2025-2026 UCSB Capstone Project

Meta-surface enabled infrared polarimetric imaging

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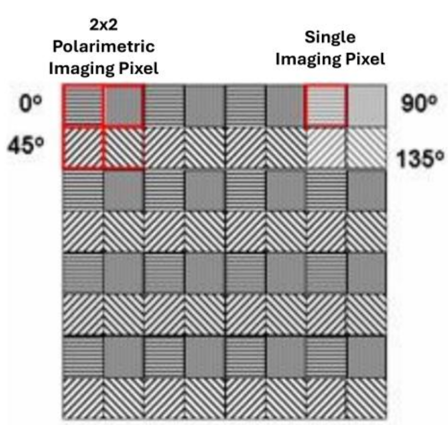
Background: Infrared cameras capture images of the infrared spectrum, which is electromagnetic radiation with wavelengths longer than visible light. Natural and synthetic objects emit electromagnetic radiation when they have a temperature above absolute zero, and therefore imaging of infrared radiation is widely used in industrial, scientific, military, commercial, and medical applications.

Thermal imaging in the mid-wavelength (3-5µm) and long-wavelength (8-12µm) infrared spectrum is of interest because sensors can 'passively' image objects even with no illumination (i.e 'in the dark', no sun or moon, or infrared illuminator).

Polarization imaging adds a new dimension to conventional thermal imaging with capture and analysis of the polarization properties enabling additional information about a scene or an object. In particular, because natural and synthetic objects can have distinctly different and unique polarization characteristics.

Problem Statement: Conventional methods for high performance polarimetric imaging use linear polarizer grids placed in close proximity to the infrared imaging pixels. The architecture is similar to commercial color cameras that use a Bayer color filter overlay on visible imaging pixels.



$$s_0 = \frac{1}{2}(I_H + I_V)$$

$$s_1 = I_H - I_V$$

$$s_2 = I_{45} - I_{135}$$

$$DoLP = \frac{\sqrt{S_1{}^2 + S_2{}^2}}{S_0}$$

The image intensity captured at the different orientations of polarization are used to determine the "Stokes images" of the scene, which are the linearly polarized images in Horizontal (0^o), Vertical (90^o), 45^o and 135^o orientations. The degree of linear polarization (DOLP) image, representing the percentage of light that is linearly polarized, can be used as a polarization imaging metric.

There can be a number of factors (or engineering trades) in optimizing imaging performance metrics with conventional polarimetric imaging approaches:

- trade-off in spatial resolution for polarimetric information
- loss of signal intensity through the polarizer grids
- quality of the polarizer grids
- proximity and alignment of the polarizer grids to the imaging pixels

Meta-surface designs – wherein nanostructured surfaces produce electromagnetic resonant effects – provide a new degree of engineering design flexibility to more fully optimize the linear polarizer grid designs or develop new methods for infrared pixel polarization, where polarization sensitivity is incorporated into the imaging pixels themselves.

Project Description: The objective of this project is to develop meta-surface designs for infrared imaging that are comparable or exceed conventional methods, taking into account practical considerations in fabricating and characterizing the imaging pixels and polarimetric performance.

A baseline polarimetric imaging collect will be co-ordinated (with support from the industry team) to establish an understanding of polarimetric imaging phenomenology, imaging data reduction, and quantitative polarimetric imaging metrics.

Modeling and simulation will be used to develop a quantitative evaluation of software tools and methods, optimization of conventional polarizer grid designs, and comparison to meta-surface designs.

The team will downselect and identify a recommended path for fabrication and characterization of an optimized polarimetric imaging design (with a stretch goal to implement and characterize this design with the industry team).

This project is ideally suited for students with an interest in microfabrication, semiconductor technology, optics, and electromagnetic simulation and modeling. Students participating in this project must have some background in microfabrication and testing, and must have taken ECE 120A and 120B or have equivalent fabrication experience.

Further Information:

https://www.polarissensor.com/white-papers/