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REAL-TIME ADAPTIVE CONTRAST ENHANCEMENT FOR IMAGING SENSORS*

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Abstract

A new recursive filter approach greatly simplifies real time implementation of a local area adaptive contrast enhancement scheme for imaging sensors (FLIR, TV). Local area contrast enhancement adaptively stretches the intensities in each local area of a scene to the display luminance dynamic range. Even scenes possessing large global dynamic ranges (>40 dB) can then be squeezed into the limited dynamic range (20 dB) of a display without losing the vital local area contrast essential for target acquisition. This paper describes the recursive filter implementation (using charge coupled devices) of the local area contrast enhancement scheme and the resultant real time hardware. This module can accept standard 525 and 875 line TV compatible video from any source (FLIR, Vidicon, Video Tape Recorder, etc.). Several examples from video taped FLIR imagery are included to demonstrate the effectiveness of this simple hardware.

Introduction

The scene dynamic ranges encountered by imaging sensors can be much higher than the CRT display luminance range (~20 dB). Moreover, the scene intensity extremes are changing in time (as when panning a scene, for example). It is obvious that some form of global automatic gain/bias control system can avoid extensive interactive manipulation of the display gain/bias controls. This is easily done by a linear scaling of the intensities governed by the scene extrema or the global scene variance.

But mere global gain and bias control does not suffice when the scene has a large global dynamic range. When the high dynamic range scene information (available at the focal plane) is squeezed into the limited luminance range of a typical display, low contrast local details (targets, etc.) tend to fall below the contrast sensitivity threshold of the human eye and are not perceived. It is of course possible to adjust the gain and brightness controls on a FLIR imager to selectively expand a given temperature range of interest. But this involves extensive interactive manipulation of the controls and therefore limits the effectiveness of the operator who has to simultaneously perform several other functions.

Therefore, in addition to global gain and bias control, we need local area contrast enhancement - to compress the global scene dynamic range presented to the display while enhancing the local area contrast. Previous work in this direction includes Ketcham, [1] "Local Area Bias and Gain Control" and Harris's [2] "Constant Variance Enhancement". Both schemes use local area statistics (mean and variance) computed on a sliding window to control the local area contrast and bias levels.

Our present approach differs from the above in the way the complex computations of the local area statistics are replaced by simple two dimensional recursive filters. This enables very simple real time implementation at video rates. CCD line delays are used to provide the time delays needed in the recursive filter. This in turn results in a sampled analog structure that uses CCD line delays, analog multipliers, and adders. We therefore avoid expensive and bulky highspeed A/D converters, digital multipliers, adders, and shift registers at the 10-30 MHz rates encountered in real time video applications. In sections II and III we describe the basic Local Area Contrast Enhancement (LACE) scheme, discuss various alternate implementations of the local area statistics computation and introduce the recursive filter to greatly simplify these operations. The description of the simple hardware implementing this approach follows in Section IV. We include several examples of video taped FLIR imagery enhanced by this real time hardware to demonstrate its effectiveness.

The Local Area Contrast Enhancement Scheme (LACE)

Figure 1a is a one-dimensional illustration of a scene which can be seen as a slowly varying background envelope. Superimposed upon it is higher-frequency local variation representing targets, background detail and other information cues. The problem with real-life imagery is that, if the wide

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dynamic range of the entire scene (often as large as 1000:1) is squeezed into the small (20:1) luminance range of the display, then the local contrast (i.e., difference in intensities) between the target/background, and within the target, falls below the contrast sensitivity threshold ΔI of the human eye and cannot be perceived. The contrast sensitivity threshold ΔI is a function of both the local-area (i.e., target) size and the average local intensity.

For a given local-area size, the contrast sensitivity obeys Weber's Law (i.e., is proportional to the intensity - $\Delta I/I = C_S$, a constant). This constant C_S can vary from less than 1 percent for large areas to infinity for very small local areas. Local-area constant enchancement schemes operate under the premise that the large slowly varying intensity excursions can be reduced without degrading the information in the scene. The local contrast can then be enhanced (by increasing the local gain) without exceeding the dynamic range of the display. Figure 1b illustrates this; the low-frequency envelope is brought closer to the global mean while the higher frequency local variations are now amplified above the contrast sensitivity threshold ΔI. Since the relative brightness of distant areas within the scene contributes little to discrimination, this does not significantly degrade the information content of the image.

