Single-Frequency Imaging from Dynamic Metasurface Antennas

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Traditionally, microwave imaging has been carried out with large apertures in the form of electronically scanned arrays (ESAs) or synthetic aperture radar (SAR). Alternative platforms have attracted attention for achieving comparable performance from a simplified physical layer, using a computational imaging framework. They employ metasurfaces or cavity-backed antennas to generate uncorrelated radiation patterns which are then used to multiplex the spatial content of a scene with a minimal number of measurements. Once the uncorrelated radiation patterns encode the scene information, computational post-processing techniques are used to reconstruct an image. High-quality imaging has been achieved in this setting, which is especially attractive due to its low cost, simple form factor, and fast frame rates. We aim to show that these methods can be exploited further by removing any bandwidth reliance, dramatically simplifying both hardware and post-processing.

Across all microwave imaging schemes, novel and traditional, one factor has remained constant: the aperture must be electrically large. This enhances cross-range resolution, but is a challenge that must inevitably be overcome among all systems. To achieve satisfactory range resolution ultra-wideband (UWB) waveforms are typically used, which places a burden on the RF hardware design. However, when operating in close proximity to the imaging platform (in the Fresnel zone) the use of UWB signals is not a strict requirement. In fact, as aperture sizes have trended up in size to meet cross-range resolution metrics, they have also obtained the ability to extract range information without the need for wide spectral bandwidths. This ability comes from the various spatial frequencies (or, equivalently, the spectrum of decomposed plane waves) that illuminate the scene from different locations along the large physical aperture.

To implement a monochromatic imaging system that can image in range and cross-range two requirements must be met: (i) the aperture must be large with objects located in its Fresnel zone and (ii) locations along the aperture must be sampled independently to generate spatial frequencies and interrogate the scene. Multiple-input multiple-out systems represent a straightforward approach to this goal, but can be costly and possess complicated hardware. An alternate approach is to use an electrically-large reconfigurable aperture that can sample spatial components through electronic switching, achieving the two conditions with a favorable form factor and significantly simpler architecture. Dynamic metasurface antennas consist of electronically tunable metamaterial cells in a waveguide-fed structure. We show that such antennas can multiplex scene content to discern objects in range and cross-range using one frequency. This simplifies the radio architecture and circumvents several challenges which plague wideband microwave imaging systems, including calibration, alignment, and bandwidth regulations. In this presentation we expand upon this notion and experimentally demonstrate the utility of a dynamic metasurface aperture in a single-frequency microwave imaging system.