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Abstract

When image processing techniques are applied to real images, differences in information content between the horizontal and vertical directions should be considered. The minimum spatial scale at which an algorithm can be applied isotropically is limited by the characteristics of the imaging system. Below that scale, threshold values used within algorithms are dependent on the orientation of a objects in a scene.

The response of an electro-optic system has been described based on the ability of a human observer to detect changes in intensity. However, when the observer is a machine rather than a human, the size of the response required for detection is likely to be larger. In addition, the orientation dependence of the magnitude of intensity changes must be considered.

This report is a brief review of three sources of differences between the horizontal and vertical directions in real images, using equipment in the University of Pennsylvania General Robotics and Active Sensory Perception Laboratory. The shape of the pixels is not square, the pixel data is not independent, and the spatial frequency response is different. Other image acquisition errors, such as blooming, CCD blemishes and uniform illumination signature are addressed in [I]. The impact of these differences on several basic image processing algorithms is discussed.

Comments

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GRASP LAB CAMERA SYSTEMS AND THEIR EFFECTS ON ALGORITHMS

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GRASP LAB 161

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GRASP Lab Camera Systems and their Effects on Algorithms

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October 27, 1988

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This report is a brief review of three sources of differences between the horizontal and vertical directions in real images, using equipment in the University of Pennsylvania General Robotics and Active Sensory Perception Laboratory. The shape of the pixels is not square, the pixel data is not independent, and the spatial frequency response is different. Other image acquisition errors, such as blooming, CCD blemishes and uniform illumination signature are addressed in [1]. The impact of these differences on several basic image processing algorithms is discussed.

1 Pixel Shape

The shape of a pixel is the aspect ratio of the rectangle associated with each intensity value. Video cameras, such as the Sony XC-39 and XC-77 family, image an area with aspect ratio 4:3. Digitizers, such as the Data Translation DT2651 and DataCube, have image size of 512 by 512, an aspect ratio of 1:1.

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The camera CCD response is sent from the camera to the digitizer as an analog signal. The analog signal which covers a 4:3 area is then digitized and stored as a square matrix by an 8 bit video A/D converter. The data is in pixel format only after digitizing, so the pixel shape is determined by the relationship between the aspect ratios of the imaged area and the digitizer array size. Therefore the pixels themselves have a 4:3 aspect ratio. If the matrix is displayed on a monitor which also has a 4:3 aspect ratio, the picture is shown with the original aspect ratio. However, algorithms which operate directly on the pixel data are not isotropic.

Algorithms which are affected by non-square pixels are edge detection and region growing. Also, statistics on image texture and noise taken at a small spatial scale are changed by the rectangular shape of the pixels, since more averaging of the scene reflectance occurs in the horizontal direction than in the vertical direction. Algorithms which depend on size measurements, such as eliminating regions smaller than a threshold size in segmentation, also should take pixel aspect ratio into account.

2 Resolution Shape

The information content of pixels depends on the number of sensing elements in the video camera and on the digitizing rate. For example, the Sony XC-39 camera has 378 pixels per horizontal line, and 485 lines. When the analog signal from the camera is digitized at 512 pixels per line, then horizontally adjacent pixels in the image array cannot be considered as independent data points. This digitizing rate increases the width of the transition zone between regions of constant intensity, and may reduce the response from edge detectors. Also, texture and noise statistics become anisotropic. Image bandwidth is limited below the apparent bandwidth. Algorithms which depend on the assumption that pixel intensity values are independent samples of a continuous function plus additive noise should not be expected to work properly, since the horizontally adjacent samples are not independent. The problems of resolution shape and pixel independence have also been discussed in [1].

The specified vertical resolution of the XC-39 is 485 TV lines. The bottom 27 scan lines are blank. The highest spatial frequency is 256 cycles per vertical screen dimension. The specified horizontal resolution is 280 TV lines. Since TV lines are defined with respect to the vertical dimension, and there is a 4:3 aspect ratio, this corresponds to 187 cycles per scan line and 140 cycles per vertical screen dimension. The actual spacing of the photo sensors is 23 μm horizontal by 13.4 μm vertical [2].

