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LOCAL INTENSITY ADAPTIVE IMAGE CODING

Friedrich O. Huck

NASA Langley Research Center

The objective of preprocessing for machine vision (low-level vision processing) is to extract intrinsic target properties. The most important properties ordinarily are structure (contour outlines or primal sketches) and reflectance (color). Illumination in space, however, is a significant problem as the extreme range of light intensity, stretching from deep shadow to highly reflective surfaces in direct sunlight, impairs the effectiveness of standard approaches to machine vision. To overcome this critical constraint, we are investigating an image coding scheme which combines local intensity adaptivity, image enhancement, and data compression. It is very effective under the highly variant illumination that can exist within a single frame or field of view, and it is very robust to noise at low illuminations.

In this presentation, I will 1) review some of the theory and salient features of the coding scheme, 2) characterize its performance in a simulated space application, and 3) describe our research and development activities.

The local intensity adaptive image coding consists of an innovative model of processing in the human retina referred to as Intensity Dependent Spread (IDS)[1] and some additional logic to extract contour outlines and reflectance ratios at the boundary of two surfaces. Figure 1 is a schematic representation of the IDS model. The line of detectors represents a slice through a two-dimensional array of detectors. When an optical image, or light distribution, falls on the detector array, then each detector sends a signal into a network, where it spreads out. Each channel, in turn, sends out a signal that is the sum of all the signals that arrive in its location in the summation network. The special property of the IDS model has to do

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with the way that the signal from each detector spreads in the summation network. As depicted in the lower half of Figure 1, the magnitude of the signal at its center is proportional to the intensity of the light falling on the detector, and the spread of the signal is inversely proportional to this intensity. The total volume under the spread remains constant. That is all there is to the model. It has been demonstrated that this simple space-variant model of image processing has many of the properties of human visual perception[2].

Figure 2 demonstrates the response of the IDS processor to a spot, or point source, that is brighter than the background. Each detector spreads its signal as governed by the intensity of the light falling on the detector. All of the spreads for the uniform background are the same except for the one detector that is more brightly lighted. Its spread is higher and narrower. Each output channel just adds up all of the contributions it receives. The result of this processing is shown as the output signal. As can be seen, the IDS response to a point source has the same shape as the response of Marr and Hildreth's[3] familiar Laplacian of a Gaussian ($\nabla^2 G$) operator for enhancing edges. In fact, the IDS processor exhibits center surround antagonism and all other manifestations of bandpass filtering that have made the $\nabla^2 G$ operator a favorite algorithm for low-level vision processing. However, the IDS response is nonnegative and spatially variant. As we will show in the next three figures, the IDS processor accounts for several familiar perceptual phenomena of human vision that make it a highly robust low-level vision operator.

First, let us compare the IDS operation to conventional imaging. Figure 3 shows intensity profiles taken across conventional and IDS images of a step-type edge input for three illuminations, or SNR's. Conventional image-gathering yields a blurred representation which is visually representative of the target if the SNR is sufficiently high. As the illumination decreases, the representation gets buried in the noise. Image gathering with the IDS processor yields a target

representation that consists of pulses. The one-crossing of each pulse locates the position of an edge in the target. The peak and trough values of the pulse are proportional to the ratio of the reflectances at the two sides of the edge, entirely independent of illumination. As the illumination decreases, the width of the pulse becomes broader (thereby trading resolution for sensitivity), but the accuracy of the one-crossing is unimpaired. For machine vision, this property means that edge detection for determining structure is highly robust to widely variant illumination.

Next, let us compare the IDS operation to edge detection with the linear Laplacian of a Gaussian ($\nabla^2 G$) operator as well as conventional imaging. Figure 4 shows intensity profiles taken across conventional images and outputs from the $\nabla^2 G$ and IDS operators for two illuminations, high and low. Noise is disregarded for simplicity. The peak and trough values of the $\nabla^2 G$ pulses are proportional to both illumination and reflectance. It is therefore not possible to characterize the reflectance properties of the target independent of illumination. However, the peak and trough values of the IDS pulses are proportional only to the reflectance changes. This striking property of the IDS processor mimics human visual perception (Weber's law). For machine vision, this property means that it is possible to extract the reflectance ratio at the boundary of two areas.

And finally, let us turn to a scene which realistically simulates a scene that may be encountered in space. Figure 5 compares the IDS operation to conventional image gathering and edge detection with the $\nabla^2 G$ operator. A single source of light (35mm slide projector) was used to illuminate the model of a satellite and astronaut surrounded by a black curtain. The image was obtained with a standard 640-by-484 sensor-array camera using 8-bit encoding. By being locally adaptive to both the directly illuminated part of the satellite as well as to the astronaut located in deep shadow, the IDS operator provides a much more complete and reliable rendition of the scene.

