Hacking a Consumer DSLR Lens for Computational Imaging

Ned Danyliw, Sam Girvin, Meredith Burkle

Motivation

Today's DSLR systems are inexpensive, ubiquitous, and reasonably high-quality imagers. However, as conventional imaging systems, they require some modification in order to be suited for most computational imaging techniques. In this project, we will build a framework for implementing a variety of computational imaging capture techniques in standard consumer DSLR hardware. Specifically, we plan to enable custom control of lens focus as well as lateral movement of the image stabilization element inside a lens.

These hardware modifications and software interventions will enable a variety of existing computational techniques by either allowing image capture with a modified blur kernel or the capture of a sequence of modified images. Changing lens focus during an image exposure allows for depth-invariant and motion-invariant image capture, for instance. Meanwhile, controlling the position of the image stabilization element of a lens could also be used for motion-invariant image capture, as well as for super-resolution and sequential-shot lightfield image capture.

By making experimentation with these lens manipulations inexpensive and straightforward, it is our hope that more novel applications will become practical to explore.

Project Overview

This project has both hardware and software components. The hardware component will involve the reverse-engineering and physical modification of a lens, while the software component will involve the characterization of our hardware modifications, simulation of any techniques made possible by the modified lens, the creation of an interface for sending instructions for image capture, and the implementation of some computational techniques on real-world data collected from the modified imaging system.

Hardware

The lens that we will be modifying in this project is the Canon EF-S 18-55mm f/3.5-5.6 IS II. This is the kit lens that ships standard with most Canon DSLRs, and is also the cheapest Canon lens to offer image stabilization. We'll be implementing the focus control hack as outlined previously by Bando [1], as well as reverse engineering the image stabilization system and developing a method for driving it externally.

Software

On the software side, there are a variety of tasks, beginning with simulation and system characterization. In order to effectively test the hardware, we will need to have testbeds for our algorithms and an accurate representation of the point spread function of our lens. We will also need a way to easily control arbitrary lens focus and lateral lens movement from the computer. Finally, in our implementation of the computational techniques, we will incorporate various priors like TV and anisotropic to try to achieve good results.

Milestones, Timeline & Goals

Week 7 Take apart Canon lens and recreate Bando focus control results (spoofing focus commands to lens using an Arduino/Teensy). Examine the image stabilization system and develop a plan for external control. Recreate Bando paper depth-invariance results in simulation.

Week 8 Design and implement control of image stabilization system. Characterize lens point spread function and test depth invariance on captured images. Write MATLAB wrapper for sending commands to camera for focus sweep.

Week 9 Package modified lens so both focus and internal lateral lens control can work simultaneously. Characterize control of lateral lens control. Capture images to test motion invariance, super-resolution, light-field image capture, etc. Simulation of motion invariance, MATLAB wrapper for sending commands to camera for lateral lens motion.

Week 10 Implement super-resolution, light-field image capture with real-world data. Tweak algorithm parameters. Document results and methods.

1 Primary Responsibilities

Ned: Hardware with a focus on the microcontroller (generating focus commands/control loop for coils). Matlab interface to microcontroller.

Sam: Hardware with a focus on the lens teardown/electrical modifications, simulation of focal sweep.

Meredith: Software with a focus on system characterization and implementation of the deconvolution algorithms with real-world data.

Related Work

(1) `http://web.media.mit.edu/~bandy/invariant/TOG13invariant.pdf`
Near-Invariant Blur for Depth and 2D Motion via Time-Varying Light Field Analysis. Our main reference for focal sweep information. Studies a method of image capture that moves the plane of focus through a range of scene depth during exposure, shows that it is near-optimal both in terms of depth and 2D motion-invariance as well as in terms of high frequency preservation for certain combinations of depth and motion ranges. They analyzed a time-varying light field in relation to combined defocus/motion blur and created a frameworkfor evaluating performance of joint defocus and motion deblurring (involves measuring depth/motion-invariance and high frequency preservation), found that the focus sweep method also works as near 2D motion-invariant capture (most other methods require 1D linear motion to be successful).

(2) `http://web.media.mit.edu/~bandy/sweep/CCD13sweep.pdf`
An Analysis of Focus Sweep for Improved 2D Motion Invariance. This paper builds off of the above findings that the focus sweep method can make motion blur invariant to object speed/in-plane motion direction. The researchers perform time-varying analysis of the PSF to derive a frequency power assignment that derives perfect 2D motion invariance in theory (in the limit of infinite exposure time). They also design a custom lens bokeh to improve motion invariance in practice and produce better worst-case performance than the conventional focus sweep method derived in the above paper.

(3) `http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5753127&tag=1`
Motion Invariance and Custom Blur from Lens Motion. Shows that lens stabilization hardware can be used to generate custom blur kernels for motion-invariant blur deconvolution. Demonstrates 1D blur deconvolution with modified hardware and discusses the internal structure of the image stabilization hardware and techniques for modifying it.

(4) `http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=1398765`
A Deconvolution Method for Confocal Microscopy with Total Variation Regularization. Describes a method for incorporating multiple priors into a blur deconvolution. Modifies the Richardson-Lucy method to include a total variation regularization, which helps preserve edges while preventing ringing. In simulation, successfully removes Poisson noise and blur from microscopy images.