Simulating a deformable mirror with a digital micro-mirror device

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Abstract

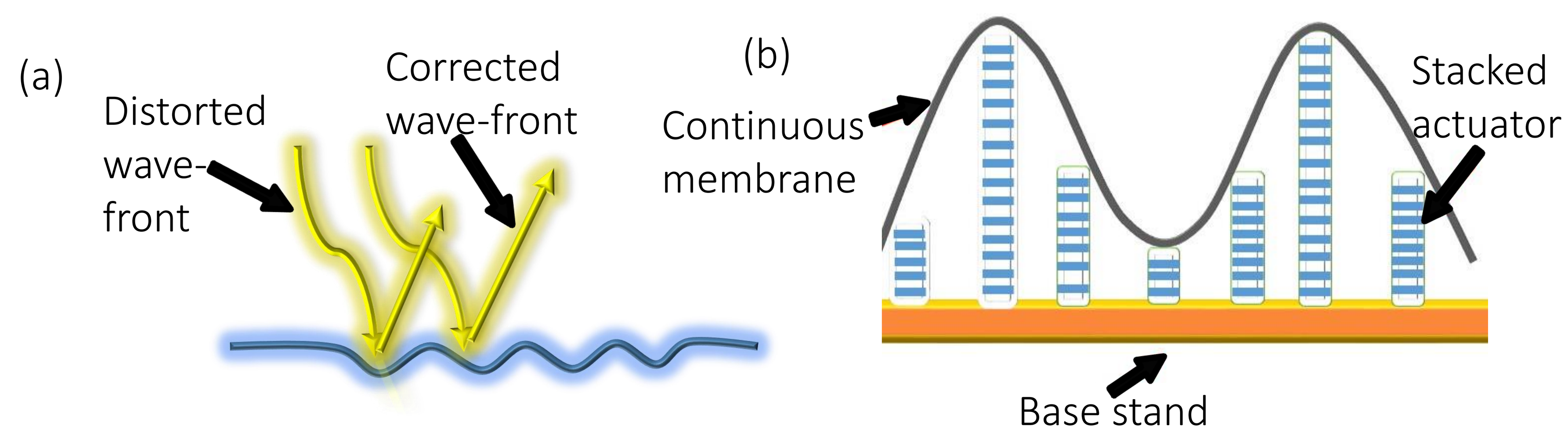
The generation of unique spatial profiles for high-power applications is becoming more topical, ranging from high-power, high bandwidth optical communication to spatial profile control in additive manufacturing and other laser-material interactions. We make use of a Digital Micro-Mirror Device (DMD) in order to execute real-time, dynamic beam-shaping, which is capable of handling optical powers on the order of Watts. Here we outline and discuss the working principles of the DMD and compare it to other beam-shaping technologies. Ultimately, we plan to generate various spatial profiles with the use of a deformable mirror (capable of handling powers on the order of kilowatts). Here, we mimic the mechanical design of a bimorph deformable mirror on a DMD (as a proof of concept).

Introduction

High-power laser beams have great impact in many applications like high-bandwidth communication and material processing. This is achieved by controlling the beam's spatial intensity profile.

Deformable mirrors

Deformable Mirrors (DMs) are mirrors where their reflective surface can be deformed in a controlled way to correct the distorted incoming wave-fronts. There are various types of deformable mirrors, each one has a certain type of performance in the deformation of their surface to correct deformed wave fronts. These mirrors can either be classified as segmented or continuous mirrors (which consists of Bimorph mirrors [1]).