If we use the $\nabla^2 G$ processor and zero-crossing detection logic, then we need to transmit only the location of the (correctly and incorrectly) identified edge locations. The corresponding data compression is 24. If we use the IDS processor together with one-crossing detection logic, then the data compression ratio is 20, similar as before. However, in addition to this data compression, the astronaut, who was nearly lost before, is now clearly detected and could probably be identified by a higher level AI algorithm. It should also be noted that we did not yet attempt to use efficient coding techniques for transmitting contour outlines. To do so would probably lead to further significant increases in compression.

The identification of the scene from structure alone could be significantly improved upon when information about reflectance ratios is retained in the transmitted data. The data compression would then reduce from 20 to 13. Figure 6 presents three representations that can be extracted from the complete IDS data. As before, we could display structure alone, or we could display reflectance changes as well as structure. We could draw the contour outlines on the restored gray levels in white to emphasize structure or in black to enhance visual sharpness. In either case, it is important to note that we have not sacrificed our accuracy of edge location by the data compression, and that we have been able to extract reflectance changes independent of illumination. In fact, it is possible under suitable conditions to locate edges with higher accuracy than the sampling intervals of the camera. The only sacrifice we have made is to trade discrimination of fine detail for increased sensitivity to adapt to low illuminations. However, this fine detail would otherwise often be lost in noise. An important extension of IDS processing would be to extract color. Color could then be correctly detected independent of illumination.

We must now admit that the structure-plus-reflectance images in Figure 6 are fakes to illustrate a potential capability. They simply represent the superposition of (correctly extracted) structure on

regular (brightness) images. We are now extending our structure extraction algorithm to an improved structure-plus-reflectance extraction algorithm.

The IDS model of retinal processing was conceived by Tom Cornsweet of the University of California, Irvine. Langley Research Center (LaRC) is now working with Cornsweet and Odetics, Inc., in the evaluation of this model for various applications of interest to NASA, including, in particular, machine vision and image coding for space operations. Odetics is also under contract to LaRC to develop a hardware implementation of the IDS processor (see Figure 7). This processor will be capable of handling image data at real-time TV rates (30 frames per second). It will be implemented on several boards for the DATACUBE of Sun image-processing work stations. This board will become commercially available in the Fall 1989.

The full potential of the IDS processor for data compression as well as image enhancement and feature extraction is realized, of course, only when it is implemented as a focal-plane processor, or "retinal camera" (see Figure 8). The present design of the IDS processor for Sun workstations could be implemented in one 5" by 5" board with 8 VLSI chips. A more advanced approach would be parallel asynchronous focal-plane image processing (see Figure 9). This processor is representative of a new class of devices which would permit full two-dimensional parallel readout and processing perpendicular to the focal plane. Advantages over conventional image gathering and processing techniques include rapid parallel distributed processing, high dynamic range, and the elimination of conventional charge transfer, multiplexing, and preamplifiers. Vision processing could potentially be performed several orders of magnitudes faster than with conventional approaches. Moreover, parallel processing would be ideal for tasks like visual pattern recognition. However, the development of this approach is still in its initial experimental stage.

REFERENCES

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2) Cornsweet, T.N., Visual Perception, Academic Press, New York, 1970.