The XC-77 has the same vertical resolution as the XC-39; however, the horizontal resolution is specified as 570 TV lines [3]. This corresponds to 380 cycles per scan line, which can be confirmed with the camera connected directly to a monitor. Through the Data Translation digitizer, the highest frequency is 256 cycles per scan line [4]. Though the horizontal sampling rate of the XC-

77 is higher than the XC-39, the horizontally adjacent samples are still not independent.

3 Spatial Frequency Response

The horizontal response in the camera/digitizer system is much less than the vertical response, at high spatial frequencies. This occurs because horizontally adjacent pixels are separated in time by approximately 0.1 microseconds, while vertically adjacent pixels are separated by approximately 33 milliseconds, due to interlacing. The resolutions in the horizontal and vertical directions in interline transfer CCD's is discussed in [5]. This can be demonstrated by a pattern of narrow parallel lines, which is a square wave in cross section. For example, in Figure 2a, a 60 by 60 pixel portion of a square wave pattern imaged with a Sony XC-77 camera and a Data Translation 2651 8 bit video digitizer is shown. When the lines are oriented vertically, the amplitude of the square wave is approximately 25. In Figure 2b, the same camera set-up is used with the lines oriented horizontally, and the amplitude is approximately 85.

In the vertical direction, the response is nearly flat until the Nyquist rate; however, the horizontal response drops off gradually before reaching the Nyquist rate. A television test pattern is used to estimate the response of the camera/digitizer system for both the Sony XC-39 and the Sony XC-77 with the Data Translation DT2651 digitizer. Since the lens mounts are different, different lenses are used. For the XC-39, a Sony 16 mm lens is used. For the XC-77, a Cosmicar 16mm lens is used. Both are set at at f2.8, hand focused. The response is taken from sets of 4 black lines on the test pattern, with the amplitude measured as half the maximum peak-to-peak intensity difference. The spatial frequencies are calculated from the actual spacing of the peaks. The results are shown in Figure 3. From the graphs in Figure 2, it is clear that phase does make significant difference; however, that difference is small compared to the difference between horizontal and vertical response. The difference in low frequency response appears to be due to the difference in uniform illumination signature of the lenses.

The limiting resolution of an electro-optic system is defined by the spatial frequency at which a human observer can no longer discriminate differences in light and dark transitions in a bar pattern. This response level is approximately 3% [6]. However, when the observer of the response is a machine rather than a human, 3% may not be sufficient. In addition, when the vertical response is much greater than the horizontal response, this fact should be considered in machine vision applications.

Algorithms which are affected by directional differences in bandwidth are histogram splitting, region growing and edge detection.

For a histogram splitting example, both images in Figure 2 can be segmented by producing a bimodal histogram; however, no bin width produces a bimodal histogram for both images. Acceptable bin widths for Figure 2a range from 6 to 24. Acceptable bin widths for Figure 2b range from 40 to 75. Therefore, the bin width parameter is dependent on direction. These histograms are shown in Figure 4.

In edge detection, the magnitude of convolution response decreases with increasing width of the edge transition zone. Since the horizontal response to changes in scene reflectance is less than the vertical response, image edges oriented vertically (and detected in the horizontal direction) can be expected to be wider than image edges oriented horizontally. The edge magnitude will then be reduced. The amount of reduction varies with scale. For example, compare a transition zone of width 5 (intensities 100, 100, ... 100, 120, 140, 160, 180, 200, 200,...) to a transition zone of width 2 (intensities 100,... 100, 150, 200... 200). When a difference of Gaussian convolution of $\sigma = 1.4$ is applied to these edges, the magnitude of response of the width 5 edge is 31% less than the width 2 edge. With $\sigma = 5.6$, the reduction is 6%.

Region growing uses a local similarity parameter, the difference between intensities of adjacent pixels. This is similar to edge detection at a fixed, spatially small scale, and thus is also dependent on direction.

4 Conclusion

Image processing algorithm parameters have been shown to be dependent on the direction in which they are applied, particularly at small scales. This applies specifically to local similarity thresholds for region growing, bin widths for histogram splitting, edge detection thresholds. The correctness of the algorithms themselves are not dependent on direction; however, direction should be considered when using fixed response thresholds.

