Calhoun: The NPS Institutional Archive
DSpace Repository

Faculty and Researchers

Faculty and Researchers' Publications

1997-10

An Adaptive Technique for the Enhanced Fusion of Low-Light Visible with Uncooled Thermal Infrared Imagery

Therrien, Charles W.; Scrofani, James W.; Krebs, William K.

Therrien, C.W.; Scrofani, J.W.; Krebs, W.K., An Adaptive Technique for the Enhanced Fusion of Low-light Visible with Uncooled Thermal Infrared Imagery, Proc. IEEE Int. Conf. on Image Processing (ICIP), Santa Barbara, CA, 26-29 October 1997.
<https://hdl.handle.net/10945/43788>

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

<http://www.nps.edu/library>

An Adaptive Technique for the Enhanced Fusion of Low-Light Visible with Uncooled Thermal Infrared Imagery

C. W. Therrien, J. W. Scrofani, and W. K. Krebs
Naval Postgraduate School
Monterey, California 93943

Abstract

A new algorithm is introduced that performs spatially adaptive enhancement on low-light visible and infrared images of the same scene and fusion of these into one composite image. The algorithm involves low-pass/high-pass filtering and simple nonlinear operations that can be table driven. Examples of the processing on image data collected in field tests are given.

1 Introduction

Current night vision sensors, such as image intensifier (II) tubes in night vision goggles and forward looking infrared sensors (FLIR) are routinely used by U.S. Naval personnel for night operations. The quality of imagery from these devices however, can be extremely poor, suffering from poor contrast, limited dynamic range, graininess and many other reported problems. These deficiencies often lead to confusion of textures, the inability to segment them and visual illusions, resulting in disorientation, aborted missions, and lost aircraft and personnel. Since these sensors exploit different regions of the electromagnetic spectrum, the information they provide is often complementary, and therefore, improvements are possible with the enhancement and subsequent fusion of this information into a single presentation. Such processing can maximize scene content by incorporating information from both input images as well as increase contrast and dynamic range.

A number of schemes (e.g., [1, 2]) for the enhancement and fusion of low-light and IR imagery have been proposed and are being investigated under a program known as Color Night Vision in the F/A-18 NITE Hawk Pod. Although these methods demonstrate that color night vision is significantly better than either of the two monochrome bands, they have not overcome the problem of color constancy. In some situations, an observer's ability to identify false color targets was degraded due to the scene and target reflectivity and emissivity characteristics. Accordingly, we have also developed the monochrome enhancement/fusion algo-

rithm described here, which is simple to implement and is not degraded by the limitations of color constancy. In implementation, many aspects of the algorithm can be "table-driven" so that the evaluation of required nonlinear functions is reduced to indexing and reading data from memory and the contents of this memory can be easily changed or even put under control of the user.

The new algorithm performs adaptive enhancement of both low-light visible (II) and thermal infrared imagery (IR) inputs, followed by a data fusion technique for combining the two images into a composite image. The goal is to develop an enhancement/fusion algorithm that consistently produces a final image that is superior to either of the original images, for a wide range of reflectivity and emissivity conditions. Utility of this development includes improvements in night piloting, both navigation and targeting, man overboard detection, firefighting, special forces operations as well as civilian night driving, law enforcement and assistance for the visually impaired.

2 Enhancement/Fusion Algorithm

The new algorithm, which produces a fused and enhanced monochrome image, employs a two-part scheme. First it performs adaptive modification of the local contrast and local luminance mean for enhancement of both the low-light visible (II) and thermal infrared imagery (IR); this is followed by a data fusion technique based on a comparison of the II and IR image energy computed in a local region.

