

Active Optics for Enhanced Sensor Performance

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Abstract

Optical sensing systems are increasingly required to deliver higher spatial resolution, faster acquisition rates, and improved 3D imaging capabilities. However, their performance remains constrained by fundamental physical limits, fabrication complexity, and cost. This work demonstrates how active optical elements combined with dedicated control strategies can significantly extend the capabilities of conventional imaging systems.

First, focus-tuneable liquid lenses enable high-speed, inertia-free focusing with millisecond response times. This allows continuous focus stacking without mechanical motion, providing extended depth of field in high numerical aperture systems, post-acquisition focal plane selection, and depth reconstruction from image stacks.

Second, the spatial resolution of image sensors — typically limited by pixel count, sensor size, and manufacturing yield — is enhanced using dynamic beam shifters. By introducing controlled sub-pixel lateral displacements and combining multiple acquisitions, the effective sampling density is increased. This approach enables resolution gains of up to 4× for RGB Bayer sensors and up to 16× for hyperspectral sensors with super-pixel architectures.

Finally, large field-of-view (FOV) imaging with high detail is addressed using high-speed scanning mirrors. These systems either reconstruct gigapixel-scale images from multiple sub-frames or dynamically direct the field of attention to regions of interest identified by overview sensors. Integration with focus-tuneable optics ensures sharp imaging across varying object distances within the extended FOV.

The presented approaches illustrate how adaptive optical components can overcome conventional trade-offs in resolution, depth of field, and FOV, enabling enhanced performance in applications such as machine vision, surveillance, and advanced sensing systems.

Keywords

Active optics, focus-tuneable lens, focus stacking, pixel shifting, field of view expansion, image stitching