Multi-channel, Agile, Computationally Enhanced Camera Based on the *PANOPTES* Architecture

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Abstract: A multi-channel, agile, computationally enhanced camera based on the ***PANOPTES*** architecture is presented. Details of camera operational concepts are outlined. Preliminary image acquisition results and an example of super-resolution enhancement of captured data are given.

OCIS codes: (110.0110) Imaging systems; (100.6640) Superresolution

1. Introduction

The ***PANOPTES*** (***P***rocessing ***A***rrays of ***N***yquist-limited ***O***bservations to ***P***roduce a ***T***hin ***E***lectro-optic ***S***ensor) architecture is an adaptive, thin, agile, multi-resolution, computational imaging architecture [1-5]. The distinguishing characteristic of the architecture is it adaptability, which allows each subimager's field of view (FOV) to be steered to interrogate regions-of-interest, and the resulting data are digitally processed to extract high-resolution detail. Figure 1 depicts the notional concept. In this figure, arrays of segmented MEMs micromirror arrays perform the steering action and a single injection molded optic performs the imaging as described in [6]. Such a system can approach the performance of a high-resolution bulk imaging device – and even potentially surpass it in situations where only a small but varied percentage of the image field is of interest.

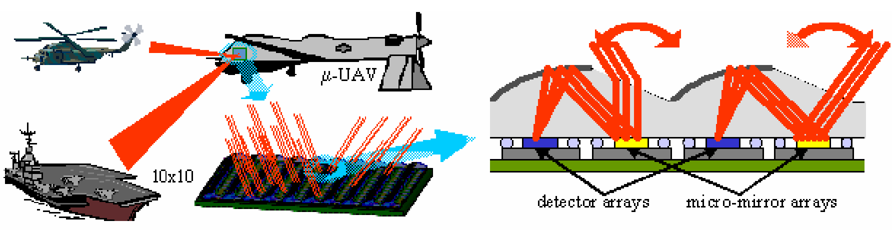

Figure 1: Schematic Depiction of PANOPTES Concept.

This paper describes work done towards a field test of an imaging sensor based on a variant of the ***PANOPTES*** approach. In this variant, a single low resolution, but wide field of view (WFOV) imaging sensor, as would be typical for a small UAV platform, is utilized for situational awareness. This WFOV imager is augmented with 4 roaming narrow field of view (NFOV) sensors which collaborate to provide increased resolution in regions of interest. This sensor is therefore capable of simultaneously providing wide-area surveillance, targeted high resolution imagery for reconnaissance and concurrent tracking of multiple targets. These NFOV imagers can be used to look at various regions of interest with a larger magnification ("zoom") or employed to implement super-resolution imaging of selected regions of interest within the WFOV low resolution image. This breadboard device is an important step towards enabling researchers to explore a new imaging paradigm in which the best attributes of low and high resolution imaging and their computational enhancement are combined. This device, once properly miniaturized, will be capable of greatly enhancing the ability of mini and micro UAV platforms to detect, identify and track targets of interest without having to carry large and bulky optics.

2. Prototype description

The conceptual layout of the modified PANOPTES system is shown in Figure 2. It comprises of five optical channels which utilize the same focal plane array (FPA). In the center is the WFOV optic, while the four corners of the FPA are used by the NFOV optic channels. Each NFOV imager incorporates two flat mirrors: the mirrors closest to the FPA along the optical path just fold the optical path, whereas the mirrors closest to the object (furthest from the center of the FPA) are gimbaled, thereby providing steerable FOVs. Custom designed lenses were manufactured for this prototype. The WFOV lens (used to provide situational awareness) is nearly diffraction limited across its operating waveband, but its spot size is larger than a single FPA pixel. However, NFOV lens, also nearly diffraction limited, provides larger magnification than the WFOV lens, i.e., it "zooms" the scene – and its spot size is substantially smaller than the pixel size. This enables implementation of super-resolution algorithms, boosting resolution of NFOV channels by approximately the same factor as the "zoom" does, allowing the operator to use imaging resources in an optimal way. Figure 3 shows the main parts of the prototype system. The *Optical head* collects images via the single fixed WFOV and the four steerable NFOV channels, which share a common focal plane array. The *On-board computer* controls the NFOV steering mirrors, FPA image acquisition, metadata collection and image and metadata transfer to the onboard mass storage device. The operator controls all pertinent payload functions via a graphical user interface, which can also be used for lab calibrations and boresighting of the optics. *Image reconstruction*, analysis and enhancement is performed off-line on the collected imagery using algorithms specifically developed for this application.

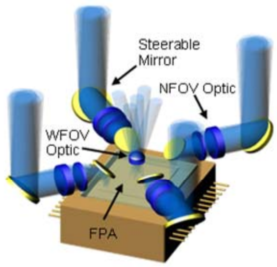

Figure 2: Conceptual Layout of the imager.

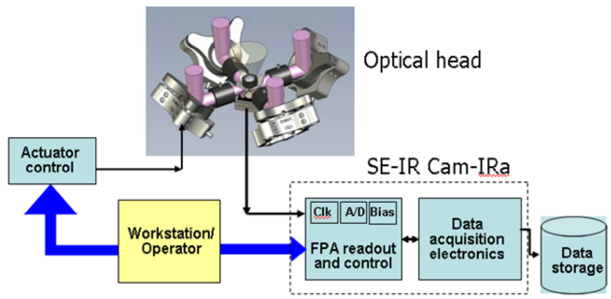

Figure 3: Main Components of the PANOPTES prototype.

