Title: Computational Imaging for Image Reconstruction and Disparity Estimation in a Dual Camera Phone

EE367 Project Proposal
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Introduction — What you are going to solve and why?

In this project, I will explore disparity estimation and image reconstruction for a dual camera phone — the Huawei Mate 9 Pro. Specifically, I will focus on computational imaging methods to formulate the image signal processing pipeline (ISP) as an optimization problem to reconstruct an image and it's disparity map from a stereo-image pair.

The image signal processing (ISP) pipeline refers to the processing steps that are applied to a sensor's raw output to yield a processed image. These steps may include some combination of illumination correction, demosaicing, image sharpening, depth estimation, and so on. ISPs for dual or multi-camera modules integrate information from multiple sensors to construct these processed images.

Although this conventional implementation of the image signal processing pipeline is widely used to process images, it does have its drawbacks. The error introduced at each step of the pipeline is propagated through to the final image. Depending on the accurate reconstruction of each step, the output image may have significant sources of error. Additionally, ISPs may become very complex and cumbersome. Each processing step adds to the complexity of the pipeline and may contribute error to the final processed image.

Technical Approach — How will you solve it?

Heide et al. [1] showed that these complicated ISP pipelines could be formulated as an optimization problem to solve for the system's processed image output. Concepts from [1] were implemented into ProxImaL [2], a domain-specific language and compiler for solving image optimization algorithms, which was shown to generalize to a variety of tasks. Tang et al. [18] extend this work for image construction in RGB-IR sensors, where they jointly address channel deblurring, channel separation, and pixel demosaicing. In this project, I aim to extend the idea of formulating the ISP as an optimization problem for dual camera systems. The pipeline will jointly optimize for image quality and disparity estimation to output a RGB color image and it's disparity map from an input stereo image pair.

In order to do so, the image formation process must be clearly defined in a way that it can be optimized. Prior information can be incorporated into the optimization problem in order to constrain the output. For example, prior information on the point spread function of the camera lenses and other intrinsic and extrinsic parameters from the cameras can provide additional information and constraints, as well as using natural image priors such as smoothness and sparse gradients. We will formulate the image formation process in a similar way as in [1], [3], but will

need to add in the concept of having two images from the stereo cameras as input and jointly optimizing for two different outputs images (one RGB image and one disparity map).

To obtain prior information on the system, the dual cameras must be calibrated and the PSF will need to be measured. The intrinsic and extrinsic parameters of both cameras were calibrated last quarter, but PSF estimation still needs to be done, following the method in [4]. Within this method, I will need to implement a mapping alignment procedure between two image spaces (further outlined in the paper), and to solve an additional optimization problem to find the PSFs of the lenses. The entire joint optimization problem to solve for the RGB and disparity map outputs will then need to be formulated, and a solver will be used to get the output images (such as Matlab's fmincon, minFunc, lsqnonlin, etc.).

Multiple aspects of the course will be incorporated into the project. Camera models and calibration (for example, in the projection mapping for PSF estimation) and epipolar geometry (for example, in estimating depth from the stereo images) will be the primary focus.

Milestones

(Prior work completed) — Calibrate dual cameras and estimate disparity via calibration results with Matlab Camera Calibration tool.
Feb 16th — Complete PSF estimation for both cameras. This will include implementation of the image mapping as well implementation of the optimization method described in [4].
Feb 23rd — Read up on disparity estimation from stereo images with optimization techniques. Brainstorm / outline concepts from readings [5], [6],
March 2nd — Formulate the disparity estimation optimization problem following the ideas in [1].
March 9th — Incorporate RGB image reconstruction into optimization.
March 16th — Run optimization method on raw imagery to give final RGB image and disparity map results.

References

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