Algorithms which make the assumption that pixels along the horizontal direction are independent samples from a continuous distribution are not appropriate for images obtained from the camera/digitizer systems in the GRASP Lab.

References

[1] R. Bajcsy, E. Krotkov, M. Mintz, "Models of Errors and Mistakes in Machine Perception," University of Pennsylvania GRASP Laboratory Report 64, MS-CIS-86-26, 1986.

[2] "Miniature CCD Video Camera Module XC-37/38/39," Sony Component Products Division, Paramus, NJ, 1986.

[3] "Video Camera Module CCD XC-77," Sony Component Products Division, Paramus, NJ, 1988.

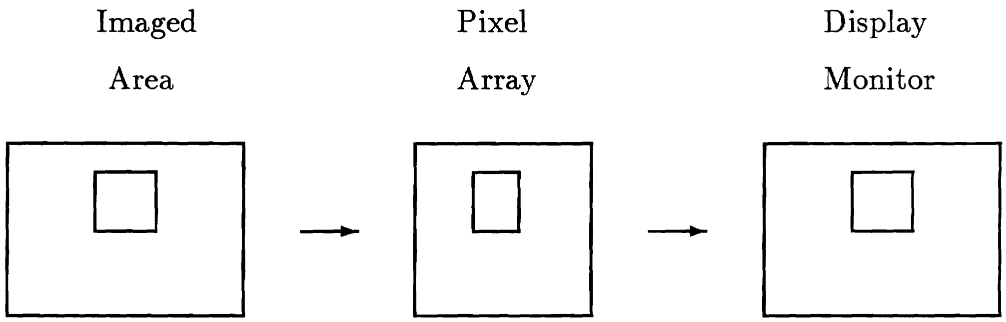
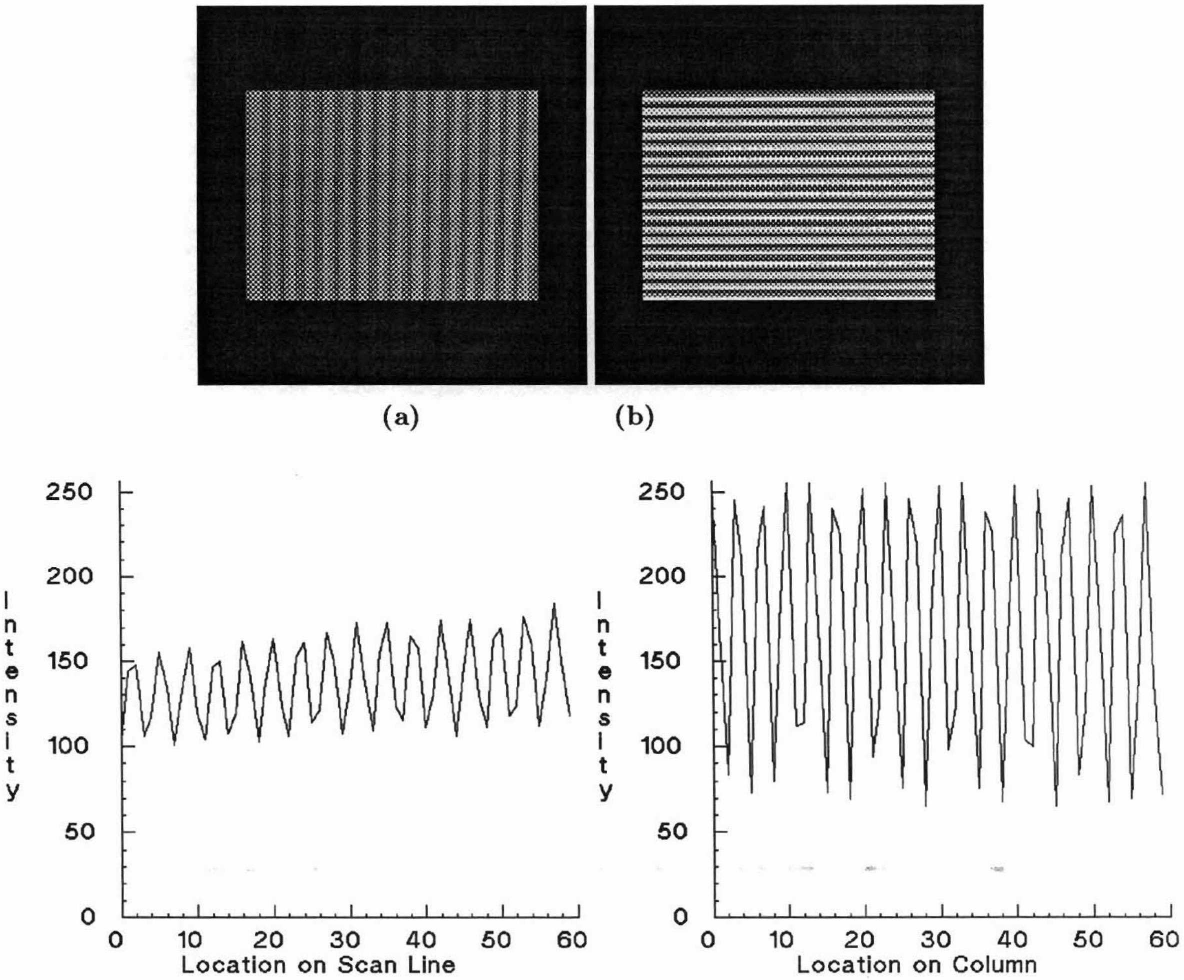


