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Adaptive Image Processing Techniques for Camera-On-A-Chip Sensors

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Abstract

We report on recently developed algorithms and architectures capable of point source target detection near or on the FPA. The goals of this work are to demonstrate image processing functions near or on the FPA in a manner efficient enough to allow hardwired algorithms for Camera Systems on a Chip (SOC) implementation. These SOCs have the potential to improve the size and power requirements for existing IR sensor systems which require larger board sets and hardware enclosures. We report on the algorithm development for hardwired target detection algorithms using recorded IR Data.

Keywords: FPA, System-on-a-chip, Near FPA Processing, Long Wave Infrared, Biologically Inspired Processing

1. Introduction

The emergence of advanced sensors with near and on Focal Plane signal processing has created interest in the Visible and IR Sensors markets. Several architectures to conduct image processing near the FPA have been integrated into compact sensor systems [1,2,3]. In addition, several major programs to increase the performance of sensors by stacking Silicon ROICs and novel circuit designs have been underway at DARPA, ARMY, and USAF facilities[4,5,6].

There is a continuing trend in the miniaturization of both visible and IR sensors. This can be seen in both the commercial camera market and the DOD sensors market. Like many other technologies, the trend is towards smaller package sizes, ease of use, and more functionality. Currently, many advanced EO vision sensors provide a useful image, but require large interface electronics for storage of data and management of the images. Often the storage and data maintenance is a arduous task. Thus SOC based FPAs are intended to offer an alternative to storing and processing the large volume of raw data that is produced by todays large formats sensors.

There are compelling reasons to create more sophisticated sensors that implement high levels of signal processing and target detection on or near the focal plane. In our world today, there more crimes involving subversive and hidden agents. The threats of terrorism, hidden bombs, homicide bombings, and secretive planning and movements are occurring without being detected. Man portable missiles threaten commercial and DOD aviation and ground vehicles. It will be impossible to defeat these subversive threats without a failsafe, affordable, and highly automated method of early detection.

On or near FPA processing is an enabling technology for Systems on a Chip that provides a potential solution to these threats, while providing the most relevant data from densely dispersed sensor networks.

2. Goals for Near and On FPA Processing

Cyan Systems goals for On FPA processing are to automate and provide more useful data to the end user in a near instantaneous manner. Recent attempts to integrate more and more processing near the FPA have been largely successful. A number of defense and security benefits will stem from the ability to automatically monitor and track larger fields of regard electro-optically with near instantaneous notification of a specific type of event.

The long term vision is that near and on FPA algorithms will provide a great degree of automation and efficiency in the detection of different scenarios. We would like to develop more cognitive sensors with a greater degree in the specificity of the target types to detect, i.e., a point target growing in intensity or a nearby vehicle. If we can detect and identify specific target types, then we will enable the ability to place sensors anywhere and provide 1000’s of sensor inputs to a central location. This allows a scale of efficiency so that very large segments or regions can be monitored for a specific activity 24 hours a day without the requirement of a dedicated staff of human viewers and intelligence gatherers in the loop.

Cyan Systems focus is on exploiting the inherent parallelism in ROICs and biological vision systems to migrate more of the post processing functions and tracking algorithms to on the Focal Plane.

3. Near FPA Processing Architectural Considerations

During the last 20-30, years research performed by various vision science groups focusing on the image processing in vertebrates and other biological vision of animals has been ongoing. Recently, researchers have been attempting to understand how the human vision system works and to mimic this higher level visual processing[7,8] using silicon circuits. Several texts have been written on the functionality of the cell layers in the eye[9], and describe techniques for performing dark/light adaptation, color detection, and inhibition which leads to spatial and temporal processing, including edge detection and other functions. Some of the pioneering work was done by Carver Mead and his fellow researchers. All sensors have a basic analogy to the eye, that is they have a lens and a focal plane like the eye. But there are major differences between the retina and man-made sensors. The retina is highly curved with several key processing layers directly adjacent to the retina[10], as illustrated in figure 1.