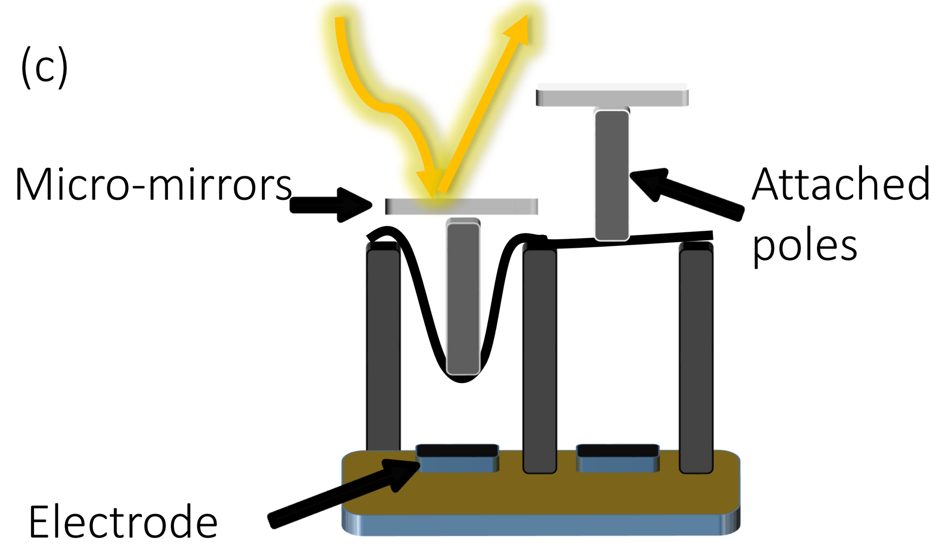
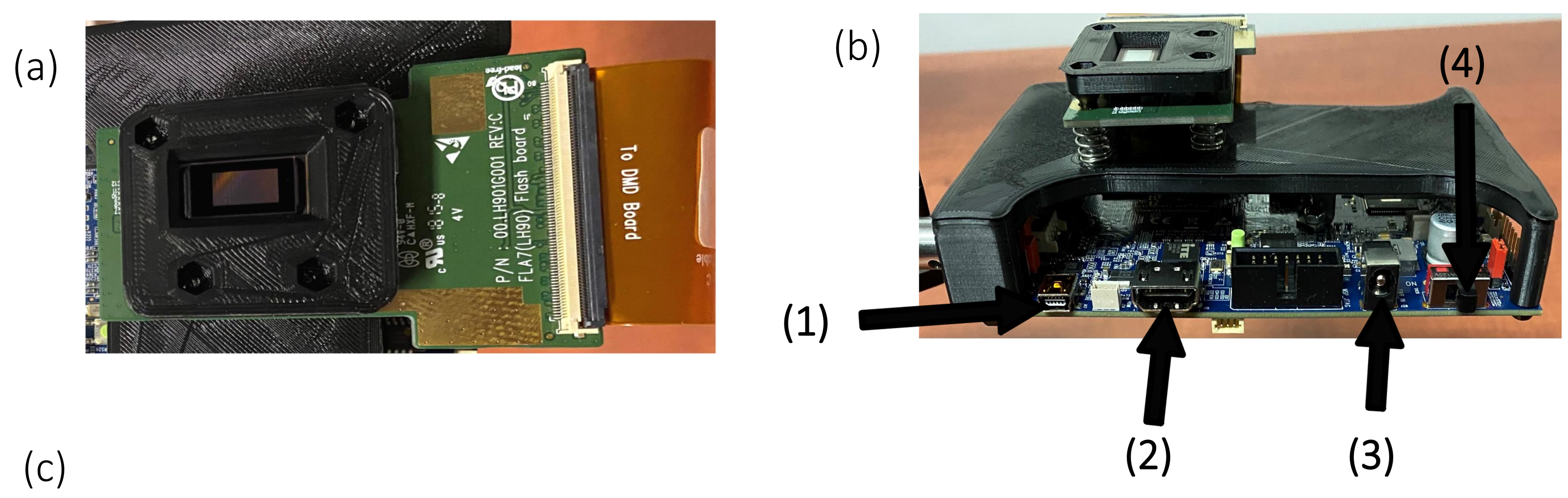


Figure 1: (a) A representation of how the (DM) corrects the distorted wave-fronts by deforming it's reflective surface. (b) Shows the continuous piezoelectric DM with an array of actuators deforming a glass membrane in response to the applied voltage. (c) Shows the segmented micro-electromechanical systems (MEMS) based DM with electrodes generating a certain amount of voltage to move the micro-mirrors to correct incoming aberrations.

