Optical Dipole Potentials Using a Digital Mircomirror Device

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Introduction

Ultra-cold atoms, trapped in arbitrary shaped miniaturized potentials [1], have interesting applications in many body physics, quantum information etc. Here we use a digital micromirror device (DMD) [2] as a spatial light modulator to generate arbitrary dipole potentials with controllable intensity. DMDs are fast, flexible and economical. Such a device may be very useful for a wide range of Bose Einstein Condensate (BEC) experiments where control over the profile of the light source is required [3].

In order to generate a desired dipole potential, the DMD is controlled by a software system which is being developed in house such that pattern design and simulation work efficiently. It also implements algorithms for other general experimental purposes such as intensity modulation for uniform beams, automatic light profile compensation for non-uniform beams and optical setup assistance.

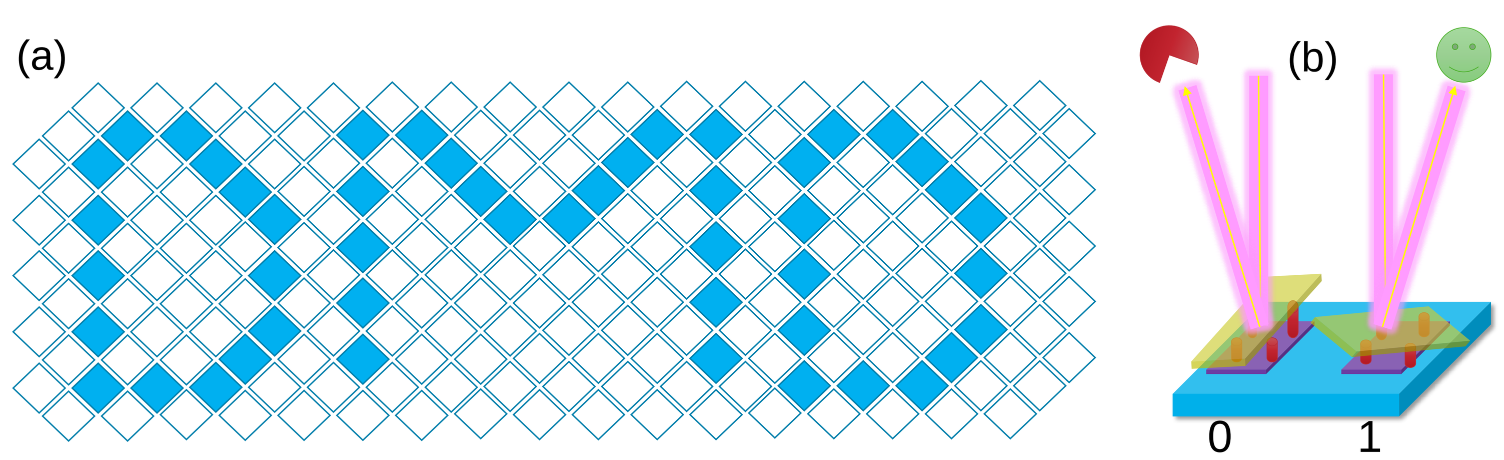

Fig. 1: Digital Micromirror Device Structure

The Digital Micromirror Device (TI DLP3000) contains a 2D array of very tiny mirrors (Fig. 1a). Each of these mirrors can be turned on or off independently. When a mirror is on, it will reflect light to the desired direction, when it is off, light will be reflected into another direction (Fig. 1b).