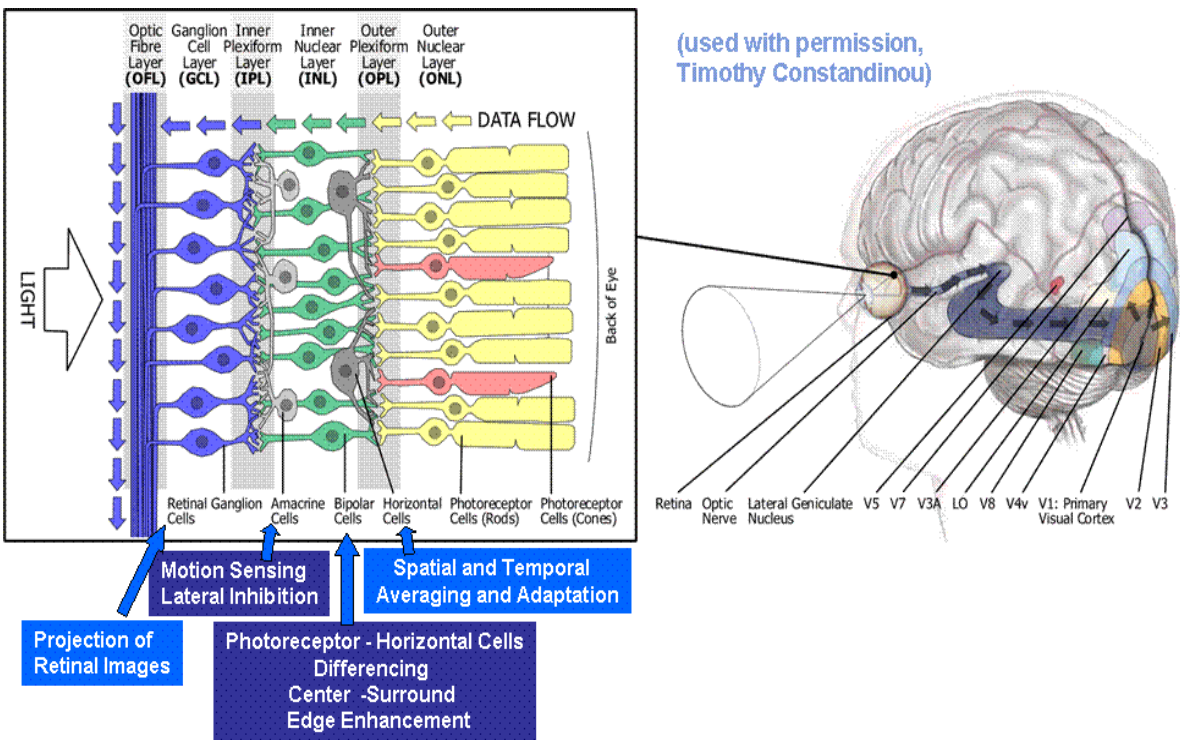

Figure 1. Human vision system processing pathway diagram shows the relative sophistication of natural vision systems. (with permission, ref. 10)

The eye provides highly parallel low bandwidth processing of the eyes rods and cones which is performed up front prior to sending the pre-filtered image down the optic nerve. In contrast, machine vision typically integrates the raw signal on the FPA, and the data is then processing in a larger off focal plane dedicated electronics set.

Engineers are attempting to understand biological vision systems to the point where we can develop electrical circuit models that mimic the parallel processing abilities of biological vision. More analog/digital parallel near FPA processing is made possible by the continuing improvements in ROIC design.

In order to effectively mimic portions of biological vision we need to understand in more detail the intricacies of the biological vision and contract the electrophysiology of the body against classical electrical circuits. The visual system which operates on electrochemical wiring of the body is so much more advanced than our most mature manmade systems that understanding the actual performance of biological vision systems is a long term endeavor, to say the least.