Figure 1 shows a block diagram of the algorithm. The spatially adaptive enhancement and fusion is based on a modified version of the Peli-Lim algorithm [3]. In the first stage, the raw visible and IR data are each separated into spatial high-pass and low-pass components (f_H, f_L, g_H, g_L). The low-pass component, which represents the local luminance mean, is

Figure 1: Block diagram of the enhancement/fusion algorithm.

computed (for the II) as

$$f_L(n_1, n_2) = \frac{1}{(2N_1 + 1)(2N_2 + 1)} \sum_{k=-N_1}^{N_1} \sum_{l=-N_2}^{N_2} f(n_1 - k, n_2 - l) \quad (1)$$

with an analogous expression for g_L . For each of these data types enhancement to the high-pass portion is achieved by multiplying by a gain factor that depends on the local luminance mean through the function $K(f_L)$. The low-pass component is passed through a generally nonlinear function NL whose purpose is to reduce the dynamic range so that when this component is recombined with the enhanced high-pass component, saturation will not occur. In general, different functions K and NL can be used for the II and IR data with each function specifically tailored to address the enhancement problems pertinent to that type of data. Figure 2 shows an example of a set of such curves. In the case shown, the functions selected for the II and the IR are identical and chosen to enhance detail in the darker portion of both images.

For the second stage (fusion), the low-pass and high-pass components are combined according to different procedures. The goal in fusion of the high-pass components is to retain detail where it is present in *either* the II or the IR images. The goal in fusion of the low-pass components is to insure that an appropriate background level of intensity is maintained and that differences in local luminance existing in either II or IR will not be eliminated by the fusion process.

For the fusion of high-pass components, the difference in local energy at a given pixel defined as

Figure 2: Gain and luminance transformation functions (K and NL) used for enhancement of Scene 1.

$$\Delta E(n_1, n_2) = \frac{E_1(n_1, n_2) - E_2(n_1, n_2)}{|E_1(n_1, n_2) - E_2(n_1, n_2)|_{max}} \quad (2)$$

is computed, where E_1 is the local energy in the II component

$$E_1(n_1, n_2) = \sum_{k=-N_1}^{N_1} \sum_{l=-N_2}^{N_2} f_H'^2(n_1 - k, n_2 - l) \quad (3)$$

with $f_H'(n_1, n_2) = K_1(f_L(n_1, n_2)) \cdot f_H(n_1, n_2)$ and E_2 is the local energy in the IR component computed from an analogous expression. A pair of gains $G(\Delta E)$ and $1 - G(\Delta E)$ is applied to the two high-pass components before summing to produce the fused high-pass component. The gain G can in general be a nonlinear function satisfying $0 \leq G(\Delta E) \leq 1$; however the simple linear function $G = 0.5(\Delta E + 1)$ has been found to be sufficient for many images of interest.

The fusion of the low-pass components is accomplished through a different procedure. Conceptually, the pair of II and IR intensity values (local luminance) at a pixel location (n_1, n_2) is represented by a point in a two-dimensional intensity space. This point is to be mapped into a one-dimensional intensity space as shown in Fig. 3. There are several possible considerations in determining an appropriate mapping. However a basic requirement is that points which are "close" in the 2-D space should remain close in the 1-D (mapped) space while points that are well separated in the 2-D space should be well separated in

Figure 3: Mapping from the II-IR domain to the fused intensity domain.

the 1-D space in order to maintain separation of the background. Mappings of polynomial form

$$B(I, R) = (a_1 + a_2I + a_3I^2)(a_4 + a_5R + a_6R^2) \quad (4)$$

were considered with coefficients a_i chosen to minimize the Sammon mapping criterion [4]. The Sammon criterion can be written as

$$\mathcal{E} = \frac{1}{\sum_{i < j}^N d_{ij}^*} \sum_{i < j}^N \frac{[d_{ij}^* - d_{ij}]^2}{d_{ij}^*} \quad (5)$$

where d_{ij} and d_{ij}^* represent intersample distances in the 1-D and 2-D spaces according to the observed intensity values in the images. Details of the optimization procedure used to determine the coefficients can be found in [5].