Figure 1: Image of a Square

[4] "User Manual for DT2651," Data Translation, Inc., Marlborough, MA, 1986.

[5] C. H. Sèquin and M. F. Tompsett, **Charge Transfer Devices**, Academic Press, Inc., New York, 1975, pp. 173-178.

[6] **RCA Electro-Optics Handbook**, RCA Commercial Engineering, Harrison, NJ 07029, 1974, pp. 114-121.



(a) (b)

Figure 2: Square Wave Pattern at 2 Orientations

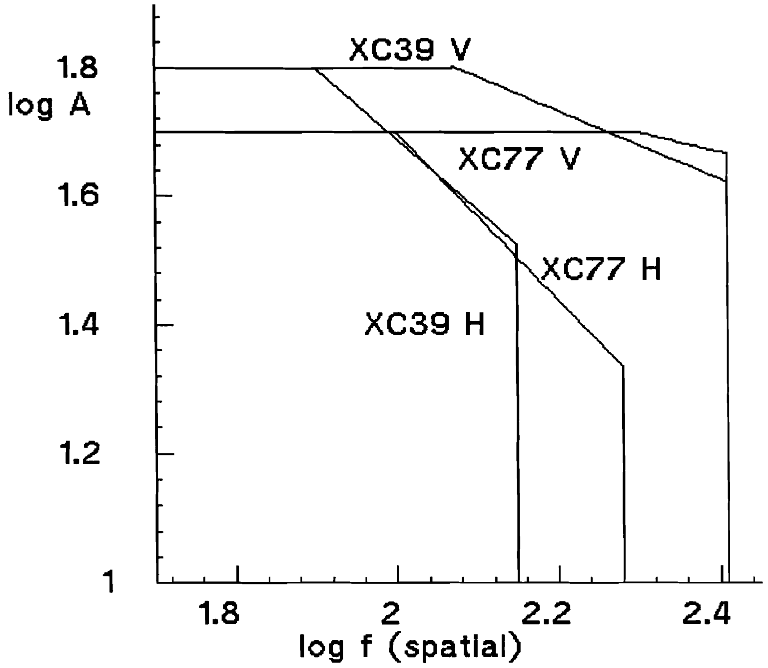
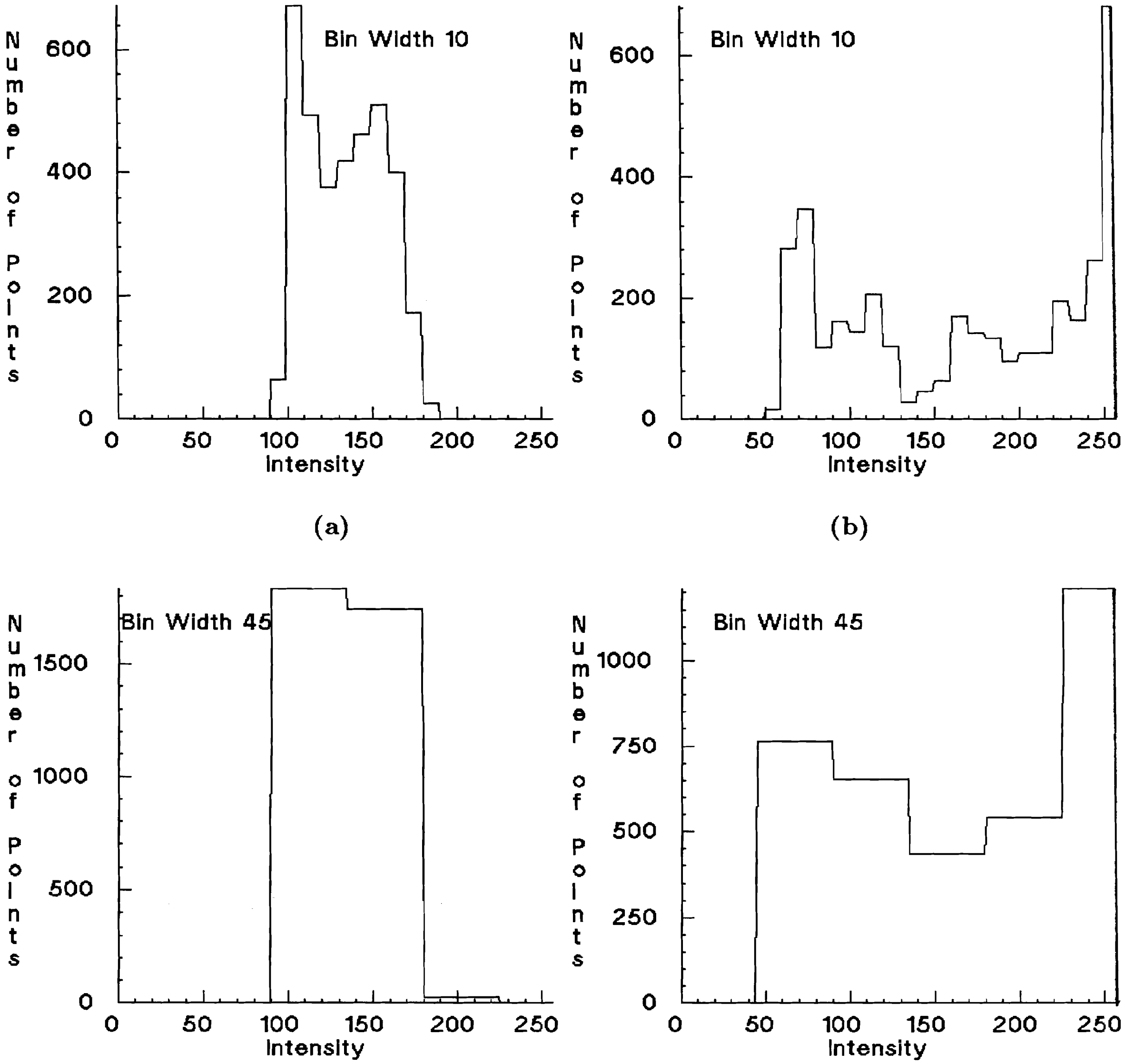


Figure 3: Response of Camera/Digitizer Systems. The XC39/DT2651 is limited horizontally by the camera response. The XC77/DT2651 is limited horizontally by the digitizer response. The vertical response of both is limited by the camera and the digitizer. The Amplitude is measured as half the peak to peak intensity difference of 3.5 square wave cycles, and the spatial frequencies are measured as cycles per vertical screen dimension.



(a) (b)

(a) (b)

Figure 4: Histograms of Images in Figure 2a and 2b. Image (a) is bimodal at bin width 10, image (b) is bimodal at bin width 45.