

# True-Color Night Vision (TCNV) Fusion System using a VNIR EMCCD and a LWIR Microbolometer Camera\*

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## ABSTRACT

A fully functional, prototype night vision camera system is described which produces true-color imagery, using a visible/near-infrared (VNIR) color EMCCD camera, fused with the output from a thermal long-wave infrared (LWIR) microbolometer camera. The fusion is performed in a manner that displays the complimentary information from both sources without destroying the true-color information. The system can run in true-color mode in day-light down to about ¼-moon conditions, below this light level the system can function in a monochrome VNIR/LWIR fusion mode. An embedded processor is used to perform the fusion in real-time at 30 frames/second and produces both digital and analog color video outputs. The system can accommodate a variety of modifications to meet specific user needs, and various additional fusion algorithms can be incorporated making the system a test-bed for real time fusion technology under a variety of conditions.

**Keywords:** Image Fusion, Night Vision, EMCCD, Microbolometer, Infrared, Low-Light-Level, True Color, Situational Awareness

## 1. INTRODUCTION

Night vision technology has evolved over the past few decades in two directions: (i) reflective light sensitive devices (e.g., image intensifier tubes, InGaAs, and EMCCD detectors), and (ii) heat sensitive (thermal infrared) devices (e.g., HgCdTe, InSb, and microbolometer detectors); both types of devices are essential for night intelligence, surveillance, and reconnaissance (ISR) operations. Reflective devices provide a more perceptually comprehensive image of the scene while thermal devices enable detection of personnel, machinery, animals etc., even in the absence of all illumination sources. Image fusion [1] of these two complimentary types of information has been an active area of investigation over recent years with new algorithms appearing on a weekly basis in various publications. However, there are few algorithms and even less actual systems that utilize the additional information inherent in true color.

Color information is used by the human brain to identify objects and understand its surroundings. Human performance studies have shown true color to improve the accuracy and speed of identification compared to monochrome (e.g., black/white or green/white) or false color [2][3]. An illustration of the difference between true and false color is given in Figure 1 below. Some fusion algorithm mappings and transformations have been used to create color fused images, but such techniques generally do not produce true colors [4] and others [5] that try to mimic true color are in reality a pseudo color scaling (i.e., intensity based) which require a priori training on similar scenes. For such false and pseudo color approaches additional (often vital) information such as the color of a person's clothing, the color of a car, and the color of road signs or lights is not available to the viewer. Only a true-color system that can discern different visible wavelength bands can accurately produce such information.

In this paper we discuss a system that produces fused night vision imagery with true-color information. Not only does the true-color enable familiar objects to be more easily recognized (e.g., grass is green), but the true-color of objects is presented to the viewer (e.g., the red car is red). The system described in this paper is a fully functional stand-alone prototype that generates fused output in real-time using an embedded processor. The rest of the paper is organized as follows: In Section 2 true-color night vision cameras are discussed and specifically the EMCCD camera used in the present system, in Section 3 general consideration for maintaining true color in a fusion system are discussed, and in Section 4 specifics details are given in regards to a True-Color Night Vision (TCNV) Fusion prototype system.

