Focusing light through a scattering medium under the influences of laser instability

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Abstract: A set-up for focusing light through opaque media has been realized. A spatial light modulator shapes the optical wavefront by means of a CCD camera together with a feedback algorithm in LabVIEW. We realize an enhancement factor of five for focusing light through a piece of white paper.

A spatial light modulator (SLM) allows one to shape the phase front of a light beam. Together with a feedback mechanism, realized by a CCD camera and an algorithm in LabVIEW, one can focus light by manipulating the phase front such, that it passes through opaque media [1], like e.g., printing paper.

The most important apparatus used for focusing light through an opaque medium is the SLM. The SLM used in this work is a *Pluto phase only spatial light modulator* from Holoeye. The SLM can crudely be interpreted as a deformable mirror, reshaping the spatial phase profile of an incident laserbeam. The "deformation" of the mirror is performed via a tuning of the birefringence of the individual pixels of a liquid crystal display (LCD), hence providing a controlled spatial phase delay to the incident light. The SLM controls a liquid crystal-on-silicon (LCOS) active matrix liquid crystal display (LCD) with a resolution of 1920 x 1080 pixels. The LCOS display operates like an 8 –bit monochrome monitor. Each individual pixel allows to introduce a variable phase shift ranging from 0 to 2-π in 255 steps. The communication between the computer and the SLM is performed via digital visual interface (DVI) operating at a frame rate of 60 Hz. The phase shift of the SLM of the LCOS is generated by applying different voltages to the pixels of the LCD. These calibrated voltages to create a linear phase response from 0 to 2-π are read from a look up table (LUT). The LUT helps to convert a grey value to the appropriate voltage needed to electrically control the birefringence (ECB) of the reflective LCD. This is called ECB mode operation. The capacity driven character of the LCD driver requires refreshing of the LCOS pixels a number of times per frame with these voltages. We bin (i.e., group) pixels in the SLM to create mega-pixels. The phase front of the light impinging onto the SLM is changed according to the amount of birefringence induced in the mega pixels.

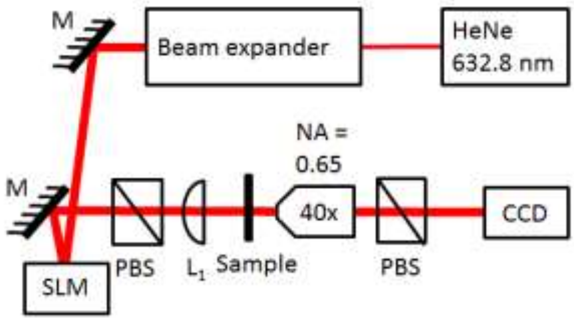

Fig. 1 The experimental configuration used to measure the transmission matrix (PC and PC connection to SLM and CCD is not shown). A HeNe laser (633 nm) was used along with other optical components; PBS, polarizer beam splitter cube used as polarizer; M, gold or aluminum coated mirror; L1, plano-convex lens with a focal length of 50 mm.

The experimental set-up is depicted in Fig. 1. The computer and the computer connection to the SLM and CCD are not shown. The algorithm used to focus light through a piece of paper was the continuous sequential algorithm [2]. Here the enhancement of the target intensity, the region of interest (ROI) on the CCD (marked by a green square in Fig. 2), as a function of the phase change induced by a mega-pixel of the SLM is monitored. Each individual SLM mega-pixel is ramped from 0 to 2-π and the maximum enhancement found during the ramping of the phase of the SLM mega-pixel is recorded. This routine is repeated for each SLM mega-pixel until all mega-pixels have been accounted for. This ends in the completion of one iteration. We iterate the program until the amount of enhancement at the focus target has reached its maximum. The results shown in Fig. 2 show an enhancement factor of 5, which is clearly seen from the bright focal spot in the center of the speckle pattern (in the left graph). Here 100 megapixels on the SLM are used to achieve this optimization (the resulting phase profile on SLM is seen in the most right graph of Fig. 2). The ROI is 25 normal CCD pixels large and contains two bright speckles.