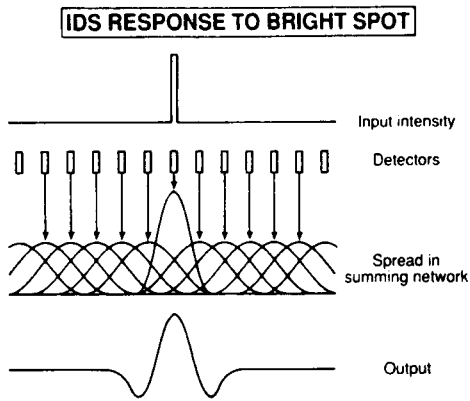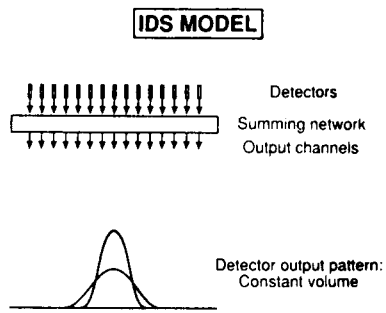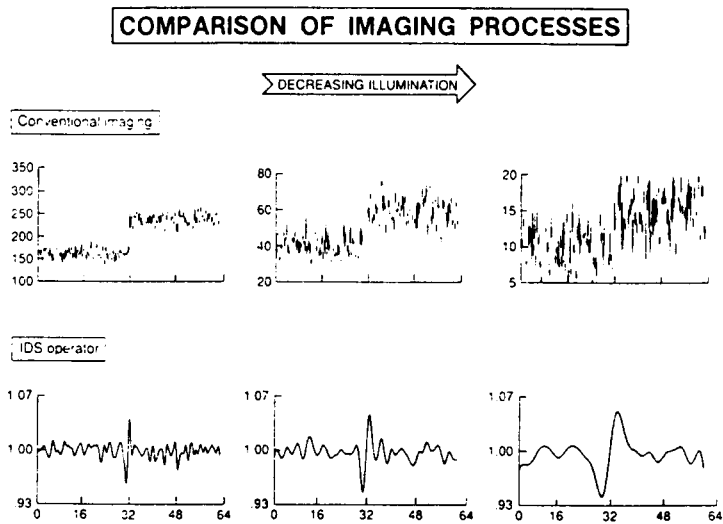3) Marr and Hildreth, "Theory of edge detection," Proc. R. Soc. London B 207, pp. 187-217 (1988).
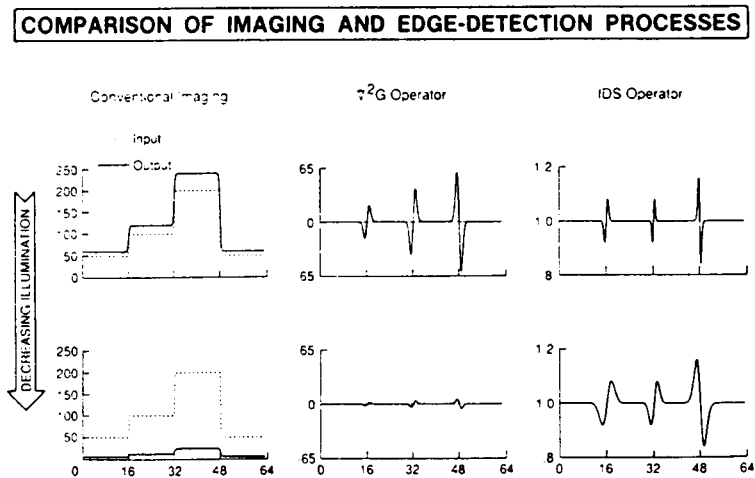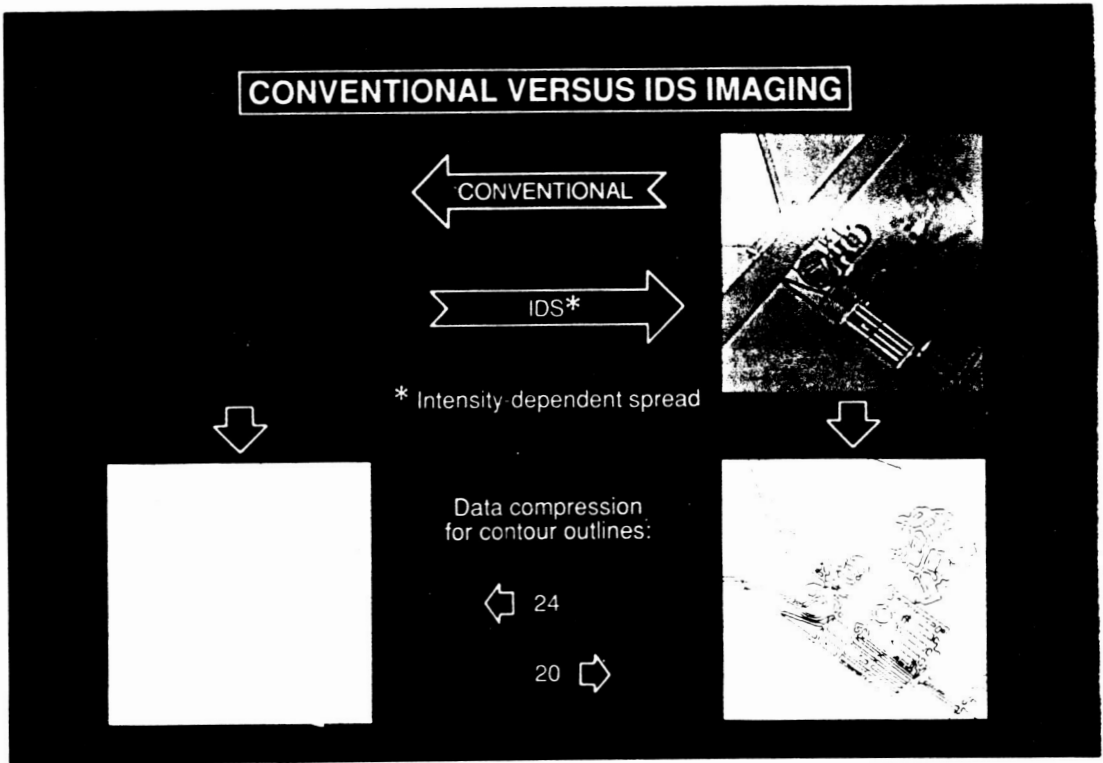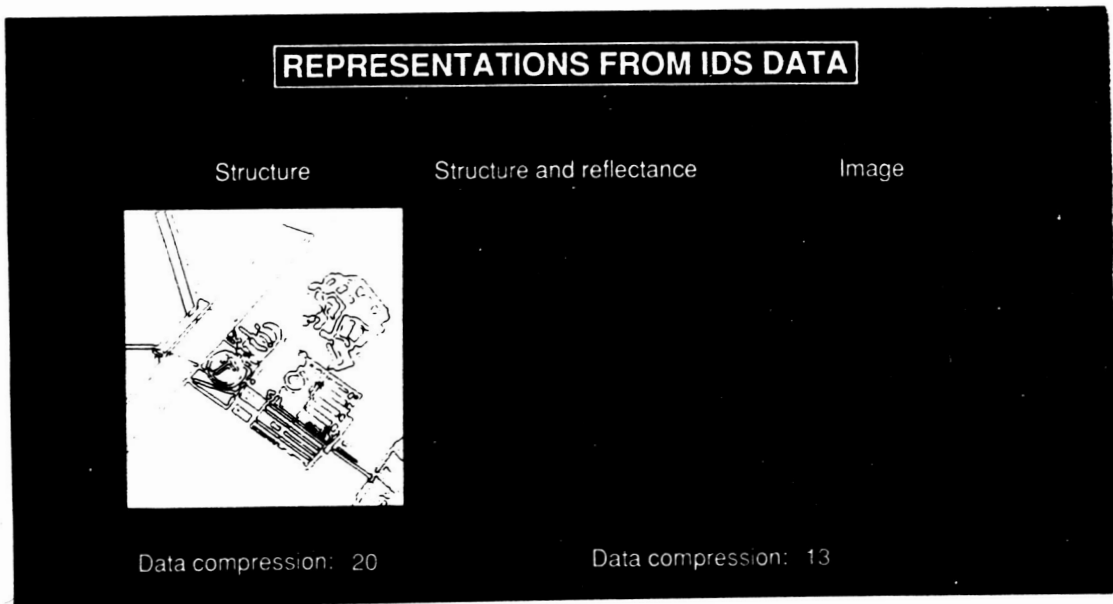
IDS RESPONSE TO BRIGHT SPOT