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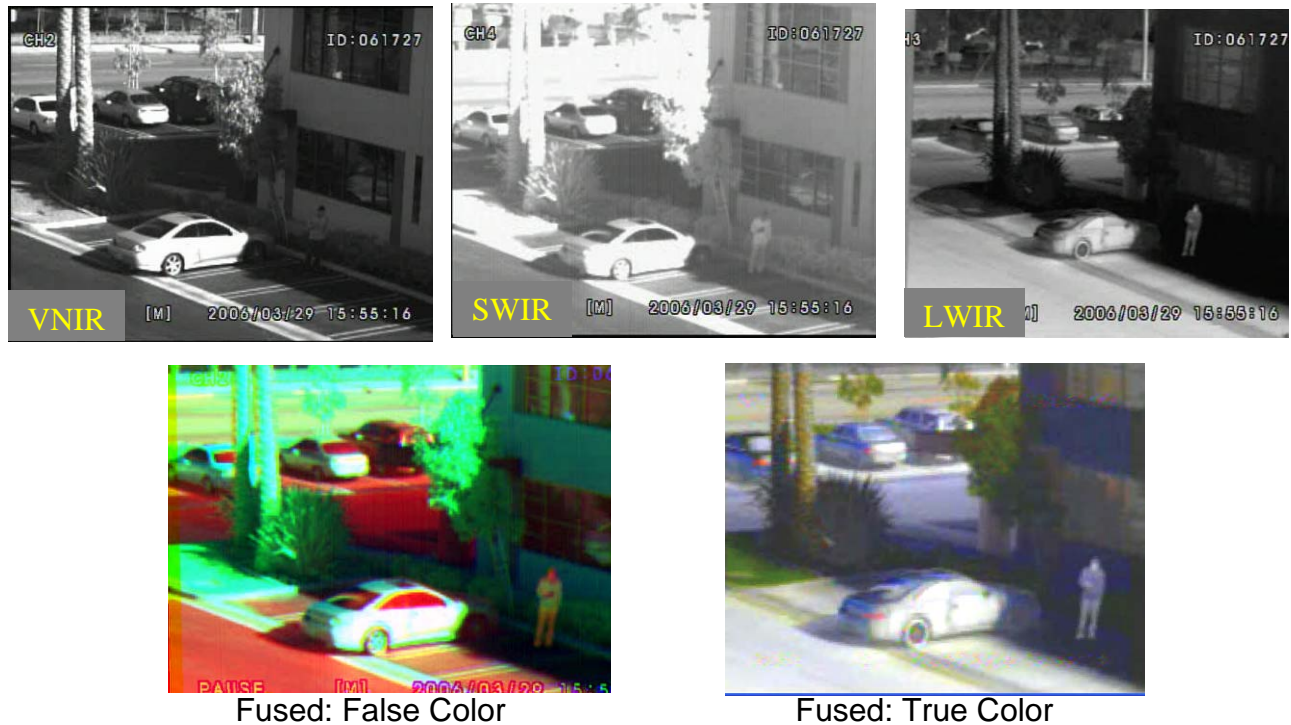


Figure 1. Illustration of the difference between “False Color” and “True Color” fused images. Input images from 3 cameras (sensitive to 3 different wavelength ranges) are shown in the top row and fused output is shown in the bottom row.

## 2. TRUE-COLOR NIGHT VISION CAMERAS

OKSI has investigated true-color night vision technology over the past several years including the development of novel prototypes based on an image intensified CMOS with switchable LC filters [6], the assessment of different types of color night vision cameras [7], and the development of figures of merit for the evaluation of such cameras [8]. For the system described in this paper, true color is obtained using a color EMCCD camera, see Figure 2. The EMCCD chip used in such cameras has a cyan-yellow-magenta-green (CYMG) mosaic filter pattern “painted” on the individual pixels which leads to the relative responses shown in Figure 3.

With an output rate of 30 frames/second (fps) the camera is useable in a color mode down to light levels approximate to  $\frac{1}{4}$  moon conditions ( $\sim 10^{-2}$  Lux) and in a monochrome mode down to approximately clear starlight ( $\sim 10^{-3}$  Lux), lower light levels are possible with longer exposure time (i.e., lower frame rates). Compared to an image intensified (I2) based camera, the EMCCD has the disadvantages that it is not as sensitive as an I2 camera and it consume more power. However, the EMCCD camera has the advantage that it can be used effectively both day and night, is not susceptible to damage from bright lights, and furthermore color versions of the EMCCD exist off-the-shelf.

The EMCCD camera is sensitive to the visible to near infrared (NIR) portions of the spectrum (roughly 400 nm to 1000 nm). The NIR portion is useful for improved sensitivity and is necessary for viewing NIR laser aiming devices, but the fact that the “colored” pixels are sensitive to NIR is detrimental to the color fidelity of the image produced. To mitigate this conflict, proprietary techniques (including use of an additional custom filter and optimized color processing algorithms) have been developed by OKSI for utilizing the NIR portion of the spectrum while maintaining appropriate color fidelity under different lighting conditions.