Digital Micro-mirror Device

A DMD is a rigid micromechanical spatial light modulator (SLM) originally made for digital projectors. DMDs are made up of two components, an array of micro-mirrors (screen) which tilt about their axis during the on and off state, they are also made up of a driver unit that controls the screen. They are used to generate the desired holograms made from beam shaping.



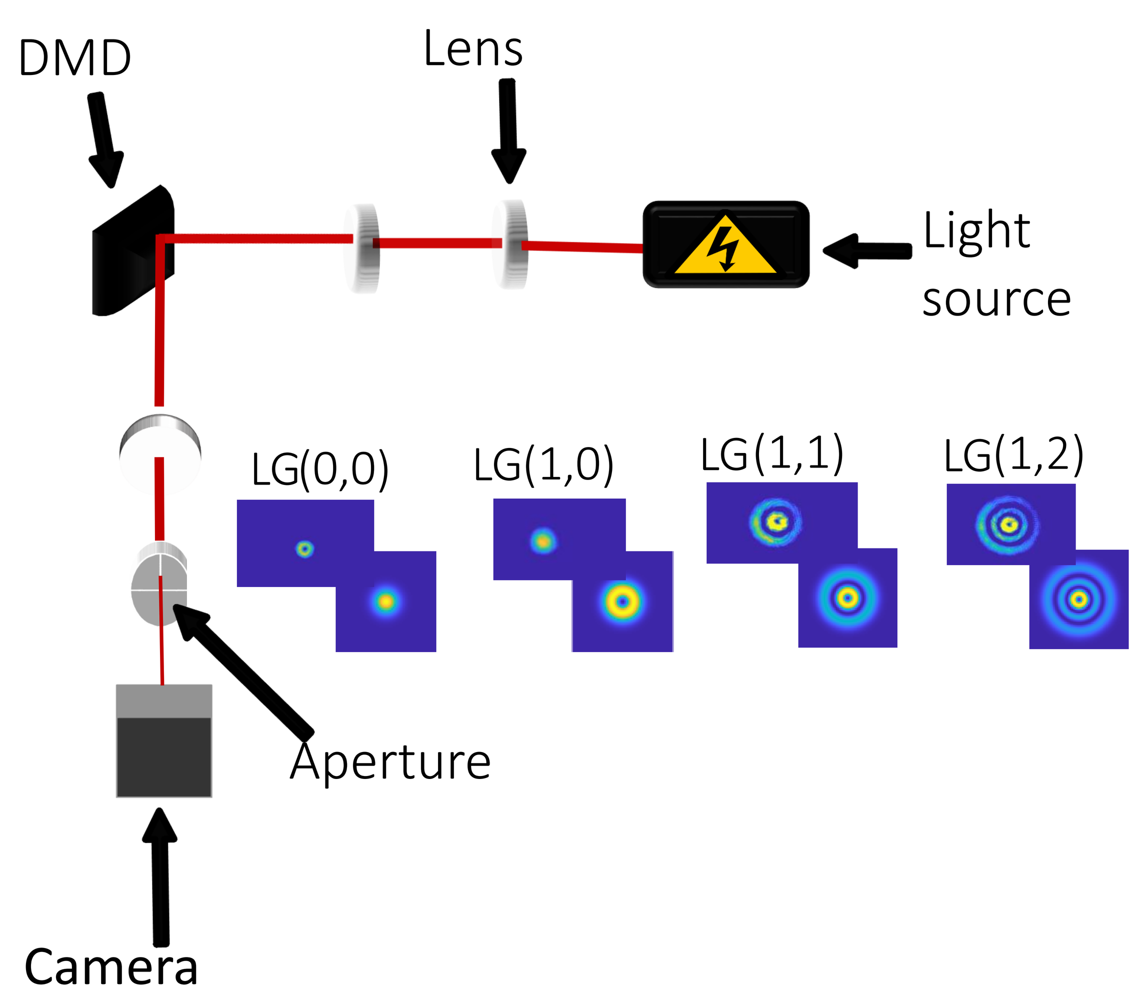


Figure 2: (a) Example of a DLP 4710 DMD screen connected by flex cables connected to the driver unit. (b) The key components of the driver board used to control the screen. (c) The laser beam pass through lenses and becomes collimated before to reaches the DMD. The DMD reflects the desired hologram . The holograms are Gaussian and Laguerre Gaussian beams with varying azimuthal and radial index numbers.

Laser beam propagation

