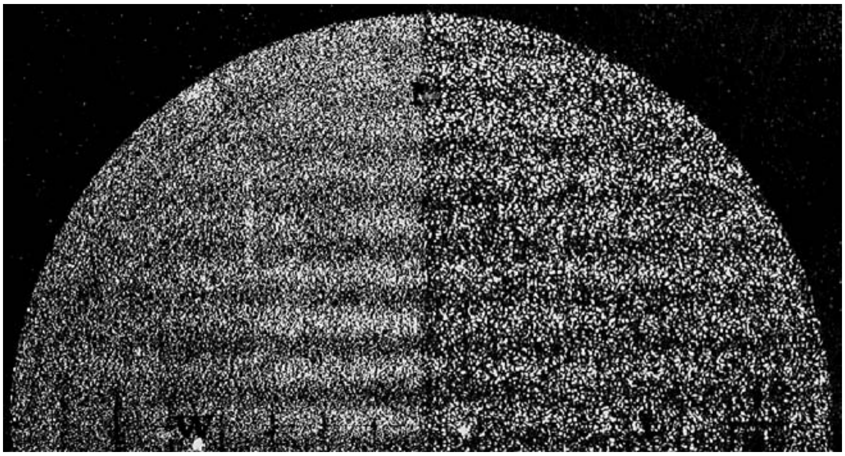
Now, move your head slightly sideways. You will see that the speckles move sideways also. The direction of the motion depends somewhat on the setup and the focus of your eyes. A conclusion is that the speckle moves with the viewer. An obvious suggestion is that if the eye is held stationary and the specimen moves, then the speckles will move with it.

While looking at the speckle pattern, move your head sideways. The speckles will seem to move sideways also. Likewise, if the screen is moved, the speckles will move with it.

Such is indeed the case, and this phenomenon forms the basis of a class of methods called "speckle photography." Lateral motion of individual speckles is related to local specimen motion. That is, the speckles act as a very fine array of surface markers. If the motions of the markers can be recorded and ascertained, then the lateral specimen displacement field can be mapped.

An application example appears below in a photograph that reproduces results from whole-field optical Fourier processing (Part 15 of this series) of double-exposure speckle photographs to obtain displacements in a disk subjected to in-plane rotation. The photo is a composite, with the left portion showing fringes related to displacements obtained with a small imaging aperture. The other half shows displacement fringes that are recorded with a large aperture. Fringe contrast is not high because the capability of the method with a low-power laser was being stretched. Notice, however, the difference in coarseness of the speckles between the two halves of the composite, although much of this difference is lost in the publication reduction. The effect is demonstrated in the next section and may also be seen in the photos at the head of this article. The point is that aperture effects enter at all stages of an experiment (photos by G. Cloud, ca. 1971).

Since the speckles move sideways with the specimen, they can serve as a fine array of surface markers and, so, can be used to measure displacement by the method called "speckle photography."



APERTURE EFFECT

The lead photograph of this article and the composite picture shown above both suggest that camera aperture affects the apparent size of the speckles and limits resolution in an image. The objective of the next experiment is to demonstrate this relationship with a convenient imaging system, in this case your eye. There are three ways of accomplishing this, with the choice depending on how much control you have over your eyes and eyelids.

(1) While staring at the illuminated patch, bring your eyelids close together so that you are looking through a narrow slit. Again, it might be helpful to fully close one eye. People with experience in shooting or archery find this approach easy to manage as do we older folks who squint to increase depth of focus.

(2) Form a small aperture by curling your index finger against the base of your thumb or by laying the index and middle fingers of one hand crosswise over the same combination of the other hand so as to form a small square aperture. Look at the illuminated patch through the aperture while holding it as steady as you can.

(3) Punch several small holes in a card, such as by pushing a pencil through it, so as to form small apertures of different sizes. Look at the illuminated patch on the screen through the various apertures.

To observe the effect of aperture size on speckle size, look at the speckle pattern through an aperture formed by:
- *bringing your eyelids close together,*
- *curling your finger against your thumb,*
- *crossing the index and middle fingers of one hand over the same fingers of the other hand,*
- *punching small holes in a card.*

You will notice that the speckles in the pattern appear on average to become larger as the aperture is made smaller, although the contrast between light and dark speckles might seem diminished. If you look through a very tiny aperture, then you might see only a few large black blobs that occupy the space formerly occupied by thousands.

You will find that the smaller the aperture, the larger the speckles, meaning we can control speckle size in an experiment.

What actually happens is that a small aperture makes it impossible for the finest speckles to be created so that they can break up the large ones.

This apparent inverse relationship between speckle size and aperture is simple to understand and will be explained presently using what we know of oblique interference (Part 4 of this series). For now, we are content to observe that the phenomenon is useful because it allows control of speckle size to match pixel size in digital imaging systems.

Some people are able to see the effect of longitudinal head movement on speckle brightness, a difficult feat that can be accomplished with practice.

BRIGHTNESS CHANGE WITH LONGITUDINAL MOVEMENT

Most people find this demonstration difficult to execute, and others can do it only on good days. Some cannot do it at all, and some maybe only claim they can. Fine motor control of head position and eye stability is required. It is worth a few attempts with the aim of getting it right.

To show that changing distance between eye and specimen changes speckle brightness:
- *stabilize the head as much as possible,*
- *look through a small aperture to make the speckle large,*
- *focus on only one large speckle,*
- *move the head slightly toward or away from the screen.*

Sit and stare at the speckle pattern as outlined above. If you lean your head against a rest to stabilize it, so much the better. Use a small aperture held right against your face to make the speckles as large and stationary as you can. Now, focus on only one large dark speckle blob and gently move your head a very small amount away from the screen. With luck and practice, you will notice that the brightness of that speckle changes from dark to light and probably back to light again. It might appear to flicker, and its apparent size and shape might also appear to change. Experiment with different degrees of head motion.

That speckle brightness changes with longitudinal motion of an object forms the basis of several measurement techniques, including:
- *electronic speckle pattern interferometry (ESPI),*
- *digital speckle pattern interferometry (DSPI),*
- *electronic and digital speckle shearography (DSS),*
- *phase shifting methods that enhance these techniques.*

That speckle brightness depends on distance from object (screen) to viewing system is the basis of a family of speckle measurement techniques that includes digital and electronic speckle pattern interferometry, laser shearography, and related phase shifting methods.

One merely records the beginning and final brightnesses of each and every speckle in the field and subtracts final intensity values from initial values to determine the displacement map for the object. This tedious chore is easily implemented with a computer.

WHAT IS NEXT

The demonstrations outlined above illustrate all the aspects of coherent light speckle that are important in measurement technologies. The next few articles in this series will deal with the physics of speckle formation, types of speckle patterns, quantitative determination of speckle size, and prediction of speckle brightness. ■

Subsequent articles will discuss:
- *the types of speckle,*
- *the physics of speckle formation,*
- *speckle size,*
- *speckle brightness prediction.*