Our goals for creating image processing functions are to attempt at some level of accuracy, mimic portions of the retina and also processing functions that occur farther back in the brain to perform elementary feature extraction such as target detection amongst moving and stationary clutter. Advanced forms of image processing may be possible because dense ROIC circuits are being fabricated by increased densities and layers on Silicon Readout integrated circuits, as well as the stacking of ROIC layers together in 3 dimensions, such as the DARPA Vertically Integrated Sensors Array program is pioneering.

Of the main limitations to manmade sensors is the bottleneck of serial processing, or the lack of implementation of parallel on FPA processing. The bandwidth limitation results in an inability to place higher level processing functions on FPA. This serial data processing places an enormous burden on our military and homeland security personnel, because a fully automated sensor with automated target detection and tracking is large, power consuming and heavy. Parallel processing based near/on FPA algorithms are a key enabling technology to create the high performance sensors needed to identify threats remotely, and also relieve our security forces of the performance limitations, burden and expense of existing target detection systems.

4. Algorithm Development for Near/On FPA Processing

Cyan has investigated a set of algorithms for the development of near FPA algorithms for NOVA Sensors[11] Near Focal Plane processing electronics system.

In order to achieve high fidelity image processing performance, we have focused on a technique called “Saliency”. Saliency motivations come from work performed by C. Koch, and L. Itti[12]. Figure 2 gives an example of the key image processing steps and a simplistic point source transformation by the algorithm. The key functions of Spatial Filtering, Difference of Gaussian Processing, and Thresholding, and Spatial filtering in visual processing is described in more detail by C. Mead[13].

The concept of Saliency deals with performing classical image filtering on features in the 2 dimensional scene. This includes performing standard filtering on the intensity, feature orientation, and spectral information in the scene. After this first layer of filtering, the data undergoes local area processing with center surround processing and difference of Gaussian (DOG) processing similar to what occurs in the retina[9]. Then after the center surround processing of intensity, features, and spectral band, maps of Conspicuity and Saliency are created with features of each DOG map used to create a representation of the most "salient" feature.

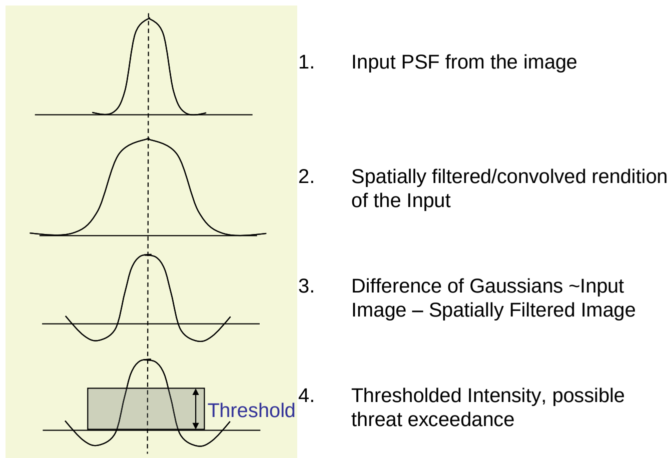

Figure 2. Processing Near the FPA using nearest neighbor convolutions.

Cyan Systems considered the combination of classical type linear filtering combined with the DOG center surround like processing inspired by Carver Mead to be a good candidate for the Nova Sensors FPGA based hardware development, because the Saliency could be modified for IR and visible sensors. More importantly, our modified Saliency uses only local area type of processing, making it compatible for near FPA hardware implementation.

Cyan Systems has developed a version of Saliency optimized for EO/IR imagers. The signal processing flow diagram is shown in figure 3.

