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Computer Estimated Probability of Detection:
Can You Hide From a Computer?

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Abstract

Several clutter metrics were evaluated and compared against the probability of detection of ground combat vehicle targets in test scenes created in a natural field environment. This paper presents the methods of testing subjects and the methods of computing the metrics. Finally, limited results of the initial testing and the comparison of this against the metrics are given thereby showing the effectiveness of these metrics on this set of targets and on all targets in general.

Introduction

One of the underlying goals of discovering metrics is to reliably compute information about images (such as probability of detection (Pd) of an object) and effectively assist the soldier in his assessment of his own Pd [1, 2]. If a computer could accurately predict Pd, it would be able to expedite the process of concealing ground vehicles within enemy territory and support tactical planning. This also helps cut down development time on new camouflage treatments and concealment methods. All of this is critical to the survivability of the soldier and ground vehicles.

The metrics in this paper, called Target Structure Similarity Metrics (TSSM), are derived from the popular Structural Similarity Metric from [3] These metrics take into account certain hypothesized characteristics of the human vision system (HVS) such as sensitivity to edges and sensitivity to areas of high contrast [3]. TSSM use these qualities to measure image quality by comparing a non-distorted reference image against a distorted image. The metric is then a measurement of how closely specific qualities of the distorted image resemble those of the reference image. The TSSM clutter metric is based on the signal processing features of human vision aided by computer comparison of the images.

Test Images

The test images were taken at Eglin Air Force Base in Florida using a Panoscan camera with resolutions reaching 52342 x 6000 pixels. These images were found to exceed the computing power of the current resources available so the images were modified. The images were compressed, cropped and the colors were rebalanced using a program called Photomatix Pro (http://www.hdrsoft.com/). They were then placed into a program developed specifically for testing human subjects on their ability to locate and identify targets. The images were comprised of pictures of the same background with military vehicles concealed in different locations in different pictures.

Fig. 1: The photosimulation lab consists of a 180 degree, wrap-around projection screen illuminated by three high resolution projectors.

Survivability's Visual Perception Lab (VPL) (Fig. 1) was used to test metrics because it is more economical than field testing. [4] The test was intended to represent military vehicles as if they were seen by an unaided eye from distances within the range of 1-3 kilometers. Subjects were given a set of instructions that told them there could be zero to four targets and that they would be given four minutes to locate these targets regardless of their success. Each subject was given six guesses. Because the images reuse the location, all efforts were taken to ensure that the subject did not know his/her own success rate. The images were displayed on a projection screen in the visual perception lab and subjects were given a joystick and a mouse. The joystick was used to pan the image back and forth while the mouse was used to point to the target. One of the buttons on the joystick could be pressed to indicate that this was the target. The program kept statistics on success rates and the time each subject took to make a detection decision. 53 images were randomly shown to the viewer with a noise screen in between each to neutralize background retinal images. A typical background is shown below in Figure 2. Actual visual stimuli were in color.

Fig. 2: A typical background of the test images. Real images have target vehicles in the scene.

TSSM

The TSSM divides an image into blocks and assesses the similarity metric values of these blocks using the region the target is located in the image as the reference. The clutter can then be determined by the overall average similarity metric measurement of all of these pieces of the background compared against the target's area in the image. To simplify the concept: TSSM clutter is how often and how much the target resembles various regions of the scene.

The algorithm for TSSM was adapted for field image testing from [3] and [5]. TSSM is implemented by taking the target T_i where i is the i'th pixel in the target block and the blocks $B_{i,j}$ where i is the i'th block of the entire image and j is the j'th pixel of that block. These blocks are twice the dimensions of the target to account for the HVS's ability to adapt its response to the size of the object being searched following appropriate training.[5] TSSM mathematically defines the following characteristics and combines them in a single metric.

Luminosity or Average Intensity:

$$L(T, B_j) = \frac{2\mu_T \mu_{B_j}}{{\mu_T}^2 + {\mu_{B_j}}^2} \tag{1}$$

where μ_x is the arithmetic mean of x.

Contrast:

$$C(T, B_j) = \frac{2\sigma_T \sigma_{B_j}}{{\sigma_T}^2 + {\sigma_{B_j}}^2} \tag{2}$$

where σ_x is the standard deviation of x and ${\sigma_x}^2$ is the variance of x.

and Structure:

$$S(T, B_j) = \frac{2\sigma_{T B_j}}{\sigma_T \sigma_{B_j}} \tag{3}$$

where,

$$\sigma_{T B_j} = \frac{1}{M-1}\sum_{i=1}^{M}\left(T_i - \mu_T\right)\left(B_{j,i} - \mu_{B_j}\right) \quad (4)$$

These three components are combined to yield an overall similarity measure. Since zero is a possible value for the denominator, they add an arbitrary constant, *C*. Here *C* = 0.02

$$TSSIM\left(T, B_j\right) = \frac{4\sigma_{TB_j}\mu_T\mu_{B_j} + C}{\left(\sigma_T^{\ 2} + \sigma_{B_j}^{\ 2}\right)\left(\mu_T^{\ 2} + \mu_{B_j}^{\ 2}\right) + C} \quad (5)$$

These values are then combined again as either a root mean square, an arithmetic mean or a geometric mean value.

Schmieder-Weathersby

One of the metrics used is the Schmieder-Weathersby metric [2] which is defined here as:

$$clutter = \sqrt{\sum_{i=1}^{N}\frac{\sigma_i^2}{N}} \quad (6)$$

where N is the number of cells across the image where a cell is twice the maximum target dimension.

Entropy

Additionally, the entropy metric on image quality was tested to assess the effect of information entropy on Pd. The poorer the picture quality, the harder it should be to find a target in the picture. This is important because the images used are processed and don’t necessarily reflect the true visibility of what test subjects saw on-site. The entropy metric is defined here from [6]:

$$H\left(f\right) = -\sum_{t=1}^{T} P\left(f_t\right)\log_2 P\left(f_t\right) \quad (7)$$

where $P(f_t)$ is the probability that the grey scale value (luminance state) of the t’th pixel appears in the image, f.

Metrics

The test images were cropped down to a 200 x 300 pixel bitmap and processed by a MATLAB program developed for implementing the metrics. The correct target was chosen subjectively (best approximation of a rectangle around the target) and then the background was divided up in a number of ways for comparison. These methods included using target sized regions of space immediately surrounding the target, using the entire bitmap and dividing it up into target sized regions and also using regions of twice that size. Comparing the target with the background in intensity, contrast and structure, the program generated a value known as the TSSM average which is then compared against the actual Pds to find a correlation. It should be noted that while the subjects were shown stimuli in color, the program discards all color information from input images at this time. Future modifications of the code will permit color processing in metric evaluation by the combination of several image color planes.

Results

As of the time that this paper was written, the results indicate that there is good correlation with the test subjects in the field compared to the test subjects in the visual perception lab. This is an important correlation, because it validates the use of data gathered at the lab which is much more easily and cost-effectively obtained than data gathered on-site in the field. Further analysis is required to determine the correlation of the metrics compared to the performance of the tests subjects at the laboratory.

Conclusion

Further analysis must be completed before a more conclusive statement may be made about the degree of correlation to experimental data of the metrics mentioned in this report. In the future, more studies will be conducted to find other metrics and better implementations that are more efficient and faster. Finally, more research will be completed for methods of testing subjects in a visual perception lab as well as for processing images for use in image metric programs.

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