EE 367: Computational Imaging and Display - Project proposal

3D distance sensing using optimized point spread function

Nayeun Lee, Jiho Hong

nayeun@stanford.edu, jihohong@stanford.edu

1. Motivation

For a conventional imaging system, there has been many efforts in both physical devices and computational methods to obtain an image of a scene containing as much information as possible. Due to such efforts, a two-dimensional (2D) image can be taken with high resolution, reduced noise, and high dynamic range. One of important information is a location of each object in a three-dimensional (3D) scene. In particular, such an information is essential in a wide range of imaging applications from Lidars for autonomous vehicles to florescent imaging of single emitter. However, retrieving depth information remains challenging because it is inevitably lost while a 3D scene is compressed into a 2D image. To overcome this, one can engineer a point spread function (PSF) with a specific depth dependence. For example, using a double helix PSF, it has been demonstrated that location of sparse emitters can be retrieved from a single 2D fluorescent image beyond the diffraction limit [1]. Depending on a scene of interest, it could be possible to optimize a depth-variant PSF for a better depth estimation.

2. Overview

In this project, we optimize a depth-variant PSF to accurately estimate a 3D location of each object in a scene. Based on that, we can calculate 3D distance between two objects of interest in an obtained 2D image. In fluorescent imaging, there has been a variety of PSFs proposed and employed, for instance, astigmation, accelerating beam and Corkscrew [2]. In particular, it has been demonstrated that a saddle-point PSF with optical Fisher information allow depth sensing over a larger depth of field, up to 5 um [3]. In this work, a pupil plane pattern is optimized using a PSF as design parameter in the imaging system. Without any initial constraints on the shape, the optimal PSF is purely achieved by solving the optimization problem of minimizing CRLB. Depending on a given constraint like a specific depth of field (applicable z range), we can find different optimal PSFs other than a saddle-point PSF. Our goal is to optimize a PSF for better 3D distance sensing within given design parameters. This can be potentially applied in imaging applications of 3D moving objects, such as optical nanoelectromechanical system with resonant metallic or dielectric particles where we can actively tune the height of them [4].

3. Timeline & goals

1) Find specific goals and constraints to optimize PSF (02/12 – 02/19)
2) Write code for deconvolution to reconstruct depth map (02/20 – 02/27)
3) Write code for optimizing PSF (02/28 – 03/05)
4) Analyze results and make final report (03/06 – 03/11)

4. Related work and references

1) Sri Rama Prasanna Pavani, Michael A. Thompson, Julie S. Biteen, Samuel J. Lord, Na Liu, Robert J. Twieg, Rafael Piestun, and W. E. Moerner, "*Three-dimensional, single-molecule fluorescence imaging beyond the diffraction limit by using a double-helix point spread function*", PNAS March 3, 2009 106 (9) 2995-2999;
2) Alex von Diezmann, Yoav Shehtman, and W.E.Moerner, "*Three-Dimensional Localization of Single Molecules for Super-Resolution Imaging and Single-Particle Tracking*", Chem. Rev. February 2, 2017 117(11) 7244-7275;
3) Y Shechtman, SJ Sahl, AS Backer, and WE Moerner, "Optimal point spread function design for 3D imaging", PRL September 26, 2014 113(13): 133902;
4) Aaron L. Holsteen, Ahmet Fatih Cihan, and Mark L. Brongersma, "Temporal color mixing and dynamic beam shaping with silicon metasurfaces", Science July 19, 2019 **365** 257-260;