

3D Imaging of Atom Clouds

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MOTIVATION

The motivation for this project comes from the MAGIS[1] atom interferometry experiment. A key component of the experiment is the imaging of Sr atoms as they fluoresce from the excitation imparted from the driving laser. For the planned MAGIS-100[2] upgrade, several viewing ports will be added along the beam line to monitor the atom clouds. This presents a novel opportunity to develop an imaging system that can not only monitor the position of the atom clouds, but also capture details about the shape of the atom clouds at different points along the beam line. Reconstruction of the shape of the clouds has not been attempted before, thus the possibility of doing 3D reconstruction with a very limited number of views (3 orthogonal views) per cloud needs to be investigated. Moreover, since these views are used for metrology purposes, telecentric cameras can be deployed to capture all in-focus constant magnification images of the clouds. This will require modelling of the telecentric system to better study effects in simulations.

GOALS

1. Investigate 3D reconstruction capability with three orthogonal views of the imaged subject. The images can be assumed to be taken by pinhole cameras.
2. Model the telecentric imaging system in simulation.

ASSUMPTIONS ABOUT THE IMAGED SUBJECT

We can make some simplifying assumptions about the atom clouds being imaged to aid in the reconstruction process:

1. Convex shaped surfaces only
2. No holes inside the body of the clouds
3. Clouds are made up of smoothly dense non-occluding gas
 - Each atom isotropically emits light
 - Point like atoms don't block light from nearby atoms
 - Imaging resolution is much greater than atomic dimensions

As a result of these assumptions we can come to a conclusion about the light detected on an imaging plane that captures a 2D projection of the cloud:

2D projections are line integrals of the light emitted from the cloud along the dimension of the projection, subject to variation in light intensity expected from different depths.

BACKGROUND AND APPROACH

The reconstruction of the atom clouds can employ a few different techniques to illustrate the 3D details of the cloud. We can extract the Visual Hull[3] as a means to visualize the surface of the cloud. We can also exploit the recorded intensities to reconstruct the 3D image of the cloud by using tomography techniques such as Algebraic Reconstruction Technique (ART)[4].

Much literature exists on the fundamentals of telecentric lenses[5] and how to go about calibrating cameras using such lenses[6], [7], [8]. The first step is to study the details of telecentric lenses to understand what the projections would look like with these lenses, and what the illuminance at the sensor would be when compared to typical lenses or pinhole cameras. Finally, we must understand the effect of the aperture in these lenses in low light scenarios.

MILESTONES

3D Reconstruction Using Pinhole Camera Projections

1. Visual Hull Extraction

We can utilize the projections along the X, Y, Z axes to constrain the cloud by extracting the visual hull of the cloud. This gives us the surface of the atom clouds.

2. Reconstructing 3D Information

With the active volume of the cloud identified using hull extraction, we can fill in the voxels within such that the projections along the axes match up with the obtained images. This can be attempted with tomographic reconstruction techniques.

Telecentric Model

1. Hull Geometry

Since the images with telecentric lenses are true orthographic projections, visual hull extraction will be different from the pinhole camera case, this needs to be studied.

2. Light Collected From Different Depths

Telecentricity is achieved by using aperture stops at the front/back focal lengths of the lens. This ensures that the chief rays are parallel to the optical axis in the object/image space. This will however also impact the amount of light collected at different depths (for apertures larger than pinholes, as seen in real telecentric lenses).

3. Light Lost due to Constraints

We must study how much light is lost by switching to telecentric lenses, which is especially important for the low light scenario of fluorescing atoms at MAGIS.

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