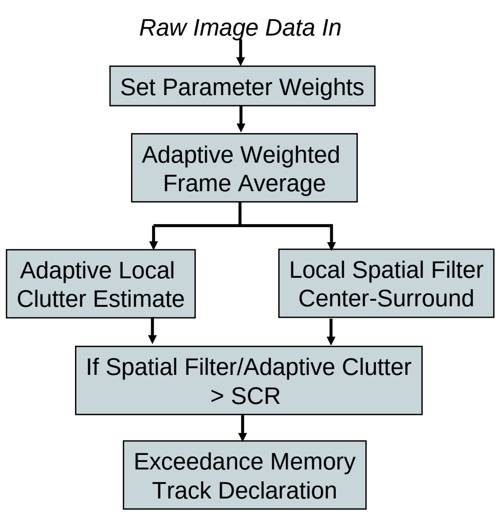

Figure 3. Processing blocks and parameters of the on/near FPA Saliency algorithms.

Key benefits of the modified saliency algorithms are that all the processing blocks shown in figure 3 are performed only over a local area in the focal plane region. Using the local area processing allows an abstraction of the concept of the bipolar, horizontal, and ganglion cells performing various temporal and spatial filtering. Nova Sensors is developing FPGA hardware for near FPA implementation. Since this algorithm lends itself to all local area processing, it is a candidate for full implementation on the FPA, which is the subject of ongoing development.

5. Processed Results

In order to validate the performance and feasibility of the near and on FPA processing algorithms, we developed software code of the block diagram shown in figure 3. Simulation software was coded in MATLAB and recorded image sequences from visible and IR Sensors were used to evaluate the near FPA image target detection algorithms performance. The near/on FPA processing software mimics near FPA processing of data assumed to be stored in capacitors in the unit cell and that lateral charge sharing results in a Gaussian blur such as what occurs in the difference of Gaussian type processing performed in recently demonstrated "Smart" sensors. In addition, all other types of processing including frame averaging and temporal filtering have been implemented with single pole discrete filters as this is a simple method for FPGA implementation.

Figure 4 below is a 20 frame sequence from a visible sensor with a target in the field of regard. This image set illustrates the ability of the algorithms to detect objects in clutter.

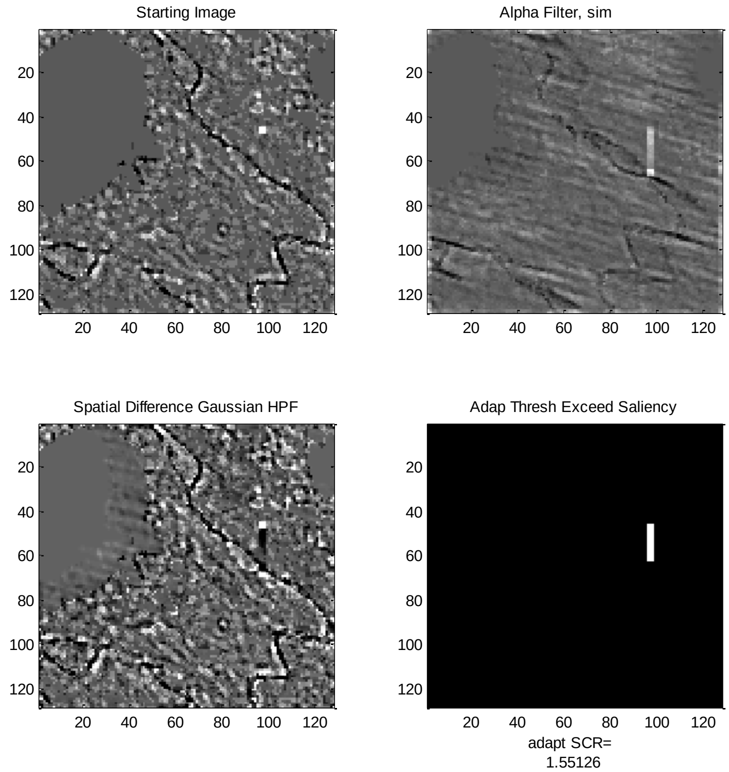

Figure 4. Visible sensor data is processed with zero false alarms using fixed threshold, alpha, and n coefficient Saliency algorithm.