In laser science , the parameter (M^2), also known as the beam propagation ratio or the beam quality factor is a measure of laser beam quality. It represents the degree of variation of a beam from an ideal Gaussian beam. It relates the beam divergence of a laser beam to the minimum focussed spot size that can be achieved [2].

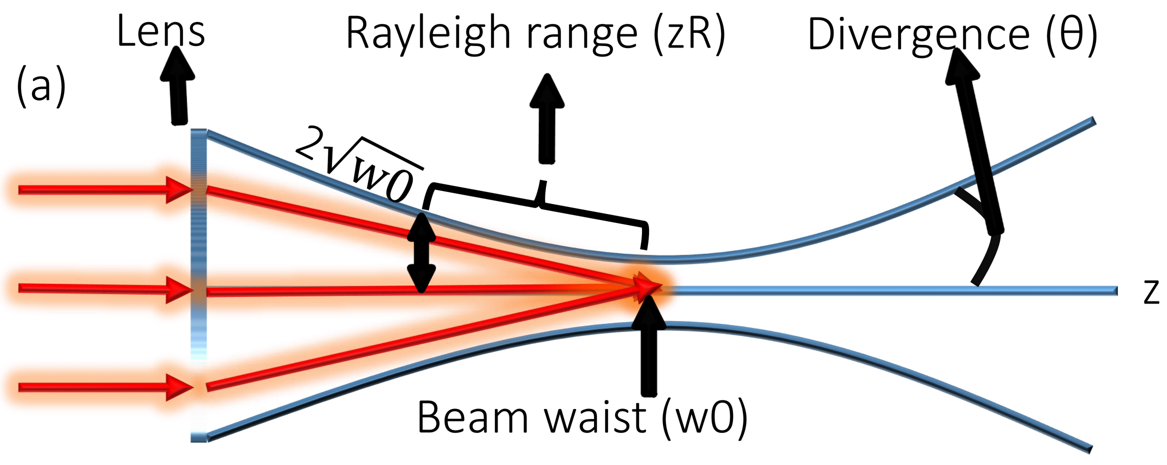


Figure 3: (a) During propagation a laser beam passes through a lens and focuses at a point at some distance z where the beam size is at it's minimum size with a particular angle of divergence.

$$w(x) = 2\sqrt{\frac{\iint (x-x_0)^2 I(x,y)\,dxdy}{\iint I(x,y)\,dxdy}} \quad (1)$$

Where $w(x)$ is the beam size along the x-axis and x_0 is the centre of gravity of the beam. The same applies along the y-axis.

$$w^2(z) = \left(\frac{M^2\lambda}{\pi w_0}\right)^2 z^2 - 2z_0\left(\frac{M^2\lambda}{\pi w_0}\right)^2 z + \left(\frac{M^2\lambda}{\pi w_0}\right)^2 {z_0}^2 + {w_0}^2 \quad (2)$$

