Title: DiffuserCam: lensless single-exposure 3D imaging using Custom Hardware

Abstract:

In the paper by Antipa et. Al [1], a lens less diffuser cam for 3-D imaging is introduced. Using a unique pseudorandom pattern of caustics on the sensor, simple calibration, and computational processing we solve for 3-D voxels with a single exposure with the use of compressive sensing and a numerical method that allows us to solve the matrix inversion problem without dealing with the large original matrix. The simplified convolution forward model, validated experimentally, has a FoV of +/- 42 degrees in the x -axis and +/- 30.5 degrees in y-axis and is object dependent for resolution. We construct a custom enclosure for our CMOS sensor that includes a diffuser and aperture.

1. Background

Why diffusers for lensless systems? Listening to Laura Waller, “If you use a , but now it is structured garbage” This statement lies at the core of compressive sensing theory, solving ill posed problems

One of the key theoretical pillars in being able to use diffusers in a lensless system is that the surface of the diffuser can be modeled as a smooth Gaussian smooth surface. So the diffractive effect causing speckles (caustic patterns) from interference can be used for reconstruction. This is because each area of the diffuser is unique creating a type of signature that can encode pleoptic information about our illuminated object.

Another important point is that diffusers which are essentially phase shifter elements can concentrate the light from a 4-D light field into a 2-D sensor better than an amplitude mask using Fourier optics.

<Somewhere here show the generic random matrix inversion problem. Eq 1>

< Show Figure 1 >

When trying to solve inverse problems with less than full rank, it is possible to recover the original vector if some conditions on a matrix are met. Such properties if satisfied such as Full Spark of matrix, and Null Space Property, both have full rank submatrices. A less computationally intensive way to calculate the sparsity that can be recovered is by computing the mutual coherence of the matrix, the combination of the measurement and representation matrix.

Some applications: 3D neural activity. ( Pegard et. Al), compressive radar imaging(Richard Baraniuk)

1. Methods

In theory a lens less system has all the information available at the sensor. However, the problem is ill-posed. Introducing a diffuser gives structure to our point spread function, or random matrix, allowing us to solve an otherwise intractable problem. If we enforce sparsity as a prior, and non-negativity (no negative pixels), minimize for the least squares we are trying to solve the equation below

[[Insert Equation (2) from Paper]]

Here the regularization term converts our image, v, into s sparse vector with the map [ use sparsity abbrv.]

Talk about our simple gradient solution and list some of the math equations.

The problem can be sped up by the use of FISTA…

An even faster way to solve the inverse problem is Mention ADMM.

The math for ADMM is more involved

1. Results

Here are results from the publication.

1. Discussion

In the original paper [1], there is a variation where the equipment used is commodity. Black tape is used for an aperture. A diffuser is created using double-sided scotch tape. The construction of a system while inexpensive and convenient is not practical and stable to construct consistently with success. The author followed the instructions outlined in a tutorial and had difficulty recreating the caustic pattern point spread function.

One example of a stability and repeatable solution is the conversion of a raspberry sensor (list the type that is used) for measurements. The first problem with using a sensor like the raspberry pi sensor is that the sensor is not a flat sensor and requires that the attached lens be removed to place the diffuser a few millimeters away to produce a goof caustic pattern. However, this requires some disassembly. Another problem with the use of the sensor is that the attached sensor does not lie flat as is a bit cantilevered above the printed circuit board. (See figure X).

A difficult problem is how to determine calibration. It is challenging to hold the diffuser so close, a few millimeters away from the CMOS sensor of the raspberry pi

A final challenge is how to with a non-varying light source, calibrate the PSF at a distance z from then sensor.

As a result, with a small investment, several hundred dollars, we propose a more stable and practical solution that increases the prospect of repeated success. As a first step we construct a custom housing using a 3-d printer. Below is a diagram of the housing. (See diagram). The housing is built on top of a sensor (list part #)

< Follow on paper of diffuser encoder >

< Brain Initiative >

1. Conclusion