DUAL BEAM OPTICAL INTERFEROMETER

Inventor: Roman C. Gutierrez, La Crescenta, CA (US)
Assignee: California Institute of Technology, Pasadena, CA (US)

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ABSTRACT
A dual beam interferometer device is disclosed that enables moving an optics module in a direction, which changes the path lengths of two beams of light. The two beams reflect off a surface of an object and generate different speckle patterns detected by an element, such as a camera. The camera detects a characteristic of the surface.

23 Claims, 2 Drawing Sheets
DUAL BEAM OPTICAL INTERFEROMETER
CROSS-REFERENCE TO RELATED APPLICATIONS
This application claims benefit of U.S. Provisional application No. 60/141,586, filed Jun. 29, 1999.

STATEMENT AS TO FEDERALLY-SPONSORED RESEARCH
The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (U.S.C. 202) in which the contractor has elected to retain title.

BACKGROUND
Common interferometer designs use a beam to measure characteristics of a surface that is being imaged.

U.S. Pat. No. 5,671,050 suggested using two different beams to measure information from the object. The two beams are reflected at different angles to the object, and the distance to the object surface can be scanned.

In addition to the patent described above, U.S. Pat. Nos. 3,958,884, 5,502,562, and 5,011,280 teach interferometry techniques.

SUMMARY
The present application teaches a dual beam interferometer with a number of additional advantages. One advantage is reference and signal beams may automatically be of the same magnitude independent of the reflectivity of the object. In one embodiment, two parallel beams are reflected from an object, and the spacing between the beams may be scanned. Imaging may be done with very small numerical apertures which allows long working distance and smaller optics.

BRIEF DESCRIPTION OF THE DRAWINGS
These and other aspects will now be described in detail with reference to accompanying drawings wherein:
FIG. 1 shows a block diagram of the present system;
FIG. 2 shows a more detailed optical diagram of the present system; and
FIGS. 3A and 3B show how an increase in resolution can be obtained by the present system.

DETAILED DESCRIPTION
One problem in interferometry is caused by the diffraction limit of light. The diffraction limit often forms a limit on sizes of features that can be imaged. The present system allows beating this diffraction limit.

The present application teaches a system that can be analogized to a speckle interferometer using a variable speckle. The distance between different components in the interferometer can be varied in order to vary the speckle. By changing the distance between the light beams, different “speckle” patterns can be produced.

These patterns include information about the surface, at the resolution of the minimum distance between the two beams.

The shape of optics may vary with temperature. The present invention overlaps the signal and reference beam paths. This may, at least partially, compensate for the shape change with temperature. In, addition, an interferometer design which has the biggest overlap between signal and reference beams may be desirable to measure variations in the shape of optics with temperature.

Since the reference and signal beams travel in nearly the same air space, the distance to the object can be arbitrary. In this way, effects of index variations in the air are reduced. High frequency localized index variations, such as turbulence, may still cause problems.

The basic system is shown in the block diagram of FIG. 1. A light source 100 produces spatially incoherent light. The light can be produced, for example, by a light bulb 102, or alternatively a light emitting diode, or a laser with a moving diffuser. The light is collimated by collimated light beam 110, which is input into the beam splitting and combining optics module 118. This optics module 110 separates the light into two beams which are separated by some distance xy. (x,y) are the coordinates for the separation between the two beams in the plane orthogonal to beam propagation. The vector xy 112 is shown as a control signal which changes the input light 106. Objective optics 118 may or may not be used depending on the desired numerical aperture.

Two beams of light are coupled to the surface 120 to be measured, and reflected back from that surface 120 through to imaging optics 130 to a camera 140. The camera 140 receives information that indicates some characteristic of the surface 120. The measurement can include detection of interference fringes between the two beams. The two beams may travel substantially the same distance and impinge on that second location onto the surface

Separation of the beams introduces a delta function spatial coherence into the object illumination e.g., white light (spatially incoherent), i.e., This forms a type of speckle interference pattern on the camera 140. This pattern can then be measured as the location or distance of the separation between the two beams changes. As the separation between beams changes, the location of the delta function in the spatial coherence and the amount of the spatial coherence also changes. A spatial autocorrelation function then can be used to accurately determine the details of the object's surface. Because of this, phase objects can be accurately imaged. Another way to think of the embodiment is as a scanning Speckle interferometer.

The optical details of the interferometer is shown in FIG. 2 with the two beams being shown using different kinds of lines. The collimated light source 100 produces output 106 which may be polarized by polarizer 112. That output light is then coupled to a first beam splitter 120 which may be non-polarizing. The light from beam splitter 120 is output into two separate light beam paths: a first outgoing light beam path 120 shown as dot and dashed lines, and the second outgoing light beam path 220 shown as dot and dashed lines.

The first path 210 comes out of the non-polarizing beam splitter 220, and couples to a right angle prism 230. The right angle prism 230 reflects the beam to a second beam splitter 240. The second beam splitter 240 is polarizing. A quarter wave plate 250 is placed at the output of the second beam splitter 240, to rotate the polarization. The second beam 220 is coupled to a right angle reflector 260 which reflects the beam 220 towards the beam splitter 240. The beam is coupled into beam splitter 240 at a second location, and impinges on that second location onto the surface 120. The objective lens 118 may or may not be used depending on the required numerical aperture which determines the diffraction limited imaging resolution. The system may further comprise a polarizer 290 and imaging optics 292.

The structure is arranged such that a light beam couples onto the surface 120, and back out of the surface 120. Each
of the light beams travel along the same path in opposite
directions. In this way, substantially the same path length
is traveled in both directions. Both beams also pass through all
of the optics, thereby equalizing any influence from the
optics.