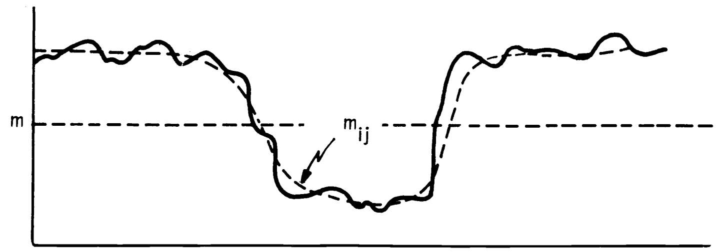


Figure 1a. Original One Dimensional Scene Example

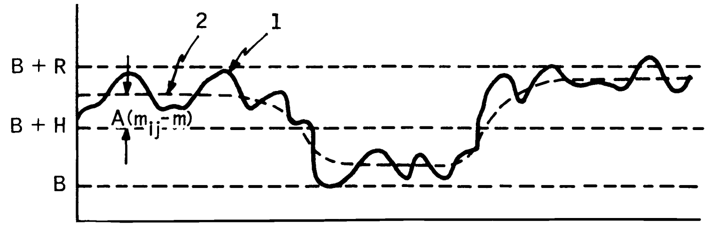


Figure 1b. LACE Applied: 1. High Frequency Component
2. Low Frequency Component

A LACE formulation that addresses the above visual psychophysical considerations is derived here. It performs the following functions.

- Vary the local average brightness (bias) so that overall dynamic range of scene is compressed;
- Enhance local variations above the contrast sensitivity threshold of the human eye; and
- Automatically fit the intensity extremes in the enhanced scene to the display limits.

A functional description of the algorithm is shown in Figure 2. The image intensity at each point is transformed based on local area statistics -- the local mean M_{ij} and the local standard deviation σ_{ij} computed on a local area surrounding the point. The transformed intensity is then:

$$\hat{I}_{ij} = G_{ij}\,[I_{ij} - M_{ij}] + M_{ij}$$

where, the local gain

$$G_{ij} = \alpha \frac{M}{\sigma_{ij}}, \quad 0 < \alpha < 1$$

where M is the global mean.

The local area mean is first subtracted from the image at every point. A variable gain is applied to the difference to amplify the local variation. A portion of the local mean M_{ij} is then added back to restore the subjective quality of image. The local gain G_{ij} is itself locally adaptive, being proportional to M, to satisfy psychovisual considerations (Weber's Law); and inversely proportional to σ_{ij}, so that areas with small local variance receive larger gain.

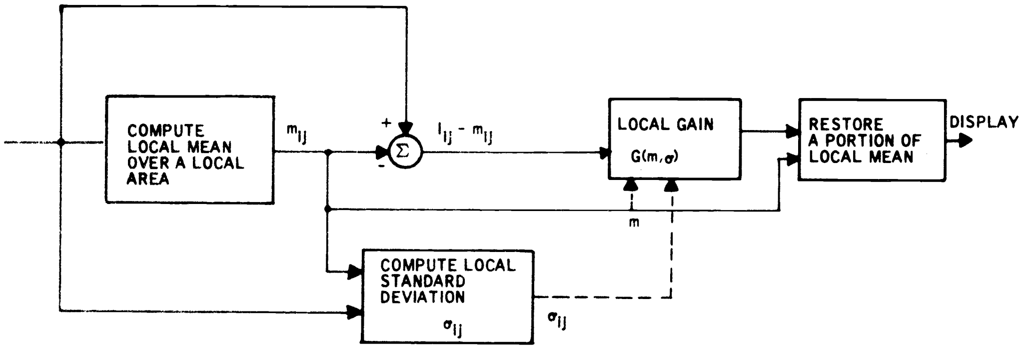


Fig. 2. Functional Flow Description of the Local Area Contrast Enhancement Algorithm

To prevent the gain from being inordinately large in areas with large mean and small standard deviation, the local gain is actually controlled as in Figure 3.

