Part 8
Speckle Interferometry

- Basic Phenomena
- Applications
  - Out-of-Plane Surface Vibration
  - In-Plane Displacement
  - In-Plane Vibration
  - Stellar Speckle Interferometry
- Electronic Speckle Pattern Interferometry

Speckle Pattern Produced by Illuminating a Rough Surface with Laser Radiation
Physical Origin of Speckle for an Imaging System

Surface

Amplitude Spread Functions

One Wavelength

Image

Experimental Setup for Measuring Out-of-Plane Surface Vibration

LASER

SMOOTH STATIONARY SURFACE

VIBRATING DIFFUSE SURFACE

IMAGE OF VIBRATING SURFACE

\[ \alpha = \frac{\text{reference beam}}{\text{object beam}} \]

Surface Height \( z = z_0 + D \sin \alpha \)

Speckle Contrast is \( C = \left[ 1 + 2 \alpha f_0^2 \frac{4 \pi D}{\lambda} \right]^{1/2} \)

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Speckle Contrast Reduction Due to Out-of-Plane Vibration

Plate Stationary  Plate Vibrating

In-Plane Displacement

Object illuminated with laser light  Photographic Plate

Laser Beam

\[ \Psi(x) = A(x) + A(x - x_0) \]

Observing Young’s Fringes

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Young’s Fringes Resulting from In-Plane Displacement

In-Plane Vibration

- Speckle drawn into lines as surface vibrates
- Diffraction pattern gives vibration information

Linear Motion

Figure-of-Eight Motion
Stellar Speckle Interferometry

- Atmosphere limits resolution to approximately 1 arc second (10 cm aperture)
- Image of star shows speckles if
  - Exposure time less than period of atmospheric turbulence (1 msec)
  - Spectral bandwidth small (10 nm) so coherence length long
- Speckle size determined by wavelength and telescope diameter (Diffraction-limited resolution)
- Speckles information limited by resolution limit of telescope, not atmospheric turbulence

Short Exposure, Narrow Bandwidth, Photograph of Unresolved Star
Stellar Speckle Interferometry Procedure

- Take large number, short exposure, photos of object, where each photo is taken for different realization of atmosphere
- Take Fourier transform of each photo (obtain diffraction pattern)
- Add square modulus of diffraction pattern of all photos
- Take Fourier transform of ensemble average of diffraction patterns
- Result is autocorrelation of diffraction-limited image of object

Stellar Speckle Interferometry Results

<table>
<thead>
<tr>
<th>object</th>
<th>Photo</th>
<th>Fourier Transform</th>
<th>Sum of 20 Fourier Transforms</th>
<th>Fourier Transform of Sum</th>
</tr>
</thead>
</table>
Electronic Speckle Pattern Interferometry (ESPI)

- Use TV system to record speckle instead of film
- Gives real-time measurements
- Minimum speckle size limited by camera resolution
- Can perform computer analysis of speckle data

Block Diagram of Electronic Sequence of ESPI System
Examples of Time-Averaged Vibration Mode Viewing with ESPI