Adaptive coded-aperture imaging and tracking in the IR

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Incorporating a reconfigurable mask in an IR system can simplify the optics and give better than a fourfold improvement in imaging resolution.

Adaptive coded-aperture imaging works by encoding the radiation from a scene using a patterned aperture, detecting the resulting intensity distribution, and then using digital signal processing to reconstruct the image. The approach has a number of advantages, including simpler optics and the potential to implement ‘post-detection beam forming’ using agile imaging modes with no macroscopic moving parts. It also has the potential for significant subpixel resolution. One of the main limitations to the resolution of imaging systems is the size of the detector pixels relative to the image detail. A way to increase the resolution is then to obtain a focal-plane array (FPA) with smaller pixels. However, there are good physical reasons why a detector pixel has an effective minimum size. The question then is whether the effects of pixelation can be undone (to reveal the hidden detail within the pixel) and, if so, how.

Various approaches have been suggested for undoing detector pixelation in images. Some of these rely on platform motion and others involve ‘dithering’ the detector array or moving part of the optics to shift the image relative to the array. Such methods are normally referred to as microscanning. Our approach is based on having a reconfigurable mask within the optical train to ensure that the information present in the data changes with the particular mask pattern used. The system is calibrated by recording the image of a point source, referred to as the point-spread function (PSF) of the system. A mathematical algorithm is subsequently used to recover subpixel images from multiple images. The advantage of this superresolution approach is that there are no macroscopic moving parts. Consequently, we can cope with very large detector arrays, such as needed, for example, in wide-area surveillance. The recorded PSF includes the effects of imperfections in the optics, and the algorithm removes these as well. System costs are often dominated by the FPA. Consequently, for a desired image-resolution × field-of-view product, this approach offers significant costs savings.

Elsewhere, we proposed the use of a micro-opto-electromechanical system microshutter-array reconfigurable mask to achieve subdetector-pixel resolution.1 Our mask consists of an array of Fabry-Perot etalons. Each of these can be switched between transmitting and nontransmitting states by applying a voltage, creating a variety of mask patterns that give rise to different system PSFs, each of which in turn gives a different

\[\text{Figure 1. Major components of the system, which consists of a reconfigurable mask, an optical system, and the detector array. (a) Concept. (b) Camera design.}\]
response on the FPA. The recorded data consists of the scene convolved with these PSFs. Suitable processing of the data enables recovery of the subpixel detail.

This process can be thought of as solving a linear system of equations with one equation for each mask pattern. The quantity to be determined—the scene—is at a finer resolution than the detector array. Accordingly, we require multiple mask patterns to make the system of equations soluble.\(^2\) This follows from needing at least as many equations as unknowns. Figure 1 shows the concept of the experimental system, together with our practical implementation. Figure 2 shows a typical set of PSFs achieved by varying the mask configuration and containing subpixel information. The improvement in resolution using the system with a reconfigurable mask was initially demonstrated using large-area pixels produced by binning. Figure 3 shows detail at \(1/4\)-pixel resolution, equivalent to a 16-fold gain in the effective number of pixels.

We have now also used our experimental system to generate true subpixel imaging. In this case, however, the subpixel detail is presently limited to around \(1/2\) pixel because of carrier diffusion in the detector, which smears out some of the highest-frequency subpixel information. These cross-talk effects can be significantly reduced in a custom-designed detector. We are working on a full-scale demonstrator that incorporates improved optical and detector designs.

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