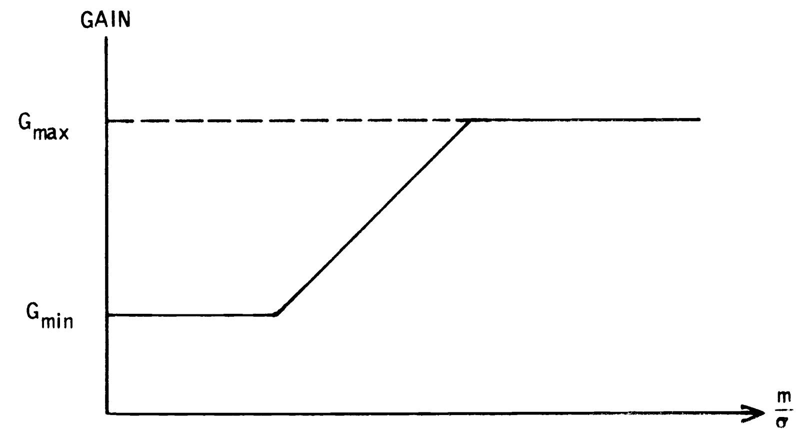


Fig. 3. Local Area Gain Curve to Prevent Excessive Gain Variations

Figure 4 shows the general configurations in which this hardware can be used. It can receive 525 line or 875 line TV compatible video from any source - a FLIR, video tape recorder, video disk recorder, Vidicon, etc. The output is a composite video signal capable of driving a 75Ω load.

The input to the LACE unit is first automatically scaled between 0 and 1 V by the global gain/bias control unit using the frame video mean and standard deviation. This adjusts the contrast and brightness on a sync separated video input from a video disk, tape, camera, etc., so that effective use of the CCD dynamic ranges - is made in the subsequent stages.

This module has been extensively tested with real time video-taped 525 line tactical FLIR imagery (at 30 frames per second). A few examples from this evaluation are reproduced in Figure 5. These are photographs taken off the display before and after enhancement.

In the interests of a fair trial, the contrast and brightness levels on the monitors were not changed for the two conditions. In both cases the video into the display received global scaling (i.e., had the same global extrema). This is in fact evident in the photographs themselves - the global contrast and average brightness remain the same before and after enhancement.

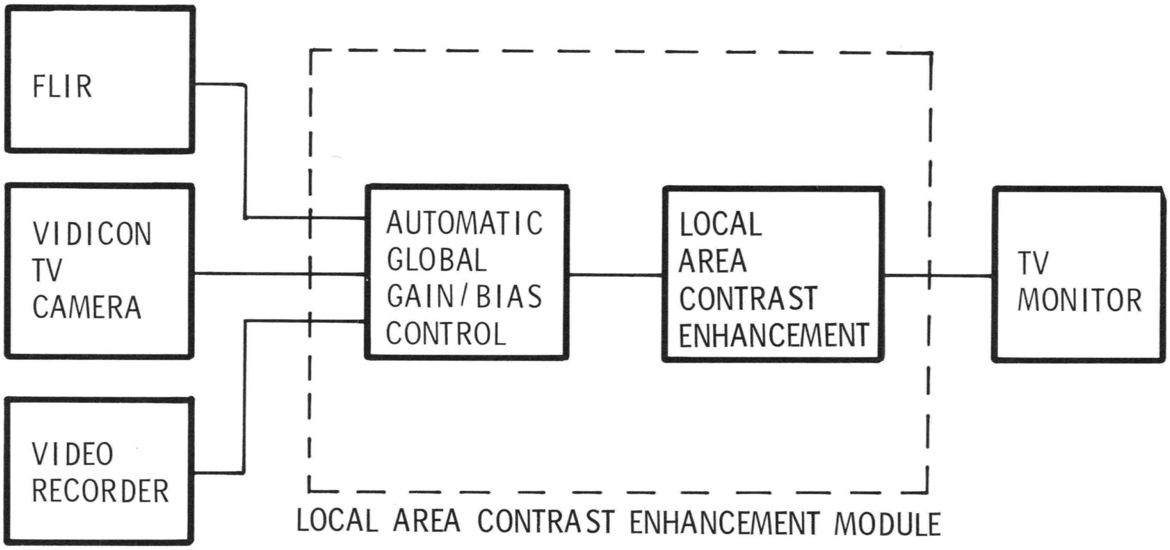
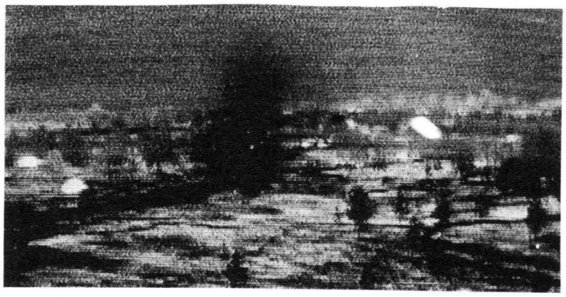


