Real time imaging through fog
by a self-referencing interferometric technique

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The ability to image through turbulent and scattering media is important in transportation, remote sensing, medicine, astronomy and many other fields.

The degradation of the quality of images transmitted through optical media can be due to scattering or phase distortion.

Phase distortion → Record and correct the aberrated wavefront

Techniques: adaptive optics, phase conjugation (double and single pass).

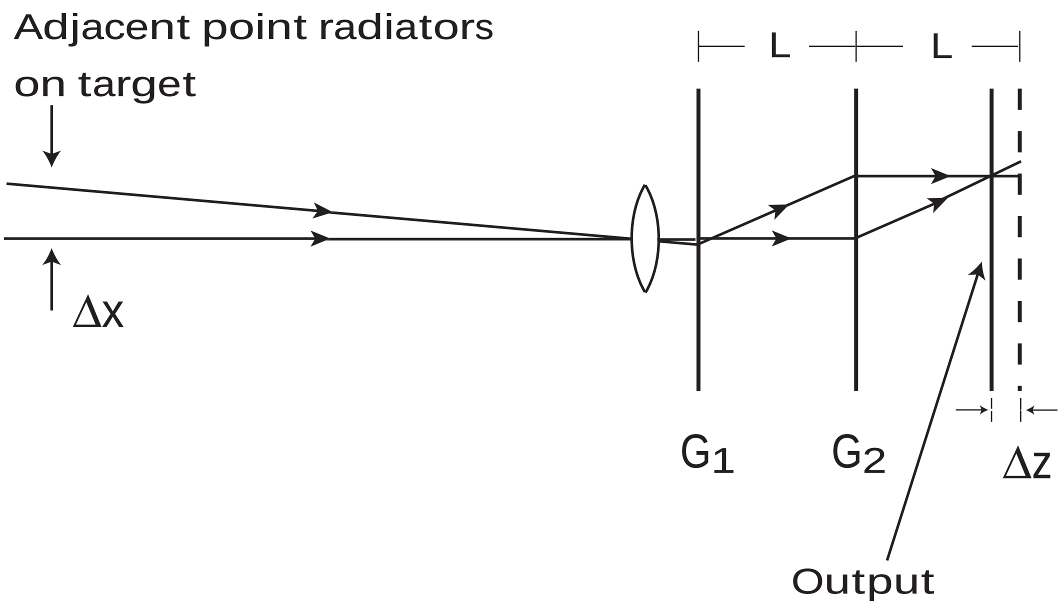
Scattering → Recording and correcting the aberrated wavefront is very difficult. It is possible to reject the scattered light.

Time gates (electronics, nonlinear optics)
Coherence gates: temporal coherence (OCT), spatial coherence (holography).

Self-referencing holographic techniques are advantageous in imaging through the atmosphere and its disturbances, when it is extremely difficult to provide a reference beam.

A self-referencing interferometric technique

Lateral shearing has been implemented by Tai et al.[#] with a grating interferometer and photographic plates.

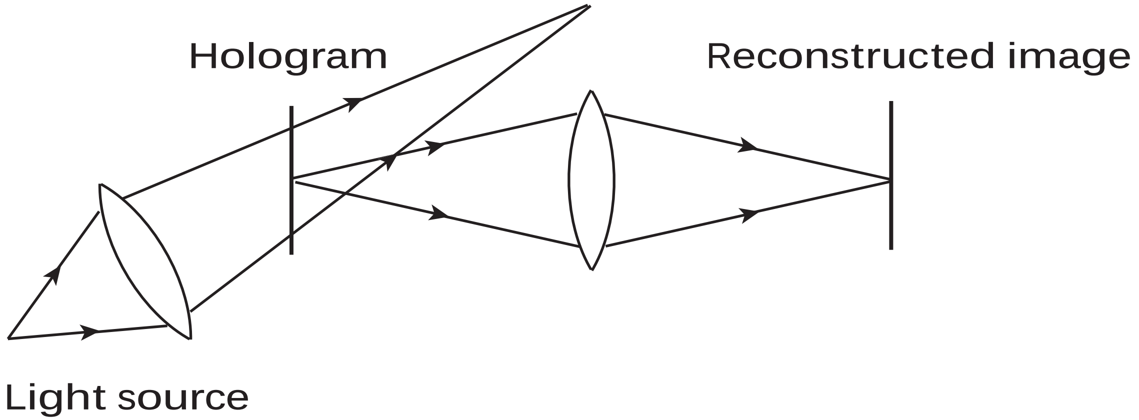


Scattered light is not spatially coherent and forms an uniform background; only unscattered light forms interference fringes.
The hologram is played back after development.