Figure 4 shows several possible steering patterns for the NFOV imagers. The larger circle with the green background represents central part of the WFOV, while the smaller yellow circles depict respective fields of view of the NFOV imagers and sample patterns for their relative positions. The operator can move all four NFOVs independently and look at four different locations within the WFOV scene simultaneously with larger magnification, or can group them in some specific pattern and point to a desired location in the WFOV scene. One of the patterns, *max-resolution*, has four NFOV imagers looking at the same spot, but with sub-pixel mutual shifts. This effectively provides four different looks at the same region, which can be exploited to further improve resolution in the image through super-resolution algorithms. Another pattern, *foveated vision*, forms a higher resolution spot comprising of partially overlapped fields of the four NFOV imagers – akin to human eye's fovea – and can be moved around the WFOV scene to get a better look of larger areas of the scene. In this way, by tailoring the pattern to the scene, the operator can optimally utilize imaging resources of the platform by placing most of the available space-bandwidth product into areas of the scene which are of the most interest. Figure 5 shows a photograph of the ***PANOPTES*** optical head. The WFOV lens is in the upper center square plate, while the NFOV lenses are looking sideways. Steering mirror gimbals and associated actuators are also visible in the front. The size of this payload is relatively

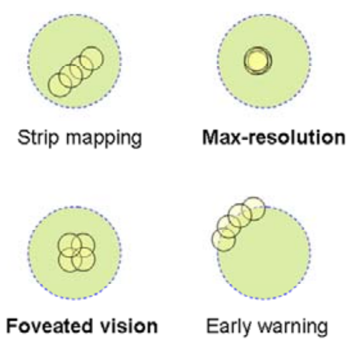

Figure 4: Some possible imaging modes.

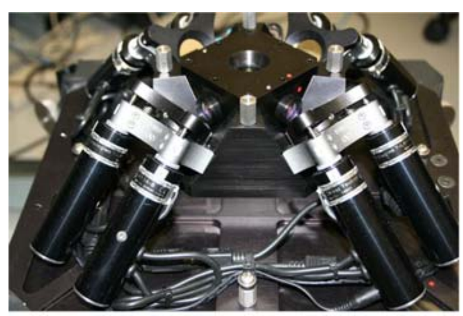

Figure 5: Photograph of the ***PANOPTES*** optical head.

large, as the goal was to explore and prove the concept rather than to build the smallest possible device.

In future versions of this system, we plan to include automated algorithms which will analyze the information content of the scene [5], based on criteria which quantitatively define the degree of importance of various shapes and structures, and steer resources so that maximum amount of information is extracted from the scene without human intervention. This approach, combined with a number of other possible enhancements, could yield a very versatile, compact and powerful imager. These enhancements could include real-time super-resolution, insertion of a laser illuminator into each NFOV channel, use of different spectral coatings on steering mirrors for multispectral image collections, implementation of micro-mirror devices for FOV steering, and general miniaturization of the camera. This device would be ideally suited for micro UAV platforms that could, either as separate entities, or combined into a net-centric swarm of miniature surveillance devices, provide critical battlefield information in a covert manner, especially in urban areas, where larger UAVs are difficult to use.

3. Imagery Collection and Analysis Results

The ***PANOPTES*** prototype was tested, validated, and calibrated in the lab, and subsequently used for a number of field data collections. A graphical user interface was developed to collect images of various targets using some of the patterns from Figure 4. A sample image is shown in Figure 6. It shows a WFOV view of an urban scene, and four NFOV looks of the same scene, chosen by the operator because they contained some features of interest. The increased resolution in NFOV channels is obvious in this Figure.

Figure 6: Sample image from PANOPTES system showing all 5 FOVs. The low resolution WFOV is the central image, whereas each corner contains 1 steerable, zoomed NFOV.

To facilitate testing of super-resolution algorithms, we constructed a number of discrete 3-bar targets. An example of resolution boost achievable with this approach is illustrated in Figure 7, on the left of which is the original image of the resolution target through a single NFOV channel. On the right is the image of the same target processed using super-resolution algorithms and all four NFOV images. The super-resolution algorithm first estimates the relative pixel offsets between the various subimagers using a correlation approach and verifies that these match the expected shifts from our calibrated set up. These offsets are then used to generate a single high resolution approach using a gradient based least squares approach. The gradient based approach quickly converges and results in the increased resolution image as shown in the Figure.

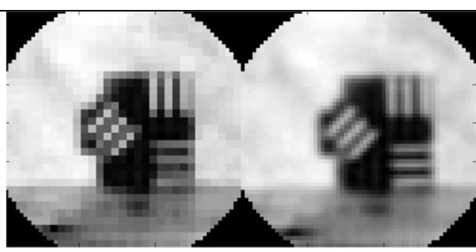

Figure 7 : Super-resolution enhancement of a 3-bar target.

4. Acknowledgements

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5. References

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