Fringes (e.g. white light) are formed on the camera 140 by
the interference of the light beams.

A movable module is shown by portion 280. This portion
280 can be moved, to allow the two beam splitters 200, 240
and the right angle prism 230 to be moved as a group. This
changes the spacing between the two beams without chang-
ing the pathlength difference of the beams. The spacing can
be changed in the plane of the paper, that is the x direc-
tion, or can be changed orthogonal to the plane of the paper, the
y direction. A variable beam height adjustment may be added to FIG. 2 to change the spacing in the y direction. The
two light paths however, reach the object 80. This can be done by imaging with a resolution that
is variable. The system describes use of incoherent light, it should
be understood that spatially coherent light could also be
used to obtain a phase front correlator.

Although only a few embodiments have been described in
the system of FIG. 1 may accurately image extremely
rough surfaces such as paper. One embodiment allows imaging of the speckle pattern which is visible on rough
surfaces. This can be done by imaging with a resolution that
may be better than the diffraction limit. FIGS. 3A and 3B show
how this is possible. In FIG. 3, the left side is the phase
across the phase object and the right side shows the intensity
of the camera pixel as a function of the beam spacing. Two
cases are shown: (a) two features within the pixel, (b) one
feature within the pixel. FIG. 3A shows the amplitude as a
function of beam spacing on a pixel of the camera 140. Two
phase features are being imaged. As the spacing is changed
from 0 to the pixel size, the variation in pixel intensity indicates the presence of two steps (left side) that have a
width a and a spacing d.

FIG. 3B shows the same measurement for a single phase
feature. The variation in pixel intensity (right side) shows a
single step with width 2a. With a conventional imaging
system, these two phase systems could not be distinguished.
Although only a few embodiments have been described in
detail above, other modifications are possible.

What is claimed is:

1. A dual beam interferometer operable to detect a char-
acteristic of a surface, comprising:

an interferometer arrangement, forming a first beam and
a second beam, said first beam traversing a first optical
path, being reflected from the surface and traversing a
second optical path, and said second beam traversing
said second optical path, being reflected from the
surface and traversing said first optical path, wherein
the first and second beams travel total optical paths that
are substantially similar in length; and
a detection element which detects an interferometric
relationship between said beams, wherein the interfero-
metric relationship provides a characteristic of the
surface.

2. The dual beam interferometer of claim 1, comprising:
a first beam splitter configured to split an initial beam of
light into the first and second beams; and
a first reflector configured to reflect the first beam along
the first optical path and to reflect the second beam along
the first optical path; and
a second beam splitter configured to direct the first beam
along the first optical path and to reflect the second
beam along the second optical path; and
a second reflector configured to reflect the first beam
along the second optical path and to reflect the second
beam along the second optical path.

3. The dual beam interferometer of claim 2, further
comprising a variable beam height adjustment module oper-
able to move the beam splitters and at least one reflector.

4. The dual beam interferometer of claim 2, wherein
the initial beam of light is collimated.

5. The dual beam interferometer of claim 2, further
comprising a polarizer between an initial light source and
the first beam splitter.

6. The dual beam interferometer of claim 2, wherein
the first beam splitter is a non-polarizing beam splitter.

7. The dual beam interferometer of claim 2, wherein
the first reflector is a right angle prism.

8. The dual beam interferometer of claim 2, wherein
the second beam splitter is polarizing.

9. The dual beam interferometer of claim 2, further
comprising a quarter wave plate between the second beam
splitter and the surface, the quarter wave plate operable to
rotate the first and second beams.

10. The dual beam interferometer of claim 2, wherein
the second reflector comprises a right angle reflector.

11. The dual beam interferometer of claim 2, further
comprising a polarizer and imaging optics between the first
beam splitter and the detection element.

12. The dual beam interferometer of claim 2, further
comprising a moving element operable to move the beam
splitters and at least one reflector in a direction that changes
a separation distance between the first and second beams in
a plane of the surface.

13. The dual beam interferometer of claim 12, wherein
varying the distance between the first and second beams
produce various speckle interference patterns that are detect-
able by the detection element.

14. The dual beam interferometer of claim 2, further
comprising objective optics between the surface and second
beam splitter.

15. The dual beam interferometer of claim 1, wherein
the detection element comprises a camera.

16. The dual beam interferometer of claim 1, wherein
the first and second beams originate from a spatially incoherent
light source.

17. The dual beam interferometer of claim 1, wherein
the first and second beams travel through air between optical
elements of the interferometer.

18. The dual beam interferometer of claim 1, wherein
the detection element measures interference fringes produced
by the first and second beams.

19. The dual beam interferometer of claim 1, wherein
the detection element measures speckle interference patterns
produced by the first and second beams.

20. The dual beam interferometer of claim 1, wherein
the detection element measures interference fringes produced
by the first and second beams.

21. The dual beam interferometer of claim 1, wherein
the interferometer provides imaging with a resolution better
than the diffraction limit of light.

22. A method of detecting a characteristic of a surface
with two beams of light, the method comprising:
forming a first beam and a second beam;
directing the first beam along a first optical path to reflect
from the surface and traverse a second optical path;
directing the second beam along the second optical path
to reflect from the surface and traverse the first optical
path, wherein the first and second beams travel total optical paths that are substantially similar in length; and detecting an interferometric relationship between said beams, wherein the interferometric relationship provides a characteristic of the surface.

23. The method of claim 22, further comprising performing a spatial autocorrelation function to determine a characteristic of the surface.

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