Tai A. M. and al.; Imaging through scattering media by interferometric techniques; Applied Optics 20, 2484 (1981)

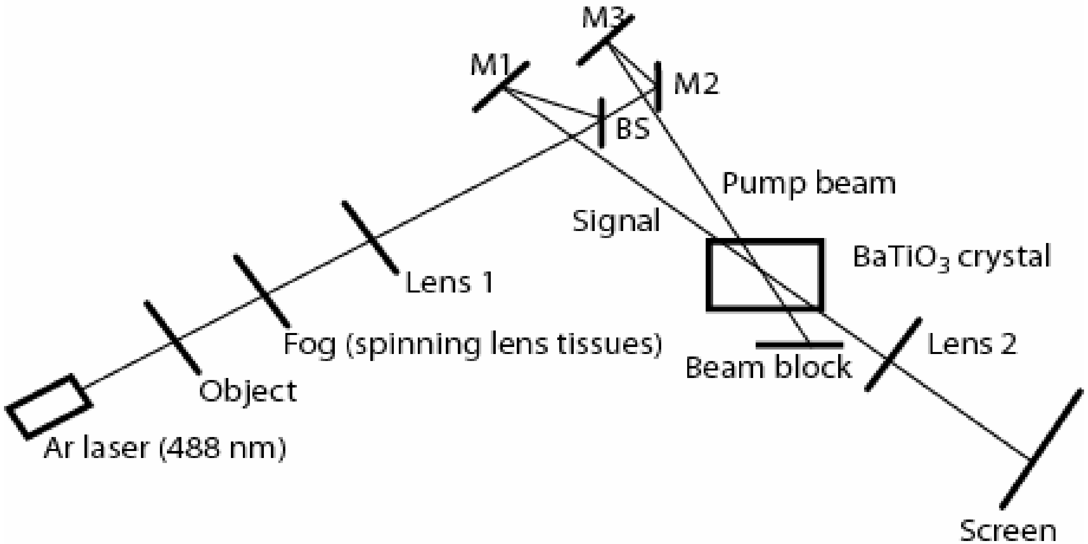
Playback

The recorded hologram is a transparency of the object modulated by a carrier.



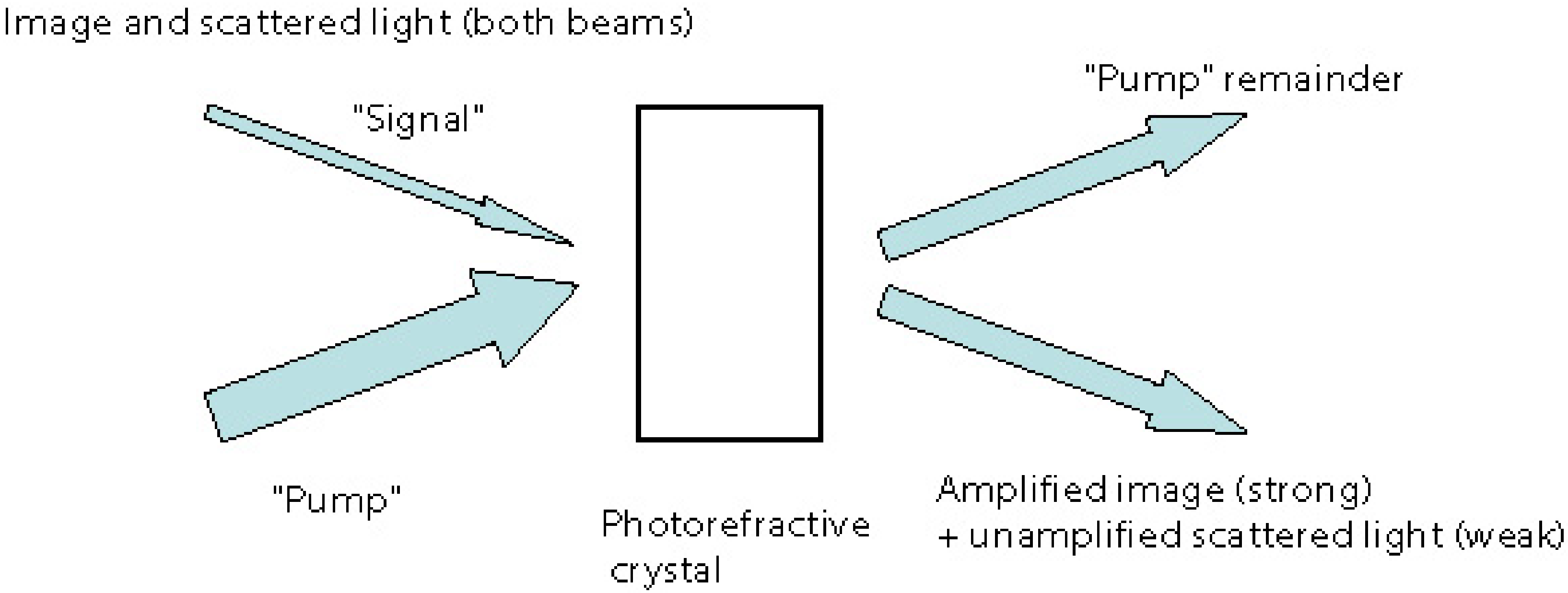
The image can be separated from the background by a coherent optical processor.