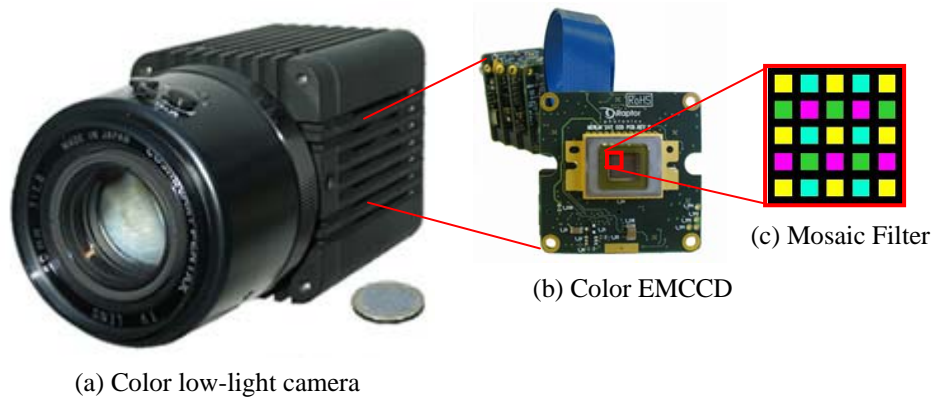


Figure 2. Images of a color low-light-level camera (Raptor Photonics Merlin EM246) using an EMCCD chip with a mosaic filter pattern.

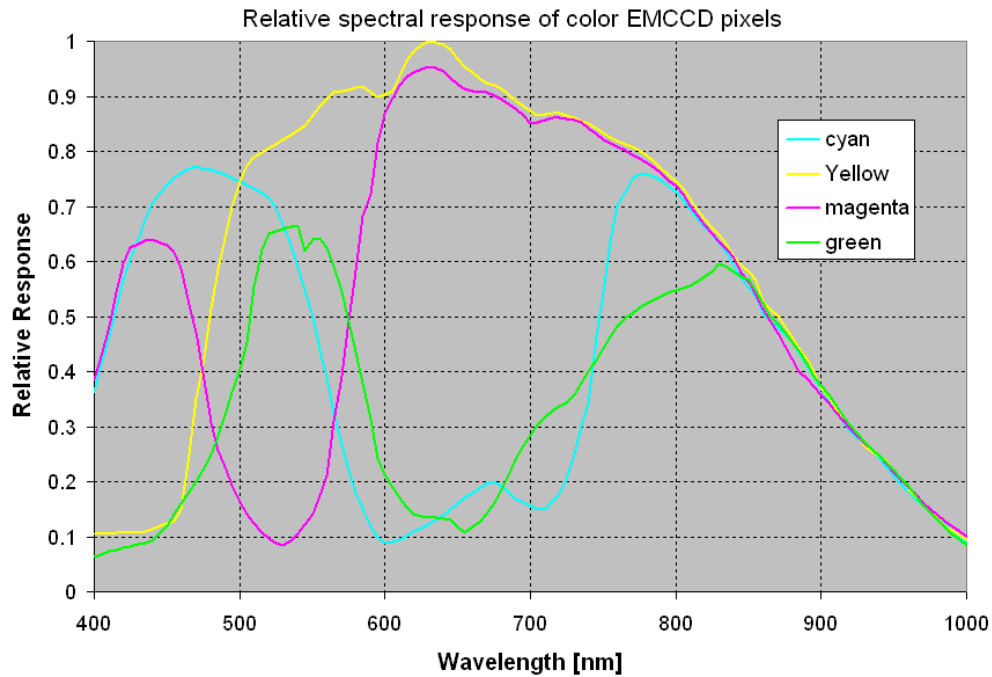


Figure 3. Plot of spectral response of the mosaic filters on the color EMCCD chip.

### 3. FUSION FOR TRUE COLOR NIGHT VISION

Typically, the goal of image fusion algorithms is to effectively combine the information in the separate input images to the fused output image in a manner that maximizes the overall information content. For night vision applications, the success of such algorithms is best measured with human performance task experiments such as scene understanding, object detection/ recognition/ identification tests. For the special case of true-color night vision, the objective assessment of color fidelity is an important metric measuring the ability to convey the additional information inherent with true color.