The data from the output of the signal path of the modified saliency algorithms is shown for each major processing block to give the view of the data at each point in the processing chain.

It is important to quantify the performance of the processed data from the near FPA image processing algorithms. To this end we have run a series of a hundred frames from 2 different data sets, with no false alarms. Obviously the false alarm rate (FAR) and probability of missed detection should be performed with a large target data set utilizing variations in the target signal to noise (SNR) ratio to create a receiver operator curve. Cyan System will be able to perform a detailed analysis on the long term FAR when a full data set with variation in target SNR becomes available.

Figures 5 and 6 below shows processed data sets from the Long Wave Infrared 256 x 256 Adaptive IR Sensor[14]. The optics and scene clutter are different, but the same algorithm is used to detect dim targets in different camera configurations. The lower right frame in each figure shows the track history of the exceedance or target location over a series of past frames. Figure 5 shows processed data from a sniper rifle test conducted in Santa Margherita, California. As can be observed in the image sequence, the bullet is tracked in the LWIR as it ingresses from 1 kilometer range.

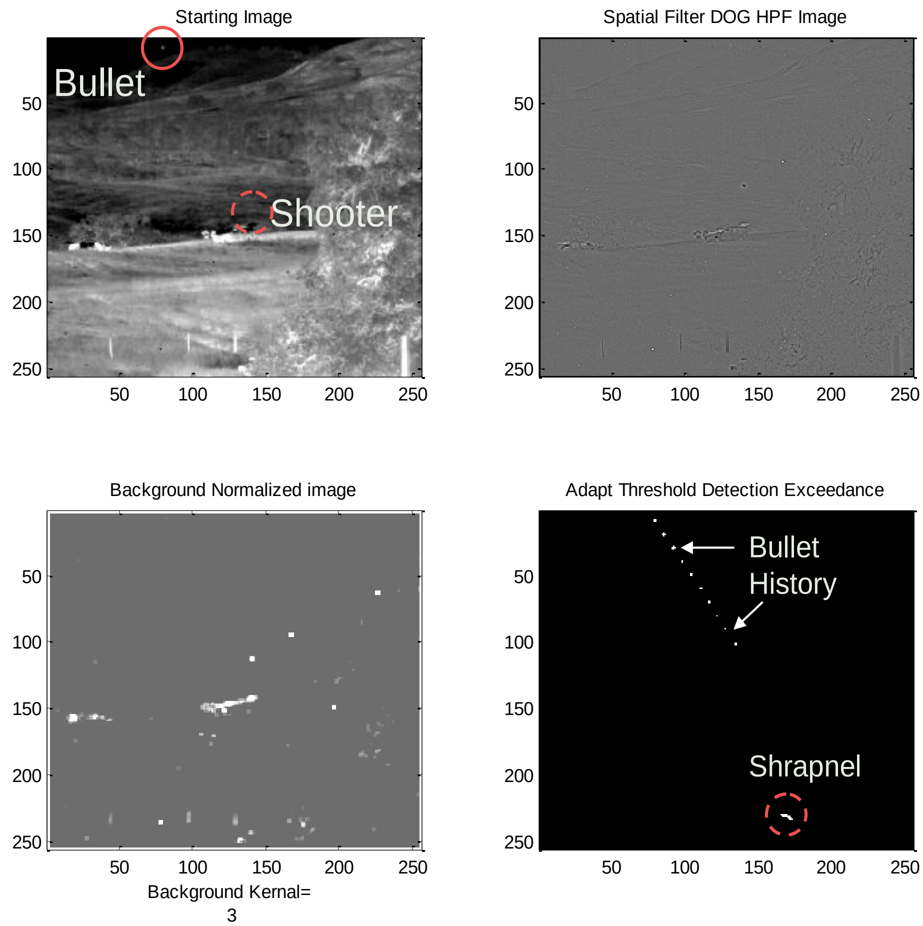

Figure 5. Wide field of view data from the NOVA AIRS sensor. The Near FPA algorithms detected bullets inbound from 1 km.

