Design of Holographic Lightfields for Manipulation of Quantum Degenerate Gases

S. Kreppel1, C. Hamner2, J.J. Chang2, P. Engels2
1Carthage College, Kenosha, WI
2Dept. of Physics and Astronomy, WSU, Pullman, WA

Introduction
Experiments with ultracold quantum degenerate gases such as Bose-Einstein Condensates or degenerate Fermi gases are at the forefront of modern atomic physics. These systems allow the investigation of complicated quantum-mechanical dynamics of many-body systems in a well controlled environment. Since these gases require temperatures near absolute zero, they must be well isolated from any room temperature environment. Mechanical forces that laser beams exert on atoms are well suited for trapping and manipulating these atoms. The goal of our studies is the investigation of holographic techniques to generate nearly arbitrary lightfields for the manipulation of ultracold quantum gases. The project has three major components: periodic lattices, aperiodic patterns, and computer generated binary holography.

1. Periodic Lattices
According to the laws of propagation and diffraction of light, a convex lens can produce the Fourier transform of an input light field entering the lens. The Fourier transformed image appears in the focal plane of the lens. The first step of this project tested the relation on simple periodic shapes as seen in Figure 1.

Dipole Force
The interaction between an atom and light can be understood by modeling the atom classically as a harmonic oscillator. When the atom is placed in laser light, the electric field of the light induces a dipole moment \( \rho \) on the atom as seen in the figure below. The interaction energy between the induced dipole moment and the electric field is given by \( V = -\rho \cdot E \). When the frequency of the laser light is less than that of the atomic resonant frequency, the force on the atom is attractive (the laser light is said to be "red-detuned"). When the frequency of the laser light on the atom is repulsive if the laser light frequency is greater than the atomic resonance.

The aperiodic masks were tested in the same manner as in the periodic case. However, aperiodic masks provide more interesting transforms which lead to new possibilities for the manipulation of ultracold atoms. From both Figure 1 and Figure 3, one can see that the optical set-up produces a fairly accurate Fourier transform.

2. General Fourier Optics of aperiodic shapes
The rules that govern Fourier transforms allow for not only periodic shapes but aperiodic shapes as well. Part two of this project tested aperiodic masks, examples of which can be seen in Figure 3.

The aperiodic masks were tested in the same manner as in the periodic case. However, aperiodic masks provide more interesting transforms which lead to new possibilities for the manipulation of ultracold atoms. From both Figure 1 and Figure 3, one can see that the optical set-up produces a fairly accurate Fourier transform.

3. Computer Generated Binary Holograms
Binary holograms provide a powerful technique to form nearly arbitrary lightfields. As part of this project, a program in Mathematica was developed for creating these binary holograms. First a random phase factor is multiplied to each pixel of the desired light pattern in order to spread the information of each pixel over a large area of the hologram. Then the Fourier transform is calculated, its imaginary part is discarded, and the real part is binarized. The resulting hologram reproduces the desired image, a symmetric twin image and a central bright spot due to use of only the real part of the Fourier transformed original image. In the photographs in Figure 4(b), the central maximum of intensity was removed for the program providing a better image quality.

Conclusions and Future Plans
Through the course of this project methods to create periodic and aperiodic absorption masks as well as binary holograms for the formation of holographic lightfields have been tested. Several Mathematica programs were written throughout the course of the project as a means to create the masks and calculate their intensity. An optics setup was constructed to test the actual performance. These programs and the experimental set-up have proven to be very effective. Printing binary holograms on transparencies using an inkjet printer has turned out to be a viable and efficient way to test calculated holograms with rapid turn-around times. The future plans include:
- Write an optimization function to reduce the amount of noise and lost information for the binary hologram program.
- Use of an aperture in optical set up in order to block out the central intensity.
- Test a binary hologram on a BEC and Fermi degenerate gas.
- Create a deep well lattice which can effectively trap a BEC for imaging purposes.

References


