Displaying Advanced Optical Imagery Information for Human Observers

J. Scott Tyo, College of Optical Sciences, University of Arizona, Tucson, AZ 85721 (USA) tyo@ieee.org

Introduction

In recent years there have been many classes of sensors that provide a day/night, all-weather imaging and vision capability in a variety of sensing applications that enhance traditional, 3-color passive imagery. These sensors range from conventional night vision systems [1-4] to infrared imagers [5-7]. There are also instruments available that provide multiple spectral bands of information in the NIR, SWIR, MWIR, and LWIR, as well as polarimetric data in all of these wave bands [8]. With all of this available information, it is possible to develop robust and reliable target identification and detection processes. However, in many scenarios an observer does not need assistance with target detection; one simply needs a view of the world that allows one to make real-time decisions. This highlights one of the most significant limitations that prevent the widespread use of these emerging technologies. Most fusion schemes available today present too much data to the user in a way that is more confusing than helpful. Often times the data that are collected – such as polarization data or infrared spectral data – has no direct analog in human color vision. Furthermore, in many scenarios the data are fused in a way that does not take into account the workings of the human vision system.

Our research team has been working with data from such sensors for many years. Of particular importance to us is the development of ergonomic display strategies. In particular, we have developed novel color mappings for spectral [9] and polarimetric imagery data [10] in the visible and infrared. Our previous work has focused on capturing and identifying orthogonal data sources and mapping them into orthogonal perceptual channels in order to preserve relationships among data. In addition to our work, there has been much effort at developing representation schemes that represent color and polarization intelligently [10,11].

Goals for Data Display

The development of strategies that are able to provide robust colorization of advanced imagery is a challenging task. The literature is rich with many approaches to this problem [1-7]. While some techniques can perform well under specific conditions, the ability to achieve a display scheme that works well across a wide range of environmental and operational conditions is yet to be discovered. For example, the technique presented by Toet *et. al.* [4], based upon the Welsh *et. al.* principle component technique [7], can yield excellent colorization results provided a visible source image of a "similar" scene is available. Other techniques take a more fundamental look at the science of color and use metrics that are based upon color contrast, multi-modal-based and other image fusion techniques [1-3,6].

In our previous work we have identified a number of important issues that should be addressed in the development of fusion and display strategies [10]. This list is not necessarily exhaustive; moreover, an effective system may require trade-offs in optimizing for the different criteria. Nonetheless, we propose that the following criteria be addressed in the design and the analysis of representational transformations like those proposed here: (1) orthogonal encoding, i.e., information should be presented with as little redundancy as possible; (2) computational simplicity, i.e., efficiency of implementation should be maximized; (3) anthropometric optimality, i.e., information should be presented in a way that maximizes usefulness to the human observer; and (4) ecological invariance, i.e., representations should remain qualitatively similar over natural variation of some significant environmental parameters, such as time of day, available sensors, and weather conditions. In applying these concepts to the development of useful fusion strategies there are two general paths that can be taken, namely colorimetric mapping-based approaches and those that perform synthetic scene generation based upon data-extracted features. In this paper we concentrate on the former.

Algorithmic data fusion based upon colorimetric mappings

The simplest and most computationally efficient methods for data fusion rely on predefined mapping strategies that translate measured data from the available sensors into display channels for interpretation. In most cases, this is simply a false-color mapping [6], but it is possible to exploit other perceptual pathways such as motion [11] and texture [12]. It is extremely easy to develop mappings from data space to color space, and it is even relatively straightforward to do so in a way that presents a pleasing image to the observer.

It is well known that the human vision system processes information in a variety of differencing channels. The use of differencing channels allows for information compression, since most scenes are oversampled spatially and temporally. For the purposes of our past research, the most relevant differencing channels are the opponent color channels [13]. The spectral responses of the three color-sensitive photopigments have significant correlations among them. The first level of spectral processing that occurs at the retina is to form three opponent color channels. The first, an achromatic channel that is approximately a sum of the three cone outputs, carries over 95% of the scene information and is preferentially sensitive to high spatial frequencies. It has long been known that human vision processed color by means of opponent channels, but it was Gottschalk and Buchsbaum that demonstrated the reason for this. They showed that the opponent color channels form approximately a principle components (PC) transform of the outputs of the spectral receptors averaged over some global set of scenes [13]. By performing the PC transformation channels, the subsequent opponent color pathways are nearly orthogonal allowing for significant information compression.

We have used this knowledge of the operation of the color vision system to create ergonomic methods to represent high dimensional data. By forming data channels that are uncorrelated, we can map orthogonal information into the opponent color pathways. Our research (as well as the research of others [14]) has demonstrated that such methods tend to be well-matched to what human observers expect to see. That is, scenes are largely de-saturated, with only limited regions of highly saturated hues. Such properties help address the anthropometric optimality criterion discussed above. An example of a fused polarimetric/LWIR image using this strategy to create a false color mapping is shown in Fig. 1.

Such schemes work well for their classes of data. However, they highlight an important feature of most data fusion schemes. Namely, to an untrained observer it is not immediately obvious what they are looking at! For the purposes of augmenting situational awareness, what is really needed is a scheme that maps the data like those in Fig. 2a and b into a false color scheme that provides a reasonable approximation to what the observer would see during the day as shown by the visible image in Fig. 2c. There are two ways to address this issue. The first is to reorient the color mapping so that important features appear in familiar colors. Examples would be vegetation appearing as green and water appearing as blue. We have made efforts along this front with spectral imagery [9]. The second approach, which is discussed in the following section, uses imagery data to catalog a scene, then creates a rendering of the scene based on database information and false illumination.