Input intensity

Detectors

Spread in
summing network

Output

Figure 1

IDS MODEL

Detectors
Summing network
Output channels

Detector output pattern:
Constant volume

Figure 2

COMPARISON OF IMAGING PROCESSES

DECREASING ILLUMINATION

Conventional imaging

IDS operator

Figure 3

COMPARISON OF IMAGING AND EDGE-DETECTION PROCESSES

Conventional imaging $\nabla^2 G$ Operator   IDS Operator

input

Output

DECREASING ILLUMINATION

Figure 4
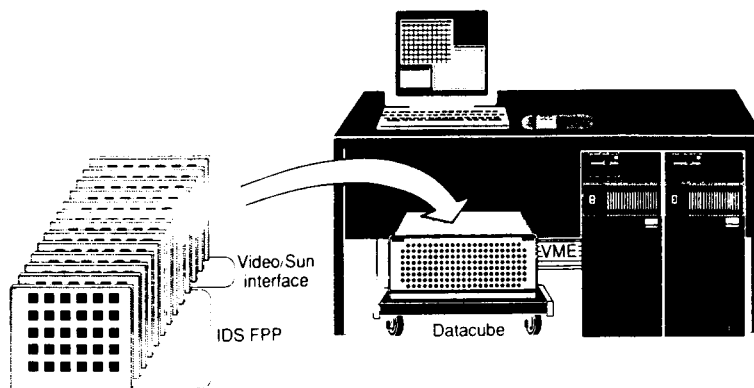
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Figure 5

Figure 6
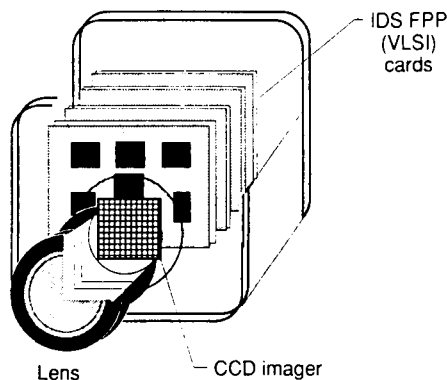
Figure 7

IDS FOCAL-PLANE PROCESSING CAMERA (VLSI)

Figure 8

PARALLEL ASYNCHRONOUS FOCAL-PLANE IMAGE PROCESSOR

Figure 9