Another benefit in addition to the compactness of the SOC algorithms is the reduction in data bandwidth. With the size of EO Sensors going towards larger formats of 2K x 2K and greater, the On FPA target detection suite offers an ideal blend of image compression that can be on the order of 100,000:1 for low target rates, and allows pre-filtering of useful target data to a remote location. More metrics on the effective compression are forthcoming.

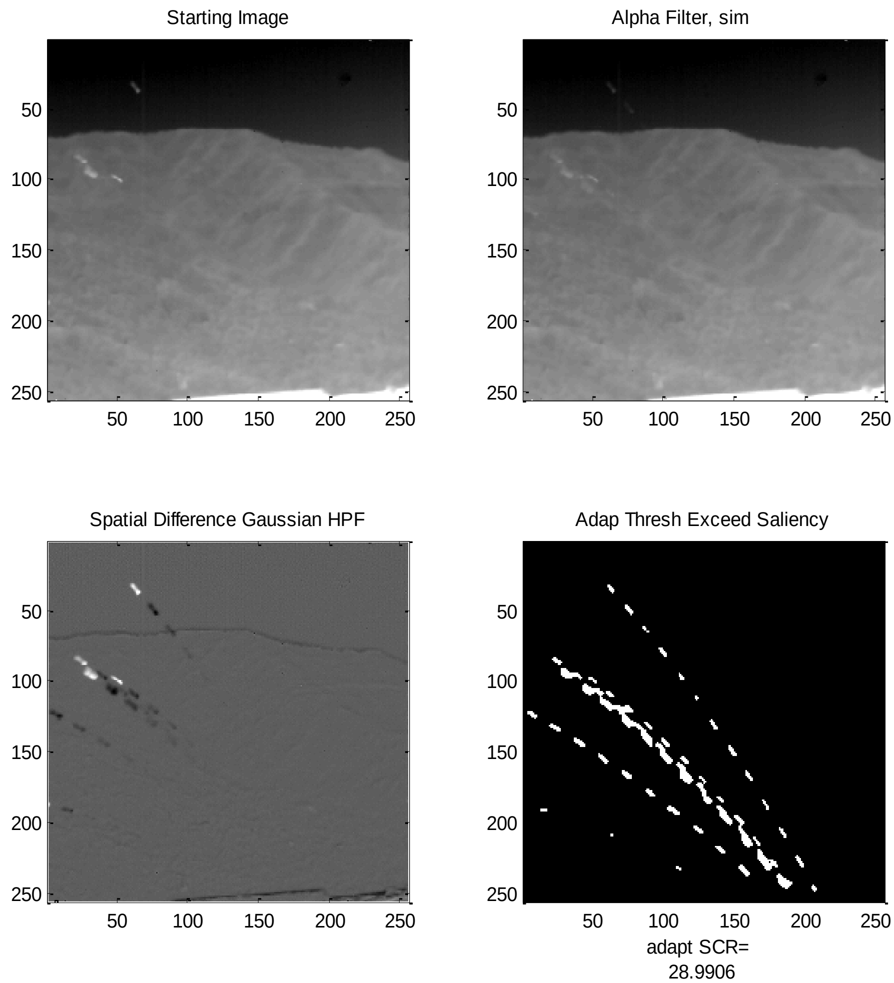

Figure 6. Data from the NOVA AIRS sensor using with targets passing through field of regard. Near FPA algorithms detect motion and starting location of the simulated threats.

6. Summary

We have developed and simulated near and on FPA capable algorithms that are targeted for implementation near the Focal Plane using dedicated FPGA electronics. On –the-FPA processing sensors such as the Mead Silicon retina and the AIRS FPA have resulted in improvements in the sophistication of near FPA processing for target detection. The performance of the near FPA algorithms has been demonstrated on real test data with dynamic targets in cluttered environments.