Figure 1*: Image showing application of our developed thermal/polarimetric color fusion strategy. Our fusion scheme has been run in software in real-time on a PC, and can be easily incorporated into a real-time DSP platform. In the color scheme color saturation is the degree of polarization, hue corresponds to object shape and orientation and the infrared image is mapped to value.*

Figure 2*: Registered multimodal imagery of an aerial scene where panel A is an LWIR thermal image and panel B is a polarimetric image of the same scene acquired at the same time. These images would be largely invariant to time-of-day because the scene is sensed in the LWIR. Panel C is a Visible three-color image of the same scene. Our aim is to create a mapping strategy that takes data like those in panels A and B without 3-band visible information and renders them to look like panel C using segmentation, database information, and false illumination.*

False Color Mappings based on Human Vision

We have spent significant research effort in developing strategies for displaying high dimensional data to human observers. Figure 3 below shows examples of a mapping from SWIR hyperspectral data to false color that we have developed based on orthogonality transformations [15] and Fig. 4 shows a similar transformation that we developed for polarization data [16].

These examples show cases where data that a human would not normally be sensitive to (polarization and IR spectral information) are mapped into color. The resulting images are not "realistic" looking, but present useful images to a trained observer. In addition to false color mappings, we also explore the use of other visual pathways such as motion and texture to convey information.

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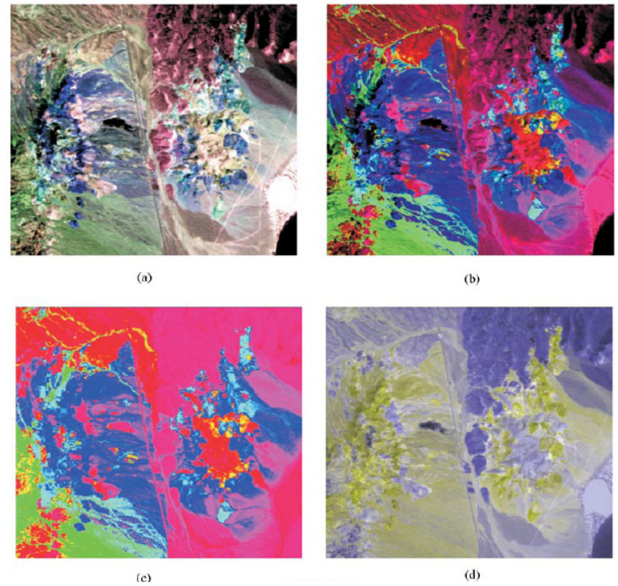

***Figure 3**: We have developed principal components based display strategies for SWIR hyperspectral data. For this particular dataset, the three-band color image is not interesting – everything appears brown. However, there is useful information in the SWIR HIS data for scene segmentation. These images are AVIRIS of Cuprite, NV, from the 1995 experiment, and the 50 bands from 1.9 – 2.4 microns were used to create these images. (a) full rendering that seeks to minimize color saturation except in regions of strong signature. (b) same mapping as in panel (a), but now all colors are fully saturated. (c) Same mapping as panel (b), but now the intensity information is suppressed, and this represent a classification-type image. (d) Same mapping as (a), but only one spectral dimension is exploited, the blue-yellow color difference.*

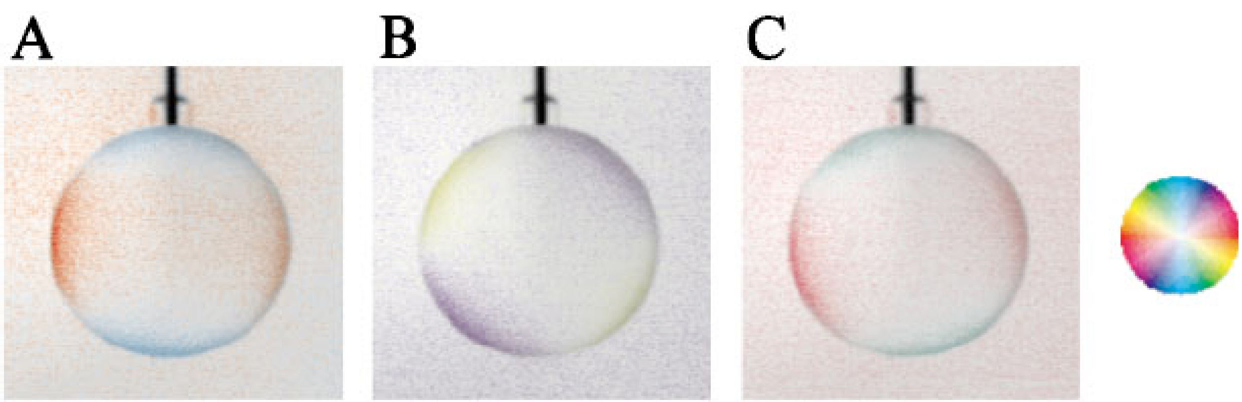

***Figure 4**: Polarimetric information is not visible to a human observer. In this experiment, we are back-illuminating a transparent plastic sphere with white light. There is little or no spectral information to exploit, so we use the color channels to represent the polarization data. There is an ergonomic, one-to-one mapping that exists between polarization space and human color space. We exploit this relationship to preserve orthogonal polarization information in orthogonal perceptual pathways where color corresponds to angle of polarization and saturation corresponds to degree of polarization.*

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