360º snapshot imaging with a convex array of long-wave infrared cameras

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Abstract: Long-wave infrared imaging systems remain prohibitively expensive for many high-pixel-count applications, such as panoramic imaging. We present a computational imaging solution which allows for low-cost, 360º long-wave infrared panoramic imaging at video rate.
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1. Introduction

A high-pixel-count detector used with many-element germanium lenses makes long-wave infrared (LWIR) cameras very expensive for wide field-of-view (FOV) or panoramic imaging. Recently, there have been significant advances in the development of compact, low-pixel-count detectors that, thanks to employing small detector arrays, enable the use of inexpensive silicon lenses [1], as they can be made sufficiently thin to have acceptable transmission. We present a computational imaging solution for video-rate and 360° LWIR panoramic imaging by integrating a circular array of such compact cameras.

Traditional approaches to extreme FOVs through conventional optical design, such as in the design of fish-eye lenses, require high levels of optical complexity and large amounts of germanium, increasing system complexity, size, weight and cost. Moreover, they suffer from high distortions, and are subject to the classical trade-offs between FOV and angular resolution set by the limited pixel count of the single detector array. Other reported approaches use panoramic reflective surfaces [2], hyper-hemispherical lenses [3], or multi-scale imaging through a monocentric lens [4], (which demonstrated gigapixel imaging in the visible [5]). The latter is a paradigmatic example of parallelized

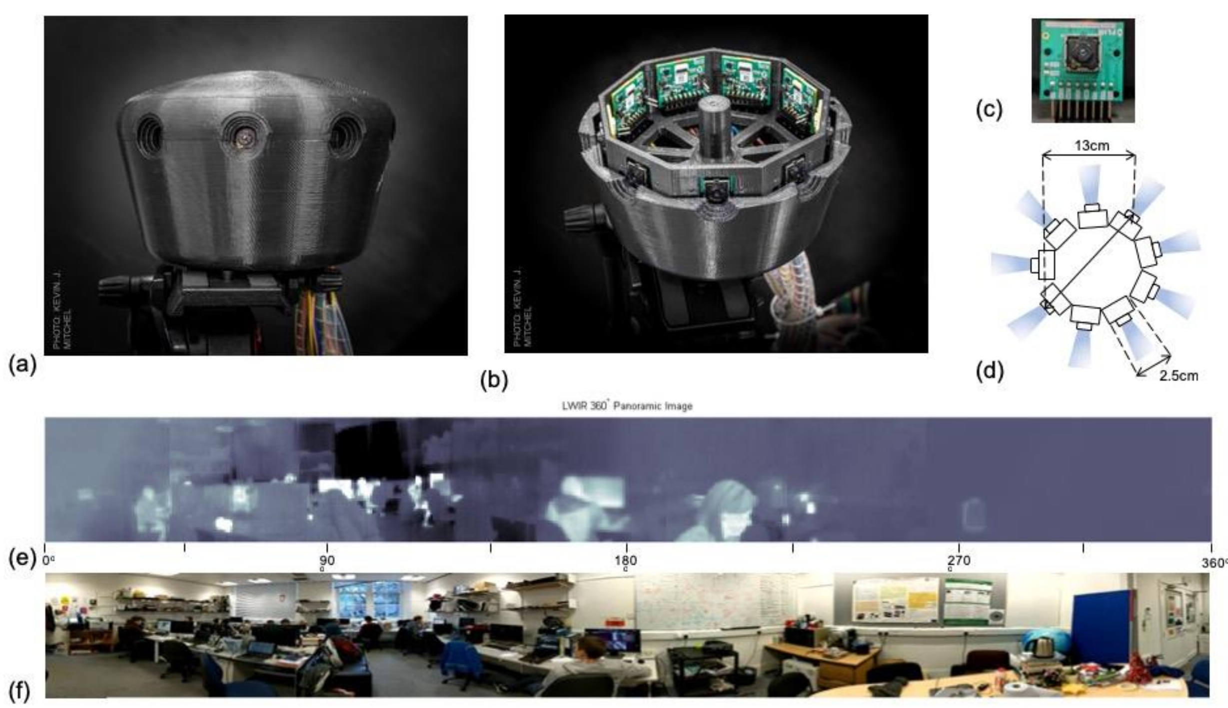

Figure 1 (a) A circular array of 9 LWIR cameras, (b) the internal cross-section of the circular camera array. (c) A single FLIR lepton camera and breakout board. (d) Schematic of the convex camera array. (e) Preliminary results of a 360º LWIR infrared panoramic image, (f) a visible panoramic image a similar scene to (e), (captured on a mobile phone).

cameras as a means of alleviating optical complexity through computation. This parallelization can also be implemented in multi-aperture [6], and integral imaging [7]. Multi-scale imaging reduces the optical aberrations at a local region of the FOV by creating a curved focal plane that is imaged through multiple apertures. Here, we employ a circular array of independent imagers that effectively recreate the curved focal plane to enable extreme FOV imaging, providing complete 360° panoramic imaging. Importantly, as each sub-imager is optimized for a reduced FOV, the system can afford fast imaging at f/1.1 with reduced optical complexity and can be mosaicked to provide arbitrary aspect ratios without significant distortion.

2. Results

We present a snapshot 360º panoramic imaging system, pictured in figure 1a, and figure 1b, consisting of a convex circular array of 9 FLIR Lepton cameras, figure1c. Each camera has a detector of 80 x 60 pixels and uses a f/1.1 silicon-doublet optic with a focal length of 1.4mm, achieving a 50º field-of-view. Data acquisition is centralized and controlled by a Raspberry Pi B 2+. The system is priced at roughly $2000, significantly smaller than the current state-of-the-art, and is portable with a diametric footprint of 13cm. Due to the small size and cost, applications of this technique lie with integration into battlefield equipment, such as airborne surveillance or helmets to give 360° situational awareness.

The simultaneous images from each camera are co-registered and combined to create 360° panoramic imaging at video rate, and preliminary results are shown in figure 1e. Figure 1f, is a visible panoramic image of a similar scene to allow for comparison. The LWIR cameras individual FOVs overlap by approximately 10º's and provide a final resolution of 576 x 60 pixels. This resolution is scalable to an arbitrary large number as pixel number depends on the number of cameras used.

3. Conclusion

We present a computational imaging solution for capturing extreme FOVs at video rate at LWIR wavelengths, using inexpensive components. The approach is based on the integration of independent sub-imagers that mosaic a combined FOV, thus enabling arbitrary aspect ratios. We have shown complete 360° panoramic imaging in a snapshot, however this flexible approach is scalable to other geometries, including 4π hemispherical imaging. Furthermore, by optimizing the overlap, computational super resolution can be applied to further increase the effective pixel count and aperture disparity allows for depth estimation.

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