Meta spectral imaging for wildfire monitoring

Wildfires are an increasingly severe global issue, exacerbated by climate change and impacting ecosystems, human health, and economies. Traditional wildfire monitoring systems, which rely on multispectral imaging from satellites and airplanes, face significant challenges such as high energy consumption, extensive data volume, and poor thermal stability. This project seeks to address these challenges by developing innovative systems that combine metasurface-based hyperspectral imaging with neuromorphic optical processing, offering a new approach to satellite-based forest fire monitoring.

Our approach leverages metasurfaces—ultra-thin, sub-wavelength structures capable of precise light manipulation. These metasurfaces enable one-shot hyperspectral imaging, capturing detailed spectral data across a wide range of wavelengths without the need for moving parts. This innovation significantly enhances the speed and resolution of wildfire detection, allowing for the rapid identification of fire hotspots, smoke plumes, and other critical indicators of wildfire activity.

In addition to the advanced imaging capabilities, we integrate neuromorphic optical processing through multiplane light conversion meta-optics. This integration forms an inbuilt optical neural network that processes spectral images in real-time with minimal latency and energy consumption. By performing optical neural computations directly on the spectral data, we reduce the computational load and data transmission requirements, facilitating efficient onboard data processing and communication with ground stations.

The project's primary objectives for the next two years focus on three main areas:

- Thermal infrared hyperspectral imaging for fire spot detection, where we will use metasurfaces to detect fire spots within the 8-14μm atmospheric window by optimizing point spread functions for multiple wavelengths and compressively reconstruct the spectral images.
- Neuromorphic pre-processing of spectral images, where we will employ multiplane light conversion based on reflective metasurfaces, performing complex linear transformations to preprocess the spectral images, thus reducing data bandwidth requirements and number of detectors in the array.
- Near-infrared multispectral imaging for vegetation detection, where we aim to design metasurfaces that differentiate between burned and healthy vegetation, enhancing our ability to assess fire damage and vegetation health.

The outcomes of this project will include the development of high-resolution, real-time imaging systems, successful fabrication and testing of metasurface prototypes, and dissemination of research findings through high-impact scientific publications and conferences. Additionally, we anticipate establishing research collaborations and securing further financial support to sustain and expand our research efforts.

The impact of this project extends beyond technological advancements. Enhanced wildfire monitoring capabilities will enable quicker detection and response, potentially mitigating the devastating effects of wildfires. The lightweight, thermally stable metasurface-based systems will reduce operational costs and extend the lifespan of satellite monitoring systems. Improved wildfire monitoring will have significant environmental and economic benefits, helping to protect ecosystems, human health, and property.

By addressing the critical need for advanced wildfire monitoring technologies, this project aims to revolutionize how we detect and respond to wildfires. Our innovative approach promises to contribute significantly to the global effort to manage and mitigate the impacts of climate change and natural disasters.