To render appropriate color fusion output it is beneficial to separate the color values (i.e., chroma) from the brightness values (i.e., luma) using a color space such as La\*b\* or YUV instead of the RGB color space. For the present system the chroma values are obtained directly from the color EMCCD camera, using several proprietary algorithms to improve the color content, and the luma values are determined using an algorithm that fuses the brightness of the two cameras.

Example images illustrating true color fusion are shown in Figure 4. In this figure (a) and (b) are input images and (c) is the final fused output, the image in (d) is simply shown for comparison. The fusion algorithm used to generate the image in Figure 4 (c) was developed to display the significant thermal information (e.g., the man in background and the hot car) while maintaining the true-color information (e.g., the color of the car and presence of a red gas can).

Additional fused output images are shown in Figure 5 with the same chroma values as Figure 4 (c), but with different luma values. Specifically, in Figure 5 (a) the thermal image alone is used for the luma channel (with no VNIR brightness) and in Figure 5 (b) a simple 50/50 blending of the VNIR and thermal brightness is used. These images highlight more of the thermal information; however, the color content suffers. The figures illustrate various fusion schemes that can be controlled by the user to aid scene understanding under various conditions.

Other more complicated fusion algorithms, such as PCA or wavelet based algorithms, can also be used to combine the thermal and VNIR brightness information into a single luma image. However, many of these algorithms produce output that is not conducive for true-color display. The system described in Section 4 can provide a test bed for a variety of such techniques, which in turn enables real-time field testing for a range of applications.



(a) Low-light color visible (VNIR)



(b) Thermal Infrared



(c) Fused output using VNIR + thermal highlights



(d) Low-light-level monochrome visible

Figure 4. Example images illustrating true-color fusion. (a) and (b) are the input images, (c) is the fused image with thermal information highlighted by red rectangles and color information highlighted by green ovals. (d) is simply shown for comparison.

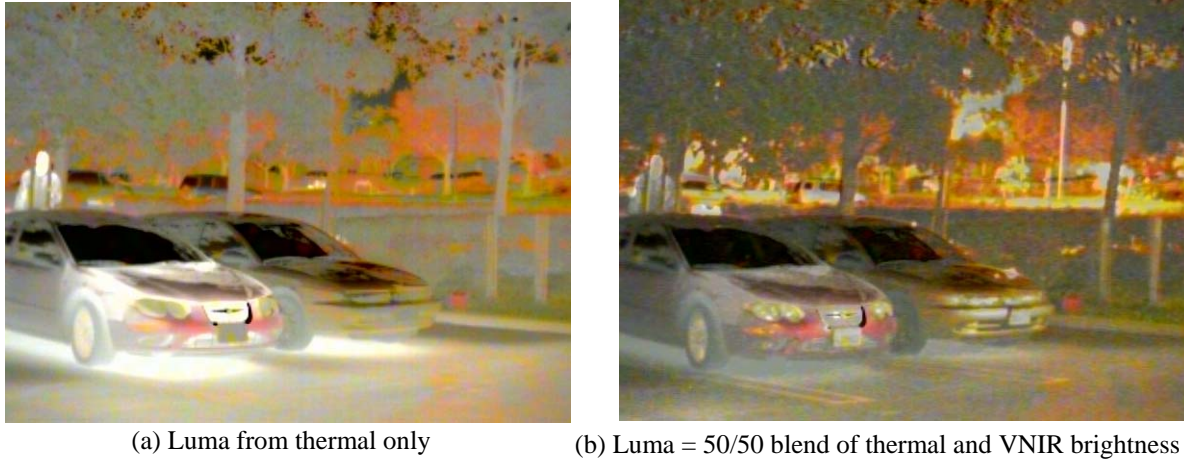
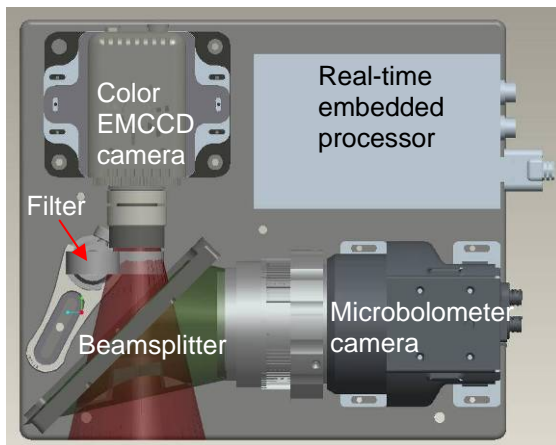


Figure 5. Example fused images using alternative methods for producing the luma component of the fused image. Note: the true-color fidelity suffers in the above examples and has lower color fidelity compared to the image in Figure 4 (c).