However, the measurement becomes instable after approximately two iterations (i.e., cycling through all the SLM mega-pixels twice). An intensity fluctuation at the target focus as large as 20 grey scale values has been measured opposed to the allowed intensity fluctuation of all noise factors combined together of 5 grey scale level tops (the CCD´s grey level value ranges from 0 to 255)[3]. This is limiting the set-up to increase the enhancement further. Upon further investigation we have found that this instability can be caused by several factors [3], namely; CCD read out noise, CCD shot noise and laser excess noise. For now we have found that the laser excess noise is the main challenge. We are currently working with a normal (i.e., not stabilized) HeNe laser. We expect that when changing to a stabilized HeNe laser, we can increase the stability of the set-up (and thereby the measurement) drastically and further increase the intensity at the target focus.

Another point is that the two speckles in the ROI are saturating the CCD. This plateaus the results. By allowing the CCD camera to change its exposure time to shorter values during the measurements, we can increase the camera´s dynamic range. Other techniques for increasing the camera´s dynamic range are being investigated.

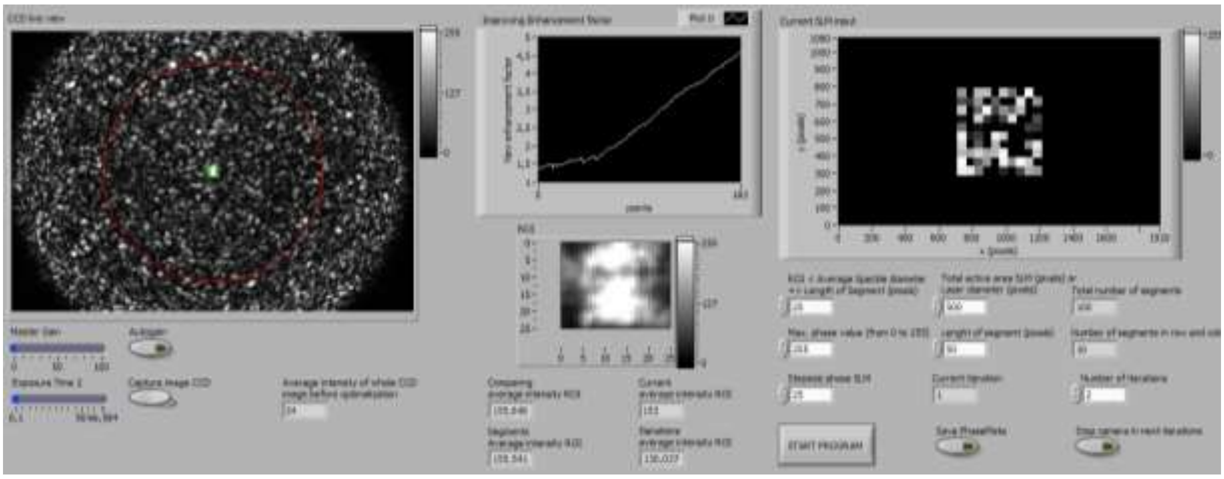

Fig. 2 Screen shot of the LabVIEW front panel (user interface). The left graph shows the speckle pattern impinging the CCD, with in the center the bright focus, with an enhancement factor of five for a normal piece of white paper. The middle two graphs show the enhancement factor as it is climbing when the algorithm looks for the best phase front. Also, the focus is shown and consists of two bright speckles. The phase front modulation induced by the SLM is shown on the most right graph.

In conclusion, we have realized a set-up that focusses light through a scattering media. We can improve the enhancement further by utilizing a stabilized HeNe laser and dynamic camera settings. We also have to improve the SLM and CCD settings such to speed up the algorithm, to allow for focusing through thicker samples.

References

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