System Geometry

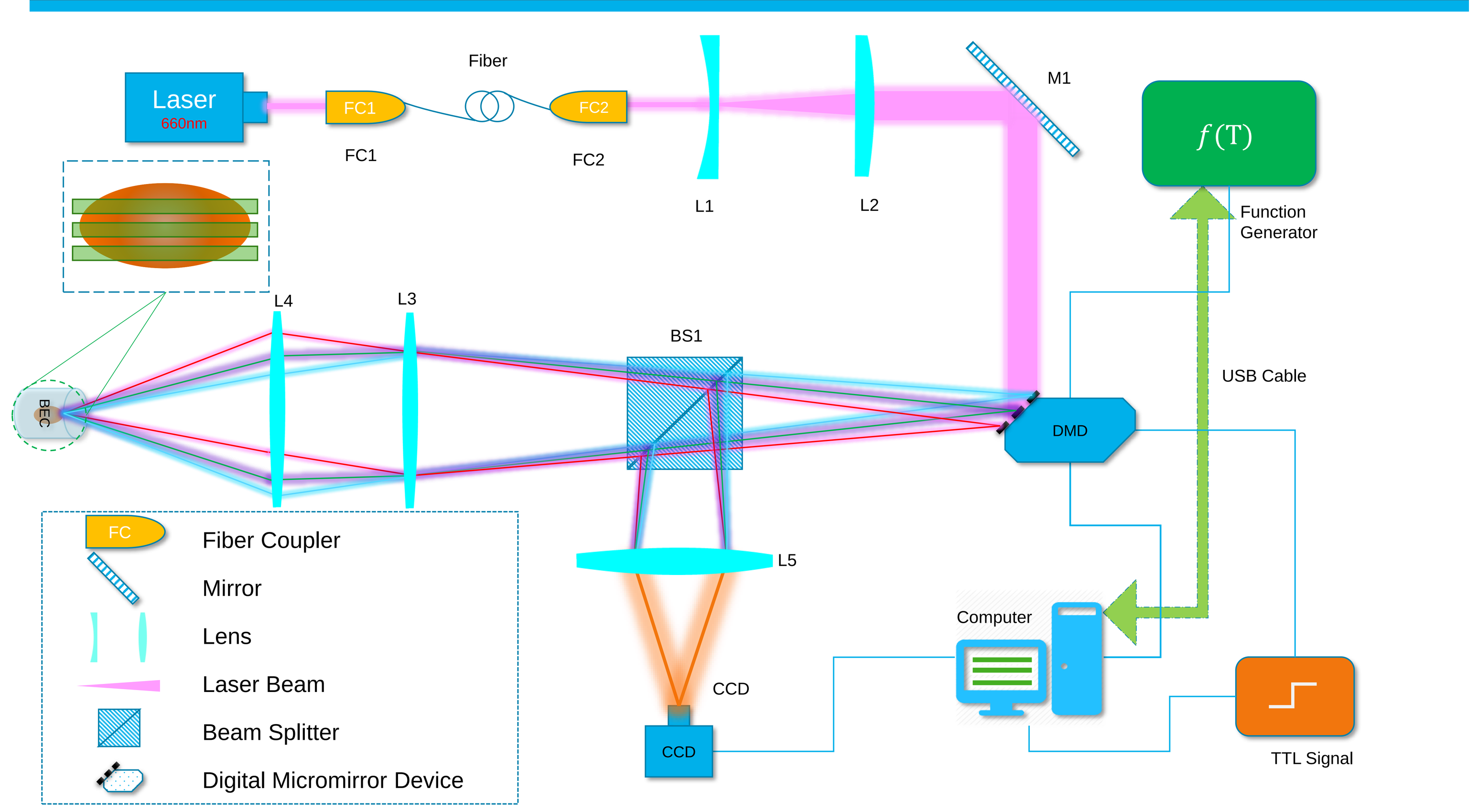

Fig. 2: System Geometry

System Parameters

Parameter	Value
DMD Frame Rate	4000FPS [2]
Single Mirror Size	7μm×7μm [2]
DMD Resolution	684×608 [2]
External Trigger Delay	200μs (Measured)
Maximum Scanning Speed	30mm/s (on DMD) (Calculated)

