Light-field camera using an angle-sensitive pixel imager

Proposal for a design project for the School of Electrical and Computer Engineering

Jason Wright

Project Advisor: Alyosha Molnar

11/13/2012
Abstract

A light field camera using angle-sensitive pixel technology developed in the Molnar group over the past few years will be designed and built. The technology uses an array of Si diffraction gratings to create an imager capable of capturing both intensity and direction of photons. The specific tasks of the project will be to (1) update PCB schematics and designs to add an embedded control system to handle image capturing, processing, and data transfer over USB, (2) find a lens that matches the imager properties and work out the optics to determine optimal positioning, (3) design and mill a lens mount apparatus that can be added directly to the PCB, and (4) make the camera portable by finding on-board substitutes for bench equipment where possible. If time permits, as much software as possible will be written to make capturing and manipulating images easier, and the possibility of improving the resolution of the camera using multiple imager ICs will be explored.

Introduction

Normal digital cameras record images by exposing an array of photosensitive pixels to light reflecting from a scene. Individual photodiodes record the amount of light measured at their particular location in the array, called an imager, and those values can be used to construct an image. However, the incident light on the camera lens contains more information than the photodiodes measure. While conventional photosensitive pixels aggregate all incident photons into one intensity value, the photons themselves also have direction, polarization, and phase. (The wavelength, or color, of the light is not directly measured; rather, a typical imager will contain a Bayer filter – a repeated pattern of pixels filtered to be sensitive to red, green, or blue light.)

The purpose of a light field camera is to capture information about a field of light, represented as vectors with intensity (their magnitude) and with direction. This information enables interesting possibilities in computational photography, such as refocusing an image after it’s already been taken. Light field cameras also have useful applications in automatic range measurement and improved 3D mapping algorithms.

The first light field cameras were built using an array of multiple imagers and lenses, carefully spaced at fixed distances from each other. The Molnar group at Cornell has invented a light field imager that can capture the direction of incident light using a single lens and imager setup, all in 180 nm CMOS. This is accomplished using angle-sensitive pixels, which are comprised of a number of photodiodes behind angled diffraction gratings. By utilizing the Talbot effect, which describes the periodic response
of a diffraction grating to incident light, the angle of the light can be recovered when considering a large number of angled diffraction gratings.

Figure 1. Structure of an angle-sensitive pixel. (a) Different angles of incident light result in different intensities at the photodiode. (b) The response of the photodiode has a regular, periodic shape.

The work that has been done by the Molnar group in the past has been experimental in nature, using a combination of lab bench equipment and LabVIEW code. The process of acquiring an image currently depends on the user manually controlling a National Instruments data acquisition box that is very large and several thousand dollars in cost. To fully explore the potential of this technology and to develop it further, the CMOS imager needs to become part of a portable, usable device.

Issues to be addressed

The first challenge is to develop an embedded controls system to automate operation of the camera. The current design will be updated to utilize a microcontroller to handle synchronizing the “read” and “reset” cycle necessary for the operation of the imager, and to quickly read the analog voltages that represent the image data being produced by each angle-sensitive pixel. That information then needs to be stored to external memory and be made available over USB. Research needs to be
done to find a suitable microcontroller and accessory hardware, the PCB will need to be updated to include this, and the microcontroller itself will need to be programmed. As a result, the National Instruments data acquisition box and external 10 MHz clock will no longer be required.

A second challenge is to fix the camera’s current optical arrangement. Right now, a standard SLR lens is attached (using Legos) to the imager. This lens is far too large for the relatively small resolution of the imager, resulting in a very limited depth of focus and images that are quite blurry to begin with. A smaller CCT lens will likely be a better solution, but the optics will need to be worked out to find a better lens and to determine how far away from the imager it should be spaced. In addition, the PCB design will need to be altered to include properly spaced mounting holes for a lens apparatus. The lens apparatus itself, which will replace the current Lego-based setup, will need to be designed in a 3D modeling program and produced using a CNC mill.

Finally, the device should be as interactive and user-friendly as possible. This will require creating an interface to perform simple operations like taking photos, deleting them, changing the

![Figure 2. The portion of the PCB design that contains the imager.](image)
camera’s settings, and powering the device on and off. Software on the user’s PC will also need to be written to handle downloading and processing the image files.

**Approach and Expected Outcomes**

Preliminary testing and operation of the existing lab bench setup has already been done. The rest of the project will follow this workflow:

Phase 1 (September-October): Preliminary testing and operation of the existing setup

Phase 2 (November-December): PCB design upgrades to included embedded controls system and peripherals

Phase 3 (January-February): Embedded software writing

Phase 4 (March): Lens experimentation and optical design

Phase 5 (April): Peripheral design and final project build

Phase 6 (May): Writing the final report

With this timeline, it is anticipated that the project will completed on time and meet all specifications.

**Conclusion**

A light field camera, a special device capable of capturing the direction of incident photons, will be designed and built using angle-sensitive pixel CMOS technology developed by the Molnar group. The work will be done by only myself, with some guidance from Prof. Molnar and his PhD students.