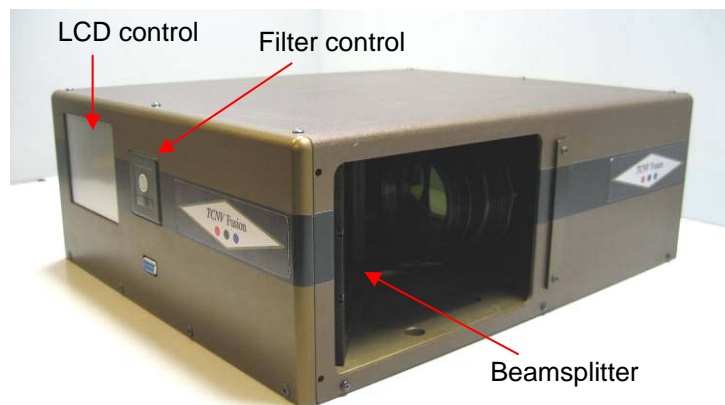
#### 4. TCNV FUSION PROTOTYPE

In this section we describe a fully-functional True-Color Night Vision (TCNV) Fusion prototype, which is shown in Figure 6 and described in Table 1. Principally, the system consists of a color EMCCD camera, microbolometer camera, and an embedded processor. In addition, a dichroic beamsplitter is used to enable the two cameras to have a common optical axis (to remove parallax), an optional filter (see Figure 3) that can be flipped in or out of the optical path of the EMCCD camera, and an LCD that is used for real-time control of the fusion parameters with a convenient graphical user interface (GUI).

The system produces true-color fused output at 30 fps with 640 x 480 resolution with two simultaneous outputs: (1) digital 24 bit RGB via cameralink and (2) analog NTSC. During each 33 ms frame period the embedded processor scales the separate input images, warps the thermal image to the same scale and orientation as the VNIR image, calculates the chroma values from the EMCCD image, runs an edge-detection algorithm on the thermal image, fuses the brightness values to produce the luma, combines the luma and chroma values, and generates the fused output images.



(a) CAD drawing showing hardware



(b) Picture of fully functional prototype

Figure 6. TCNV fusion prototype.

Table 1. Specification / Properties of TCNV Fusion prototype.

<b>Hardware</b>		<b>Feature</b>
Color EMCCD Camera		400 nm to 1,000 nm (VNIR)
Microbolometer Camera		7,000 nm to 14,000 nm (LWIR)
Additional (optional) Filter		Push button actuation
LCD GUI		Real-time parameter control
Real-time processor		FPGA based
<b>Real Time Processing (within each frame period)</b>		
Image Warping for Coregistration		
Color Demosaicing		
Edge Detection		
Image Fusion		
Color Image Rendering		
<b>Optics</b>		
IFOV		0.03 deg
Total FOV		(H) 20 deg×(V) 15 deg
f/#		LWIR: f/1.0 VNIR: f/1.4
<b>Image Output</b>		
Frame Rate		30 fps
Pixel Resolution		640×480
Digital Format		CameraLink 24-bit RGB
Analog Format		NTSC

Example real-time output from the TCNV Fusion system is shown in Figure 7. In this scene, yellow colored posts are only detectable in (a) with the VNIR camera and the man lurking in the shadows is only detectable in (b) using the thermal camera. This complimentary information is all presented in the fused output image, Figure 7 (c), without destroying the true-color information of the scene. In Figure 7 (d), a fused image of the same scene is shown after the man has come out of the shadows. In this case the VNIR information can still be used to identify the man in the fused image. This feature is in contrast with typical fused imagery, where the thermal information would dominate a warm object (such as a human) and identification would be difficult.

