Computational expansion of imaging from visible to IR and gamma imaging systems

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The integration of a time-variable array of pinholes can be used to perform high-resolution imaging with high energy efficiency, and significantly extend the field of view when combined with an imaging lens.

Lenses are used for imaging in a wide range of applications, but in many cases this leads to drawbacks. For example, in smartphone cameras the use of imaging lenses limits the flatness of the device, and in medical devices, such as micro-endoscopes, the field of view (FOV) is limited. In many applications, such as terahertz (THz) imaging—used for security purposes—or gamma-ray imaging, which is used in single-photon emission computed tomography (SPECT), conventional imaging lenses cannot be used. Instead, existing THz detectors require space scanning and bulky hemispherical lenses or mirrors, whereas gamma-ray imaging requires an array of collimators to allow only forward-propagating rays to pass.

We have found that the integration of a time-variable array of pinholes can be used to carry out high-resolution imaging. This array provides high energy efficiency if it is used to replace an imaging lens, and it can significantly extend the FOV if it is integrated into the aperture plane of an imaging lens. Avoiding the use of imaging lenses enables much flatter and cheaper imaging optics to be used in the visible and near-IR regions, and also in other spectral regions in which the use of conventional lenses is not feasible.

Whether the array is used to replace a lens, or is integrated into a lens, its operating principle involves time-variable encoding of the aperture plane, followed by decoding to recover the resolution and FOV of the enhanced image. We have demonstrated experimental results for both the above-mentioned uses of the array.

We achieved lens-free imaging by combining a variable-aperture wheel, as shown in Figure 1, with a CCD sensor. After capturing a set of images and performing inverse filtering, we obtained a high-resolution, high-intensity image. We then used the lens-free system for gamma-ray medical imaging using a GE Discovery NM/CT 670 SPECT gamma camera with a blue plate as a sample object: see Figure 2(d). The time-variable arrays of pinholes were made of lead with tungsten inserts. We compared the results of experiments carried out using three systems: a single pinhole with a hole insert diameter of 4.45mm, and single and multiple pinhole arrays with hole insert diameters of 2mm. Using a multiple pinhole array, the experimentally measured sensitivity was improved by a factor of 2.33. In this test, we used a 1D design of the array. Using the same design in 2D, the improvement in sensitivity reached a factor of 5.67. The ratio of the gamma-radiation activity of the 2mm system to that of the 4.45mm system was 4.95, which corresponded to the ratio of the respective pinhole areas. Figure 2(a–c) shows the experimental results obtained with an image accumulation time of 18s.

We also integrated a digital micromirror device (DMD) into the imaging lens of a near-IR camera. The DMD provides the same transmission function as the time-variable set of pinholes, by determining whether energy reaches the detector according

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Figure 2. Using the same scan time, we achieved improvements in sensitivity, efficiency, and signal-to-noise ratio via lens-free imaging, as shown for the three systems we used for image acquisition. (a) Single pinhole of 4.45 mm diameter: low resolution. (b) Single pinhole of 2 mm diameter: low sensitivity. (c) Array of multiple pinholes of 2 mm diameter: high resolution and sensitivity. (d) Photograph of the sample object (the blue plate) in the single-photon emission computed tomography gamma camera.

Figure 3. (a) Our experimental setup combining a digital micromirror device (DMD) with a near-IR camera. (b) Full field of view (FOV) of the camera (not limited by the sensor size) with the three parts of the FOV. (c) Reconstruction of the three parts of the FOV obtained from three captured multiplexed images with sizes of FOV/3 (each for a single state of the DMD). To the position of the micromirrors. After capturing a set of time-encoded images—for each image, a different distribution was displayed on the DMD—and performing the relevant decoding, we obtained a significantly extended FOV in the near-IR region. Using the configuration shown in Figure 3(a), we demonstrated that the FOV increased by a factor of 3. Figure 3(b) shows the full FOV (not limited by the sensor size), together with its three component parts. Figure 3(c) shows a reconstruction of the three parts of the FOV obtained from three captured multiplexed images with sizes of FOV/3 (each for a single state of the DMD). It can clearly be seen that the reconstruction in Figure 3(c) is a very good match for the full FOV reference image in Figure 3(b).

In summary, our main technological advances include the fact that we have demonstrated our unique method for lens-free imaging in an integrated, portable camera prototype operating in real time. Our main advantage with the DMD-based method for FOV extension lies in the fact that we have now widened the field of use of this method from the visible to the near-IR region.

We now intend to carry out clinical trials incorporating our time-variable array into a SPECT system, with the aim of demonstrating that reducing the radiation dose by one order of magnitude is feasible and will enable improvements in diagnostics. We also intend to develop a near-IR camera using our DMD system for use in security applications, our aim being to obtain an FOV with dimensions three times larger than those allowed by the physical optics of the sensor.

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References


