

Abstract of PhD Thesis “High-Resolution Single-Pixel Imaging in the Near- and Mid-Infrared Range”

This dissertation presents the results of research on hyperspectral single-pixel imaging in the near- and mid-infrared spectral ranges. The work is structured into an introduction and three main parts.

Single-Pixel Scanning Imaging in the Infrared Range

The first part discusses the results of studies on single-pixel scanning imaging in the infrared. This method enables the acquisition of high-resolution images using a single-pixel detector (also known as a bucket detector), a laser light source operating in one or several spectral ranges, and a two-axis galvanometric scanner.

The influence of key optical components on the quality of the reconstructed images was analyzed, along with tests evaluating how iterative corrections of the optical system affect imaging performance. An image reconstruction algorithm was also presented, allowing the conversion of arbitrarily selected sets of measurement points into final images.

Two major scientific contributions are described in this chapter. The first is the application of scanning imaging to characterize the spectral responsivity of infrared detectors, in a manner analogous to LBIC microscopy (Laser Beam Induced Current). The proposed setup achieved high spatial resolution while maintaining relatively short acquisition times - images of 1000×1000 pixels were obtained within five seconds. Several practical examples of this method in industrial applications are also presented, along with a discussion of how the collected data contributed to improving product quality.

The second innovative contribution is a hyperspectral scanning microscope based on a single fast-response detector and an Optical Parametric Oscillator (OPO). By narrowing the detector's field of view to the currently illuminated area of the sample and reducing measurement noise through the use of a reference detector and a precise triggering system, a high signal-to-noise ratio (SNR) and fine spatial resolution were achieved. The use of the OPO for continuous wavelength tuning enabled the measurement of the sample's reflectance spectrum in the infrared range for each recorded pixel.

The ability to obtain high-resolution infrared images with favorable SNR, combined with short acquisition times and without the need for cryogenically cooled detector arrays, demonstrates the potential of the proposed system as an attractive alternative to existing approaches, such as hyperspectral imaging based on Fourier-transform or Raman imaging spectroscopy.

Compressive Imaging Using a DMD Modulator

The second chapter presents the results of research on single-pixel imaging using a Digital Micromirror Device (DMD) in the infrared and visible ranges. As in scanning imaging, a single photodetector is used to acquire the image. The key difference lies in the use of the DMD as a spatial light modulator, enabling rapid spatial sampling of the image through arbitrarily chosen binary masks.

The chapter begins with a discussion of the optical phenomena occurring at the DMD surface that affect image quality, followed by an introduction to the concept of compressive sensing - that is, sampling and reconstructing images from incomplete measurement.

New compressive measurement and reconstruction algorithms are then presented, which significantly reduce image acquisition time. These algorithms do not require adaptive scene sampling, and their computational cost is sufficiently low to allow real-time reconstruction on a standard computer equipped with a graphics card.

An optical system in which a single detector was replaced by two single-element detectors, each responsible for measuring light in a different spectral range or polarization state, is also discussed. The feasibility of applying this approach to obtain high-quality infrared microscopic images was also demonstrated.

The most significant scientific contributions of this chapter are:

- Achieving real-time image reconstruction from compressive measurements with a resolution of 1024×768 pixels.
- Applying a DMD modulator to simultaneously acquire high-quality images in both the infrared and visible ranges.

Comparison of Camera-Based and Single-Pixel Imaging Systems

The third part of the dissertation provides a theoretical and experimental comparison of camera-based imaging systems and single-pixel approaches, demonstrating the advantages of multiplexing and compressive measurements in infrared imaging.

The multiplexing advantage, also known as Fellgett's advantage, is a well-established principle in the design of infrared spectrophotometers. However, its application to single-pixel imaging required additional analysis.

The study explores how multiplexing and compressive sensing affect image quality under different noise conditions, specifically when photon noise from the measured scene or detector noise dominates. It also identifies scenarios in which the systems described in chapters two and three can provide superior image quality compared to focal plane array - based systems.