A simpler weighted linear mapping of the form

$$B(I, R) = \alpha I + (1 - \alpha)R \quad (6)$$

was also used with $0 < \alpha < 1$. In both (4) and (6) it is desirable to constrain the mapping so that it is not symmetric in I and R to avoid loss of local luminance information in cases where the background changes from lighter to darker in one component (e.g., II) and changes from darker to lighter in the other in the same spatial region.

The fused high-pass and low-pass images are added to produce the final enhanced fused image (see Fig. 1). In the application of the algorithm, the nonlinear functions K_i , NL_i , G and the nonlinear mapping (4) are implemented as look-up tables. Thus the most

Figure 4: Unprocessed image-intensified and infrared images of Scene 1.

computationally intensive procedures are the low-pass filtering and energy computation, which for real-time application will need to be implemented on appropriate fast DSP hardware.

3 Image Processing Examples

Figure 4 shows the unprocessed II and IR images for a nighttime scene of ships in a harbor (Scene 1). Figure 5 shows an example of data processed by the algorithm. In this case there is severe saturation in the II image; as a result the optimized nonlinear transformation for the low-pass component was found to depend on only the IR and was given by

$$B(I, R) = 1.47R - 0.0018R^2$$

In the enhanced fused image, important features from both the II image and IR image are evident. Lighting details including bright lights appearing in the II image are combined with texture and edge detail from the IR image to form a significantly improved result.

An example of processing these images using the simpler weighted linear mapping (6) with $\alpha = 0.2$ is shown in Fig. 6. This result also provides a good combination of the features from both images but texture and edge detail is not as good as in the previous result.

4 Conclusions

Image data from image intensifier tubes and infrared sensors provide complementary information for military personnel involved in nighttime operations. A new algorithm for enhancing and fusing these two

Figure 5: Algorithm results using the nonlinear mapping (Scene 1).

Figure 6: Algorithm results using the weighted linear mapping (Scene 1).

types of data combines this information in a natural looking presentation. Although the algorithm involves spatially adaptive and nonlinear processing, it is simple to implement and nonlinear operations can be table driven.

Human perception studies were conducted on a variety of scenes where subjects were asked to perform pairwise comparisons of various processed and unprocessed images and asked to select the image that “conveys the most information about the scene.” Complete results of these studies are reported in [5]. These tests showed that the combined images were definitely preferred over either the II or the IR images alone and that combination involving nonlinear mapping of the form (4) was generally preferred to that involving the weighted linear mapping. Further studies with different orders of presentation however, showed that the preference for the nonlinear mapping result over the weighted linear mapping did not have high certainty. Although further testing will probably be necessary to determine which variant of the algorithm is recommended, the overall method appears to be successful.

Acknowledgment

The work reported here was supported by grants N0001497WR30078 and N0001497WR30091 from the Office of Naval Research.

References

- [1] Scribner, D.A., Satyshur, M.P., Schuler, J., Kruer, M.R. (1996). Infrared color vision. IRIS Specialty Group on Targets, Backgrounds, and Discrimination, January, 1996.
- [2] Waxman, A. M., *et al.* Progress on color night vision: Visible/IR fusion, perception & search, and low-light CCD imaging. SPIE-The International Society for Optical Engineering, Vol. 2736, 1996, pp.96-107.
- [3] Peli, T., Lim, J.S., Adaptive Filtering for Image Enhancement. *J. Optical Engineering*, Vol. 21, January/February 1982, pp. 108-112.
- [4] Sammon, J. W., “A Nonlinear Mapping Algorithm for Data Structure Analysis,” *IEEE Trans. Computers*, Vol. C-18, No. 5, May 1969, pp. 401-409.
- [5] Scrofani, James W., An Adaptive Method for the Enhanced Fusion of Low-Light Visible and Uncooled Thermal Infrared Imagery. MS Thesis, Naval Postgraduate School, June 1997.