Real-time implementation in a photorefractive crystal



The beam that carries the image is split into two unequal parts that are combined via two-wave mixing in a $BaTiO_3$ crystal.
The fog is simulated with spinning lens tissues.

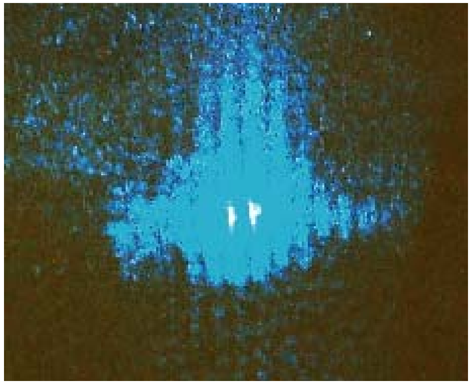
The two interacting beams have different power (ratio ~ 1:500). Photorefractive two-wave mixing causes energy to flow from the strong to the weak beam.



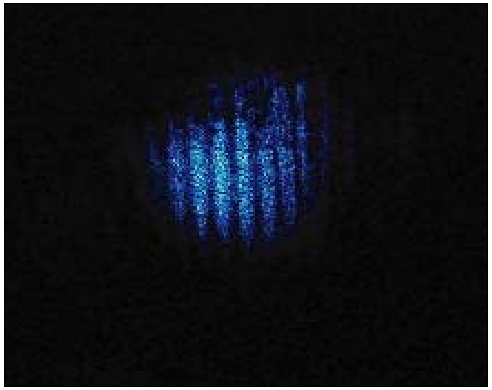
Only the image is amplified. After the interaction a strong and enhanced image is superimposed on the unamplified scattered portion of the light.

Experimental results (image of a grating)

Raw image
(through fog)



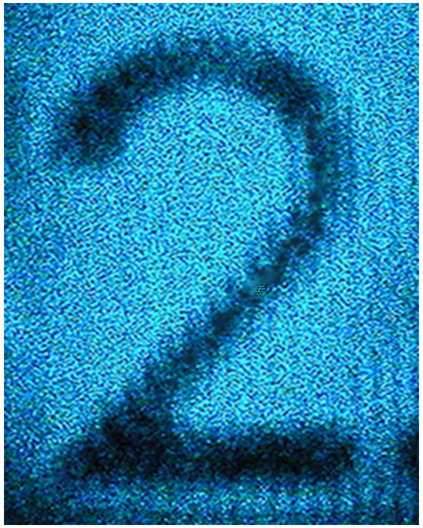
Processed image



"Real" time; the processed image appears in ~ 15 seconds; the speed of the effect increases with light intensity and depends on the type of photorefractive crystal.

Experimental results

Original image
(no fog)

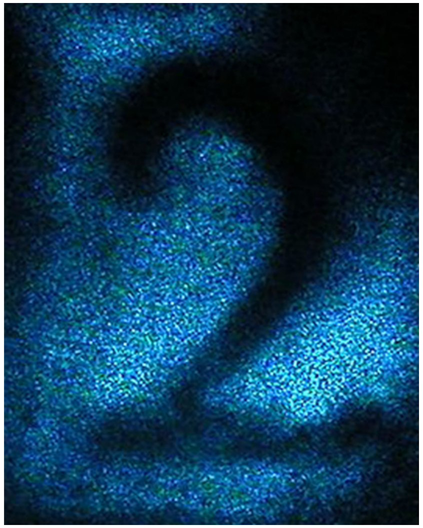


Nominal 100%
contrast

Raw image
(through fog)

Average contrast
9%

Processed image



Average contrast
33%

A few details

- Single frequency illumination: we do not need to use a grating interferometer.

- Lateral shearing is realized automatically because of the long interaction region.