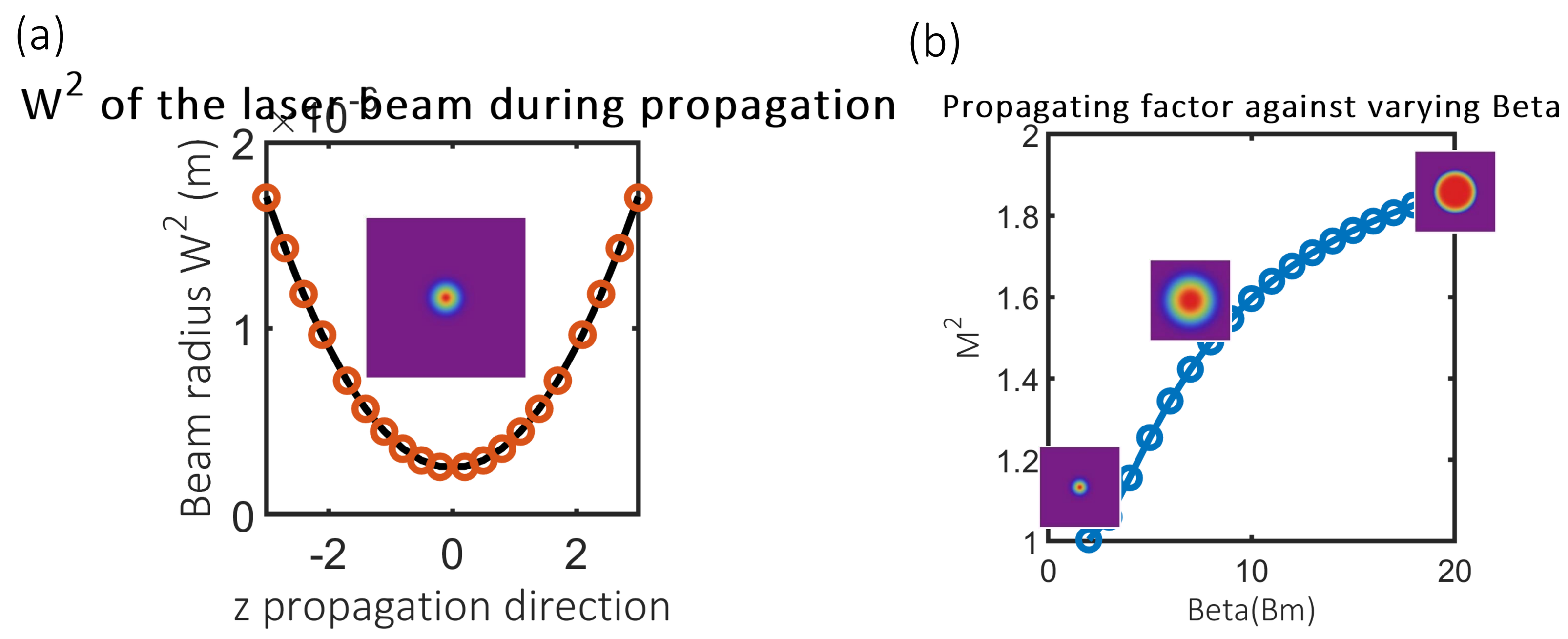
If the beam width after focusing is squared like in eq (2) and plotted against the distance along the propagation axis. The plot will be used to extract the equation of the fit.

$$Y = Az^2 + Bz + C \quad (3)$$

Eq. (3) is a second order polynomial equation after fitting eq. (2). Y can be considered as beam width squared and A,B, and C are coefficients of the polynomial fit

$$M^2 = \frac{\pi}{\lambda}\sqrt{AC - \frac{B^2}{4}} \quad (4)$$

Comparing the terms in eq. (2) and (3) and solving for M^2 leads to eq. (4)