Software System

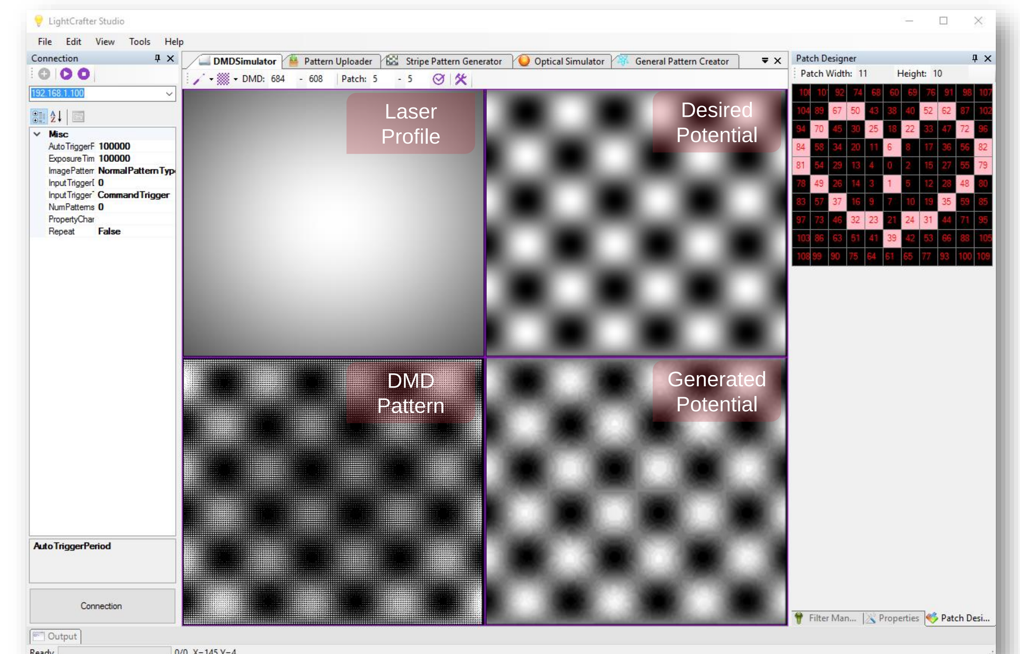

Fig. 3: Control Software Appearance

Fig. 4: Software Architecture

- The software is designed with a nice and friendly user interface (Fig. 3). The user can simply click and design a pattern and then upload it to the device.
- It supports drag and drop functionality and each component can share data via the framework (Fig. 4) and the clipboard (copy and paste).
- It supports C# script language (Fig. 5). The user does not have to learn C# language, only simple functions are needed that can be written with basic knowledge of programming.

Workflow & Interface

Extract normalized laser profile on DMD region using computer vision → Divide DMD to small patches (5x5), sum up total laser power in each patch → In accordance with the desired potential profile, turn on specific number of mirrors in each patch → Map each patch to single point in the final image

In order to gain intensity control, the imaging system that projects the DMD onto the BEC is designed such that groups of 5x5 mirrors lie within the resolution limit of the imaging. By turning on only a subset of the mirrors within each group, the intensity at a given point of the BEC can be adjusted (Fig. 6). The number of mirrors active in each group can be tailored to the light incident on the mirror by the algorithm.

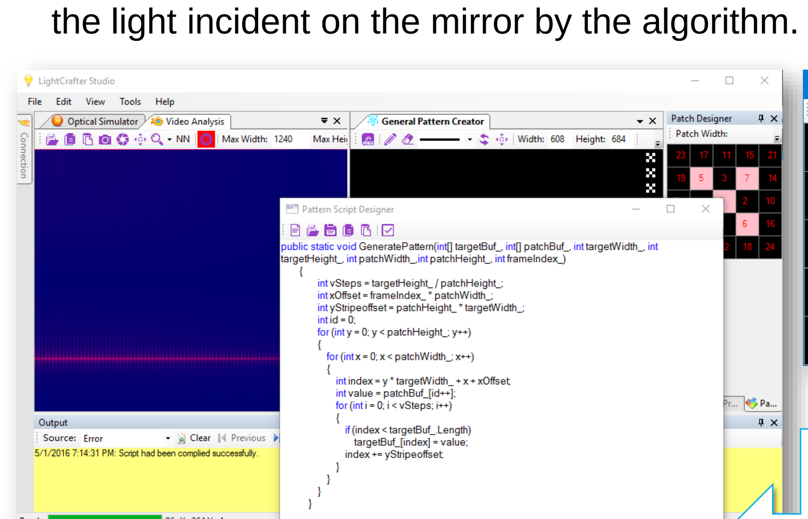

Fig. 5: Software Interface

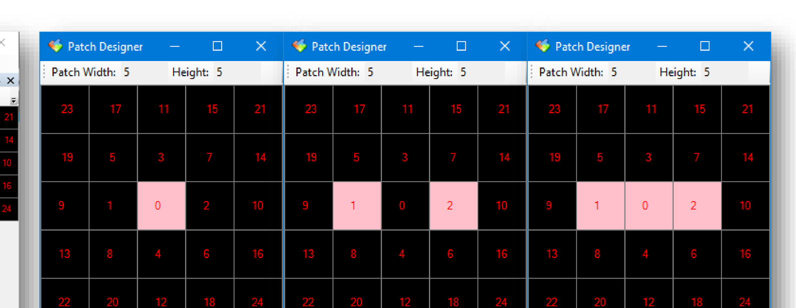

Fig. 6: Patch Patterns

The support of script language makes it very flexible and powerful tool for research. it implements real-time DFT analysis (Fig. 5), computer graphics and vision algorithms for signal analysis.

Algorithms

Pattern Generation
- A pattern generator is used to design and generate an arbitrary dipole potential for an experiment. This can be done using the pattern designer interface or by C# script commands.

Intensity Modulation
- Intensity modulation is a set of algorithms used to compensate for the laser profile and modulate a pattern in order to make the final dipole potential as close to the desired profile as possible.

Simulation
- The system is able to simulate how to generate a desired potential from a given laser profile. The laser profile can be extracted from the CCD camera automatically using computer vision.