- It is necessary to combine two beams of unequal power; this limits the visibility of the interference fringes that the form and the efficiency of two-wave mixing

- Contrast improvement can be calculated by a standard photorefractive beam coupling calculation

Photorefractive two-beam coupling with background

The refractive index grating couples the two beams:

$$\delta n = \frac{n_1}{2} \exp(i\phi) \frac{A_1^* A_2}{I_0} \exp(-i\,\mathbf{K}\cdot\mathbf{r}) + c.c.$$

The total intensity includes the background: $I_0 = I_1 + I_2 + I_{b1} + I_{b2}$

$$\delta n = \overline{\delta n} \frac{I_1 + I_2}{I_1 + I_2 + I_{b1} + I_{b2}} = \overline{\delta n} \frac{I_1(0)}{I_1(0) + I_{b1}} = \overline{\delta n} \times contrast(0)$$

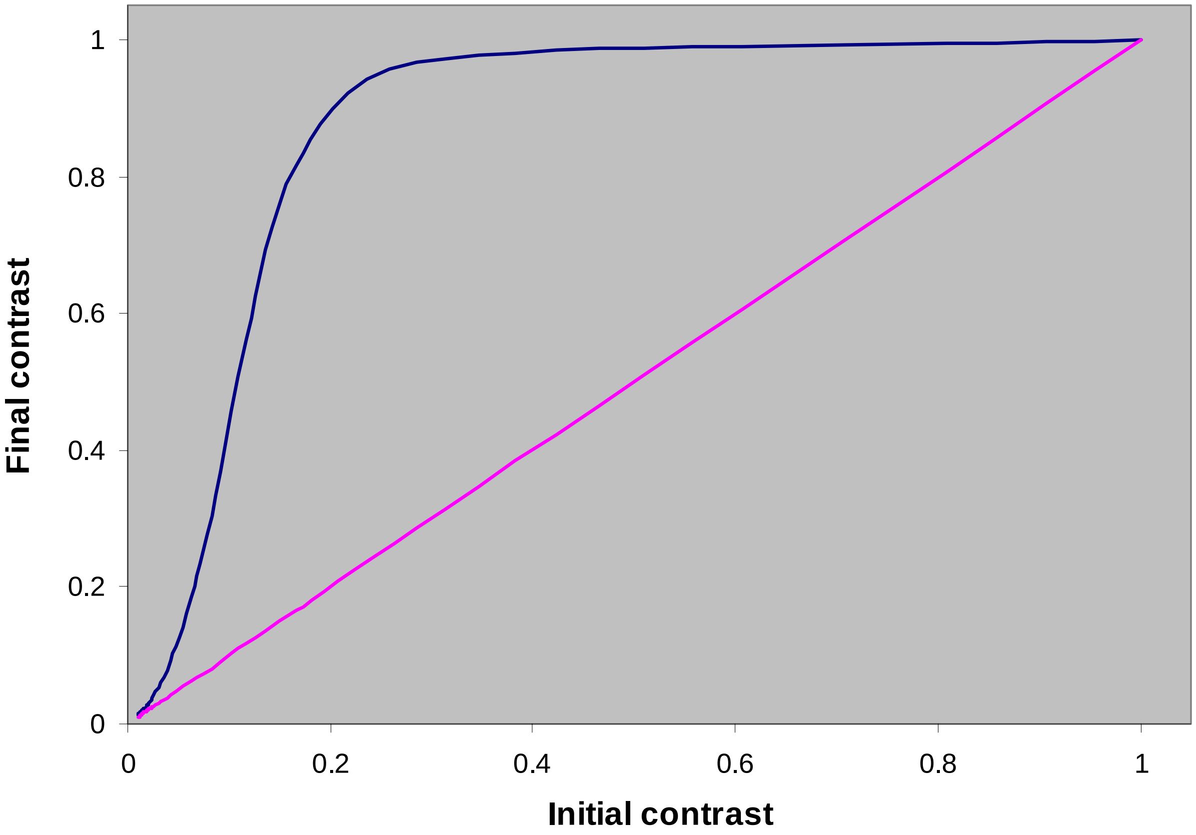
The refractive index grating is rescaled with respect to $\overline{\delta n}$, grating without background.

The photorefractive parameter that controls the gain, γL, must be rescaled: $\bar{\gamma} L = \gamma L \times contrast(0)$

Contrast improvement

Contrast after two-wave mixing as a function of initial contrast

$$contrast\ (0) = I_s(0)/(I_s(0)+I_b)\ ; \quad contrast\ (L) = I_s(L)/(I_s(L)+I_b)$$



signal : pump ratio 1:100

$\gamma L = 20$

Photorefractive processing

"Dumb" processing (contrast out = contrast in)

Future work

Contrast can be further enhanced by writing with one colour and reading with another; in this way the scattered light can be filtered away with a colour filter.

This can be achieved more easily using thin gratings rather than thick gratings (we eliminate the constraint of the Bragg angle).

Photorefractive polymers and quantum wells or dye-doped liquid crystals are materials in which it is possible to write and erase thin gratings.

Conclusions

Implemented a self-referencing interferometric technique to image through fog using a photorefractive crystal.

Analyzed the limitations of the technique using thick photorefractive gratings.

Proposed future work using thin gratings.