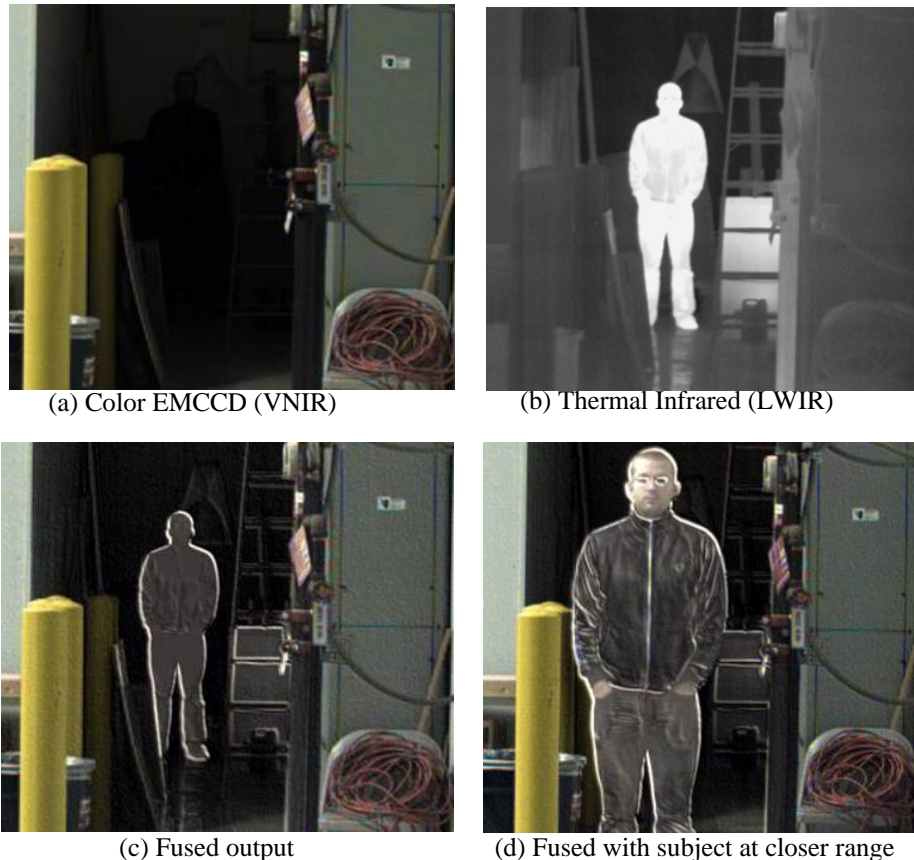


Figure 7. Example Real time output of TCNV Fusion prototype. (a) and (b) are sample input images leading to the fused output shown in (c). (d) Fused image of a similar scene with the subject at closer range. Note that the fused imagery retains true-color information while incorporating thermal information

## 5. DISCUSSION

In this paper we described a True Color Night Vision (TCNV) Fusion system that runs in real-time. While this is not the first real-time fusion system for night vision applications, see for example [9]; it is however, to our knowledge, the first such fusion system that produces true-color output.

The prototype system is useful for perimeter monitoring and vehicle mounted intelligence, surveillance, and reconnaissance (ISR) in its current form. Future versions will have reduced size, weight, and power (SWaP) and can be considered for man portable applications. The TCNV Fusion prototype, with its real-time embedded processor, is also extremely useful as a test bed for various fusion applications in need of actual field trials.

In related work, OKSI has developed techniques for producing fused color night vision imagery using a material identification algorithm [10]. This technique assumes that a true-color camera is NOT available and instead appropriate chroma values are determined using a spectral/texture based analysis of image segments together with ancillary information to determine scene content with a Bayesian type probabilistic analysis. Materials are identified based on a library of spectral / texture characteristics. Once a material is identified it is rendered with the appropriate chroma (e.g., grass is green). The approach has the advantage over the TCNV fusion system in that it can work in lower light levels and use a variety of night vision cameras from I2CCD, SWIR, MWIR, and LWIR. The technique works for most common natural materials that can be collected in a library, however, it has the disadvantage that it does not recognize uncommon materials and therefore the color of paints, clothing, and dyes may not be properly determined. As stated above, only a truly “true-color” system can properly present such information.

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