Applications

There are a variety of applications where DMDs can be very useful. Here are some examples:

- We can generate a moving line-shape potential and project it on the BEC (Fig. 7). Then the DMD can be controlled to steer the line from one end to another end with different speeds. We may be able to observe different excitations taking place in the BEC. The typical sound speed in a BEC is ~1mm/s, the DMD is able to move the potential faster than the sound speed in the BEC.
- In Fig. 8, a BEC can be loaded into the left side of an H-Shaped trap, then the dynamics of the BEC can be observed as atoms move from the left side to the right side through a narrow channel.
- Ideally, we can generate an arbitrary potential and modify it in real time. For instance, one can start with a BEC confined in a harmonic potential (Fig. 9) and then split the BEC into two pieces by changing the potential to a double well structure. After that, BEC on the right side can be pumped into another hyperfine state using two-photon process. Finally, the two BECs can be mixed to observe their dynamics.
- The DMD will allow us to cut a BEC into pieces of different sizes and shapes. It also makes it possible to move each piece by gradually translating the potential (Fig. 9). By modulating the local intensity, we may also be able to create local excitations, such as vortices by rotating a region of the BEC (Fig. 10).

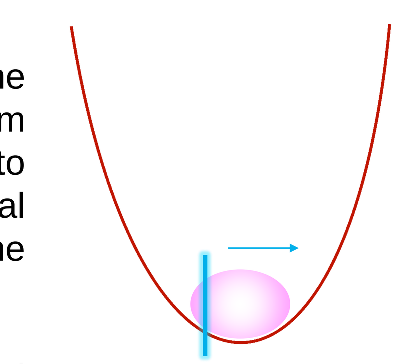

Fig. 7: BEC in a harmonic Trap

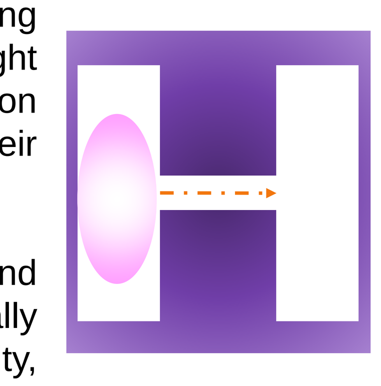

Fig. 8: H-shaped trap

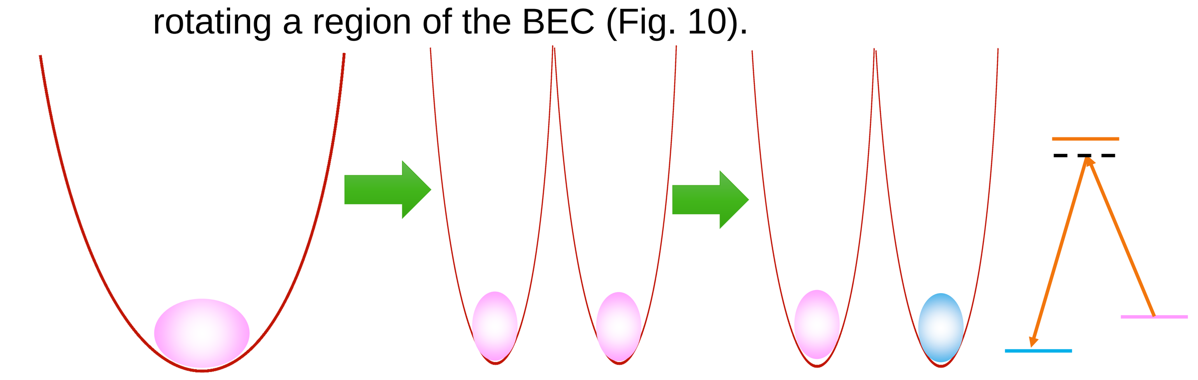

Fig. 9: Dividing BEC Using DMD

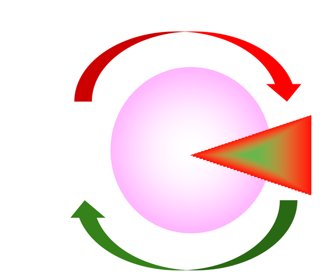

Fig.10: Rotating Potential

Conclusion

- The combination of DMDs and the software system is able to generate arbitrary dipole potentials, which opens a new research window. As DMDs have very high speed, this gives us the additional ability to create local excitation in the BEC experiment on very a short time scale. To increase the spatial resolution, we can use better DMDs (such as 1024 x 1080 version). The general purpose design of the control software will make the system very versatile and usable for a range of other experiments as well.
- A future extension of the software system will include a module that simulates Fourier optics as well. This will provide a more accurate profile of the generated dipole potential. We plan to integrate this DMD system into the BEC apparatus at WSU.

Reference

- [1] K. Henderson et al., New J.Phys. 11, 043030 (2009).
- [2] Texas Instruments DLP3000 DMD *http://www.ti.com/product/DLP3000*
- [3] See, e.g., Li-Chung Ha et al., Phys. Rev. Lett. 114, 055301 (2015).

Acknowledgement

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