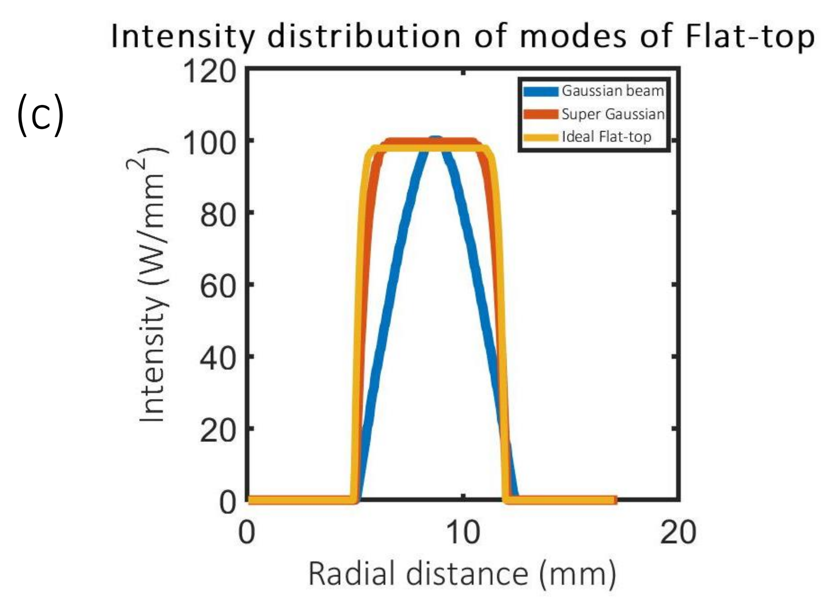
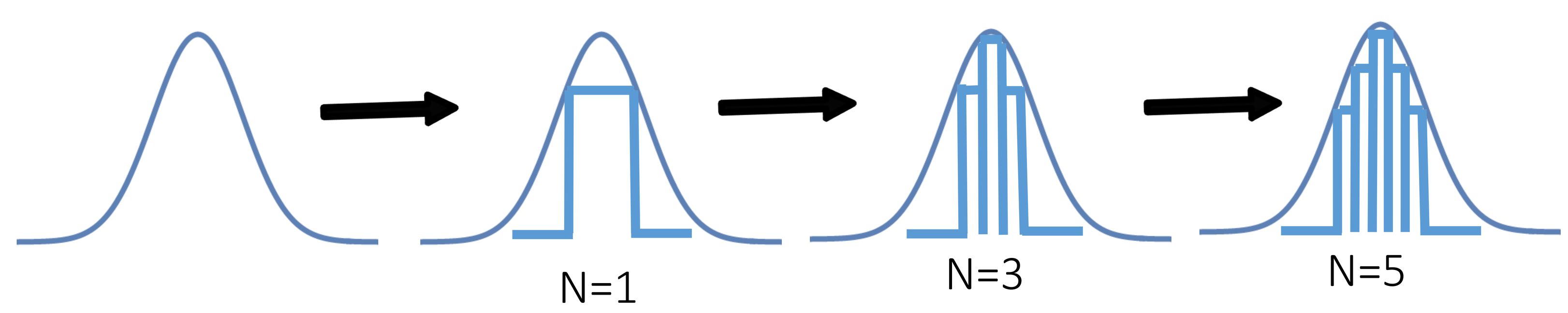


Figure 4: (a) Is a Gaussian plot with different beam radius as the beam propagates. (b) Is a flat-top starting with a simple Gaussian as beta equals two and it show how the M^2 increases with increasing beta where the Gaussian assumes a flat-top shape. (c) Cross-section plots of the intensity distribution of a Gaussian until an ideal flat-top .

Future work

I intend to binarize the Gaussian function by converting it into a discrete number of steps (N) and modelling the resulting M^2 parameter.



References

[1] Fernández, E.J. and Artal, P., 2003. Membrane deformable mirror for adaptive optics: performance limits in visual optics. *Optics express*, *11*(9), pp.1056-1069.

[2] Du, Y., 2016. Measurement of M2-curve for asymmetric beams by self-referencing interferometer wavefront sensor. *Sensors*, *16*(12), p.2014.