Fig. 4. Local Area Contrast Enhancement Module Configurations

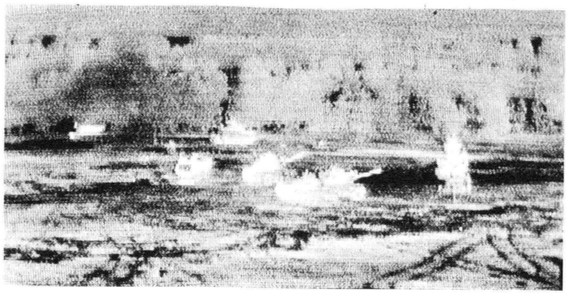
Original FLIR frame from video tape

Enhanced by real time hardware

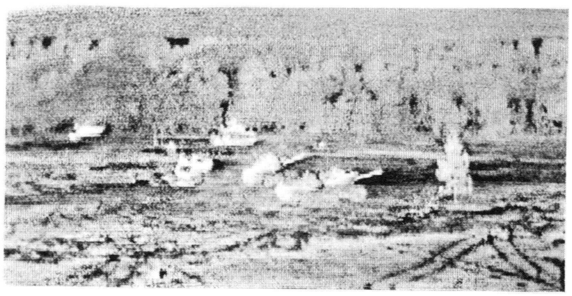


Original FLIR frame from video tape

Enhanced by real time hardware



Original FLIR frame from video tape



Enhanced by real time hardware

Fig. 5. Results of Real Time Processing of FLIR Video Through LACE Module

The most dramatic improvement in local area contrast can be seen in the FLIR images in Figure The large dark areas consist of smoke deployed as a counter measure tactic (the imagery is of simulated battle field conditions). These are intended to drive the video - blacker than black on a conventional display, obscuring surrounding details. Local Area Contrast Enhancement expands the contrast in these local areas so that the background and the targets suppressed by the smoke are now clearly visible. Note that other areas in the image with adequate local contrast are affected to a lesser degree. This is as it should be - we do not want to boost the local contrast (high frequency information) in already "contrasty" areas. Doing so magnifies the scene extrema and therefore reduces the relative global dynamic range.

As an added benefit, the enhanced images have crisper detail in the targets and backgrounds. This is because Local Area Contrast Enhancement is in fact adaptive high frequency emphasis [3]. The high frequency gain is adaptive - being greater in local areas with small local standard deviation.

Summary and Discussion

Conventional schemes for selective local area video contrast stretching employ complex digital architectures, that amount to nonrecursive computation of the local area statistics on a sliding window. The size of the window dictates the hardware complexity, although window sizes between 10 x 10 and 15 x 15 pixels are usually considered optimal. A 15 x 15 window requires simultaneous access to 15 lines of video (14 shift registers or line delays) and 225 adds per pixel at 10 - 20 M pixels/second.

The two dimensional recursive filter approach in this paper requires just one line delay and one summer (adder) to accomplish the same function. Moreover, the effective size of the local area can be changed simply by changing the summer weights. To change the local area of the nonrecursive sliding window, we would have to change the filter size i. e., the entire filter structure.

The recursive filter approach would result in much greater simplicity (compared to the nonrecursive approach) in a digital implementation as well. We chose to implement it with sampled analog hardware using CCD line delays - because this design eliminates high speed A/D converters, multipliers and adders at the 10 - 20 MHz rates encountered in 525 and 875 line video applications. It is interesting to note that the high frequency video does not pass through the CCD line delays.in Figure 2 . Therefore, it is possible to use this circuitry without modifications beyond 30 MHz while keeping the CCD clock rates below 15 MHz. This is a boon since commercially available CCD line delays are limited to 15 MHz clock frequency, but the full resolution 875 line FLIR video can have bandwidth in excess of 30 MHz. A nonrecursive digital approach would be hard put to realize these speeds.

This simple hardware occupies only three 3" x 5" cards although built entirely of off-the-shelf components. A simple hybrid repackaging of the components can reduce its size to a compact 3" x 4" x 0. 5" module. This image enhancement module has demonstrated the utility of CCD sampled analog filtering techniques for simple hardware realizations of real time image enhancement functions.

Acknowledgements

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