Using real recorded data sets from several visible and IR sensors, we have proven that near/on FPA processing can be performed with good fidelity. However, since this is a first attempt as using these novel near FPA type processing algorithms, metrics must be established to determine algorithm feasibility and the ability to detect targets without degrading the algorithm sensitivity,false alarm rate, or detection range.

Very high levels of cognitive type processing are now the subject of research[15], and quite possibly in the next decade researchers may uncover methods of semi-cognitive types of processing for visual systems such as facial recognition near the Focal Plane. Figure 7 provides a visionary roadmap for potential future sensor architectures leading to enhancements of biologically mimicking sensors.

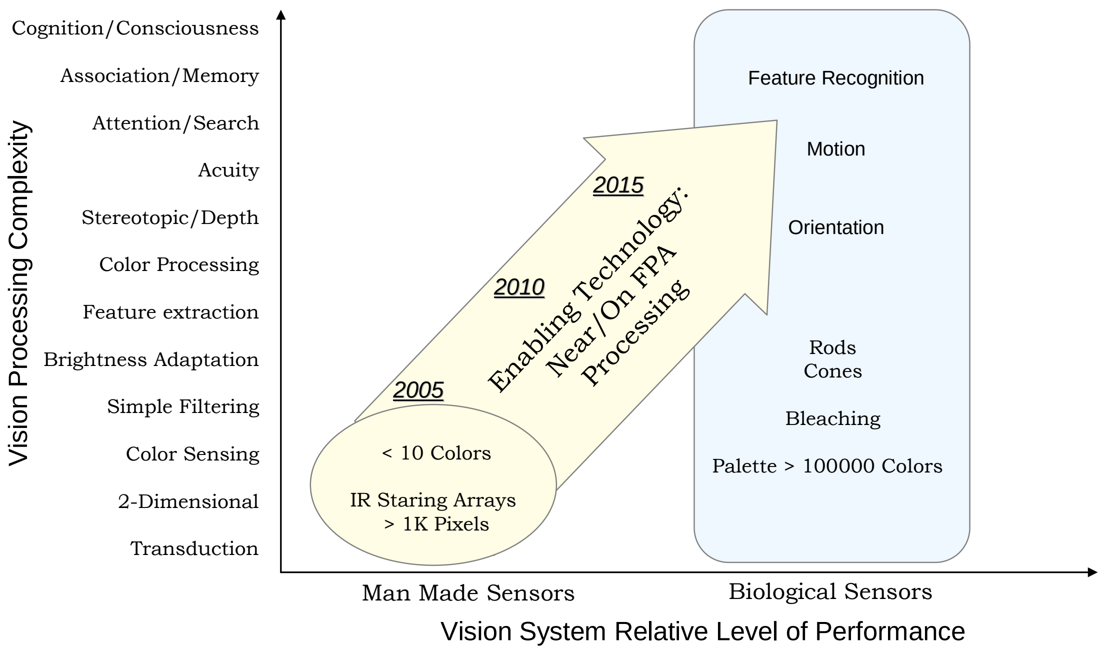

Figure 7. Comparison of capabilities and performance of man made versus biological vision systems indicate that near or on FPA processing with mostly analog processing is an enabling technology for the realization of highly sophisticated vision systems.

There is a potential payoff in terms of expendable and replaceable sensors with on FPA processing due to the ability to extract targets and send high value data at a low bandwidth to a central site. These near FPA algorithms have been tested on > 8 data sets from a variety of Visible and IR sensors. Three processed data sets were demonstrated with successful detection of dim targets with no false alarms created over 100's of processed frames.

The end result will hopefully yield a new generation of very compact, highly integrated, high performance sensors that can operate autonomously. This should result in a protective network of inexpensive system-on-a-chip cameras suitable for the a wide variety of DOD and commercial IR sensing applications.

7. Acknowledgements

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