EE367 Project Proposal: Nonlinear stereoscopic imaging

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1 Motivation

Based on work that I'd done previously (solely some theoretical derivations done on paper), I wish to explore the use of non standard (lenses which don't obey pinhole (perspective) projection, also known as rectilinear optics) in stereoscopic systems. This is an idea which has the potential to solve two existing problems in stereoscopic depth systems.

Quadratic Depth Error It's easy to show that with classic, pinhole projections, depth estimation error in stereoscopic systems is quadratic with distance from the camera plane. They also have uniform error (to a first approximation) across the field of the frame. By making the error across the frame non-uniform, and forcing the image to undergo heavy barrel distortion, it should be possible to trade uniformity of image for increased invariance to distance.

Wide-angle lenses Building very wide angle lenses is impractical under pinhole projection. This is for two reasons, first, the number of pixels required for any object grows as $\tan(\theta)$, where θ is the off-axis angle of the optical ray. This trends to infinity as pinhole imagers try to cover a hemisphere ($180°$). Second, due to the well-known laws of vignetting, perspective projection imagers exhibit $cos^4(\theta)$ [AHA01] light loss towards wide angles.

The goal for this project is to build a stereoscopic algorithm and proof-of-concept which uses wide-angle, barrel distorted lenses, to create a dense stereo depth image without any resampling back to a pinhole projection space.

In some ways, this is motivated by Fleck's article on the use of nonlinear lens projections [Fle95]. Although that work didn't focus on stereo systems, it discussed the concept that rectilinear projections have notable shortcomings for certain computer vision applications.

2 Related Work

There have been many existing methods on expanding stereoscopic correspondence algorithms to handle non ideal lenses. Abraham and Förstner developed a method setting

up valid epipolar geometry for using panaromic and wide angle lenses [AF05]. However, while their work would correctly discover nonlinear lens distortion, their methods for matching the images involved distorting the image back to a rectilinear projection, forcing large scale resampling of the image and abandoning the beneficial properties of using a nonlinear lens. Many authors similarly build on wide angle lenses, distorting the imagers back to a linear projection for stereo matching [GNT98] [Geh05]. Other authors [Sha02] [Kit11] have pursued using fish eye lenses, which are a form of nonlinear lens, but did so mostly through the use of features which were invariant under their chosen lens projection. The shortcomings of using such invariant features are that these methods produced sparse depth maps.

Li [Li06] [Li08] developed methods of using nonlinear lens for generating depth, including calibration and search, but the method only applied to only spherical projections. Additionally, their use of nonlinearities was limited to only the axis perpendicular to the epipolar line.

I wish to explore how to utilize and design lens projection geometries that provide favorable properties for stereoscopic imagers — including improved depth invariance at the expense non-uniform accuracy across the image.

3 Project Overview

For this project, I wish to create a proof of concept that shows computational techniques can expand valid geometries of optics used in stereoscopic correspondence imaging systems. Since building the entire system in practice seems challenging, I wish to demonstrate this system at least on synthetic data, and hence that structures the proposed milestones below.

4 Milestones

I assume that we have roughly have four weeks of project time and so I've proposed three milestones, roughly one for each week, with a week of overflow time.

1. A model for the errors of stereoscopic systems. A basic stereoscopic correspondence algorithm. These are things I've worked on in the past and think I can comfortably do in 10-20 hours.

2. A ray-traced way of generating ground-truth data which has undergone various non-linear distortions. I expect to modify an existing off-the-shelf, open-source rendering system such as tungsten

3. A stereoscopic correspondence algorithm that works on the non-linear images, and confirms some of the theoretical hypothesis. I believe this may be fairly straightforward application of the math derived in milestone one on the images derived in milestone two.

5 Note

I'm more than happy to change my project to something a bit simpler, but I'm not sure what. I'm also interested in BRDF capture of arbitrary scenes, or depth correspondence algorithms in general. If you'd want me to come to office hours, let me know.

References

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