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Improvements to the Gray-Level Co-occurrence Matrix (GLCM) Based Trackability Metric

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ABSTRACT

The Gray-Level Co-occurrence Matrix (GLCM) based Trackability Metric has bee used at AMCOM for many years for autotracker performance evaluation. The origins of the metric stem from the frustrating experience of trying to use such measures as delta T and signal to noise ratios to specify autotracker performance requirements. This paper presents the most recent developments and improvements to the GLCM based Trackability Metric (TM) and the resulting performance enhancements. One of the new developments is the inclusion of a hot spot or most predominant feature metric. Additionally, the results of a sensitivity study for the accuracy of target segmentation verses the GLCM TM performance is presented. These new developments for the Trackability Metric should provide better state-of-the-art performance prediction and more accurate performance modeling for specific imaging autotracker designs. The results of these studies and the final implementation of the Trackability Metric are presented.

Keywords: imaging, feature, resolved, target, signature, tracking, clutter, metric, autotracker

1. INTRODUCTION

The GLCM Trackability Metric (TM) was originally developed by the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) under the Advanced Imaging Autotrackers Technology Base Program to predict the performance of autotrackers for imaging infrared (IR) missile seekers. The original application was to predict how well an autotracker could successfully segment and track a target in its entirety from the background. For some applications full segmentation is important, for other applications it is not. We found that when the TM, as originally designed, was used for applications without a full segmentation requirement, the TM often did not correctly predict the resulting autotracker performance. Some targets with very low full segmentation TM values were easily tracked. This was sometimes caused by a single small predominant feature on the target, which allowed the autotracker to track the single feature itself against the combination of the remainder of the target and the background.

Several variations of the TM were evaluated to include the effects of a predominant target feature on autotracker performance. Several feature segmentation and predominance measurement algorithms, and methods of including this new measurement in the overall TM representation, were studied. Only the resulting design is presented here in this paper.

User feedback indicates that the time intensive ground-truthing process required for the application of the TM has lead to short cuts in the target segmentation process. The obvious question then becomes how accurate does the target segmentation have to be and what is the impact on the accuracy of the TM? The results of a study addressing this issue are addressed in section 6.

2. GLCM Trackability Metric Revisited

The GLCM is a square matrix whose elements are an estimate of the joint probability that a pair of pixels will have two specific grayscale values. The formal definition of the GLCM, found over a region of interest (ROI) within an image and for a given orientation, is given by Equation 2-1.

$$G_{a,b}(r_\theta, \theta) = \frac{N_{a,b}}{N} \approx \Pr\{I(m,n) = a, I(m + r_\theta \cos\theta, n + r_\theta \sin\theta) = b\},$$ (2-1)

where

$I(m,n)$ = the image intensity or grayscale value at the m'th row and n'th column,

$N_{a,b}$ = the number paired pixels whose grayscale values are a and b respectively,

N = the total number of pairs in the ROI,

r_θ = the quantized radial displacement between the pixels, and

θ = the polar angle or direction between the pixels.

The target and background GLCMs are found using appropriate windows as the reference Region of Interests (ROI)s for evaluation purposes. Pixel membership is determined using segmented-target ground-truth data for the image. The structure length of the target for a specified direction is given by locating the first peak in the minimum absolute difference (MAD) auto-correlation surface of the target along the direction of displacement. To account for noise and measurement uncertainty, the GLCMs are convolved with a kernel formed from the truncated noise distribution appropriate for the target area of interest. The same convolution kernel is used for both the target and background GLCMs and is used for four directional evaluations.

The measured TM value for the target area of interest is found by comparing the GLCM of the target with that of the local background using Equation 2-2. Equation 2-2 yields a directional TM value along a specified orientation. The final TM value is the average of four directional TM calculations evaluated at 0, 90, and ±45 degrees.

$$TM(\ell_\theta^{tgt}, \theta) = 1 - \frac{\sum_{a,b=0}^{L-1}\left[\hat{G}_{a,b}^{tgt}(\ell_\theta^{tgt}, \theta)\cdot\hat{G}_{a,b}^{bkg}(\ell_\theta^{tgt}, \theta)\right]}{\sqrt{\sum_{a,b=0}^{L-1}\left[\hat{G}_{a,b}^{tgt}(\ell_\theta^{tgt}, \theta)\right]^2}\cdot\sqrt{\sum_{a,b=0}^{L-1}\left[\hat{G}_{a,b}^{bkg}(\ell_\theta^{tgt}, \theta)\right]^2}} \qquad (0 \leq TM \leq 1),$$ (2-2)

where

$\hat{G}_{a,b}^{tgt}$ = $G_{a,b}^{tgt}(\ell_\theta^{tgt}, \theta) * K_{\Delta_a, \Delta_b}^{unc}(t)$, the convolved target GLCM,

$\hat{G}_{a,b}^{bkg}$ = $G_{a,b}^{bkg}(\ell_\theta^{tgt}, \theta) * K_{\Delta_a, \Delta_b}^{unc}(t)$, the convolved background GLCM,

$G_{a,b}^{tgt}$ = the GLCM of the target area in the current frame,

$G_{a,b}^{bkg}$ = the GLCM of the local background in the current frame,

$K_{\Delta_a, \Delta_b}^{unc}$ = the truncated uncertainty kernel for the current frame,

ℓ_θ^{tgt} = the target's structure length along the current direction,

θ = the current direction of interest (one of the four possible values), and

L = the number of available grayscales in the image.

     Notice that both the target and background GLCM's are found using the target's structure length. This emphatically couples the background clutter characterization with the target's structure. Note also that Equation 2-2 is still a directional quantity. Depending on the intended application, this can be exploited for comparing the target signature along different orientations or the orientation dependence can be integrated out by averaging the results over many directions. Further detail on the GLCM Trackability Metric fundamentals can be found in References 1, 4, and 5.

3. PROBLEM SCENARIO

     The first change made to the TM was the introduction of a predominant feature measurement. This requirement has been added due to the application of the TM to new programs. One of the original requirements was to measure the likelihood of correctly segmenting the entire target from the background. Obviously this is not a requirement for a successful track for many applications. The particular case that drove the Predominant Feature Measurement is presented here. Figures 3-1 demonstrates typical IR imagery for which the GLCM TM measurement for the whole target is low but a relatively small but bright hot spot is present at the target's engine port. In this case, the number of pixels comprising the hot spot is small compared to that of the whole target; consequently, the hot spot makes a rather small contribution to GLCM TM of the whole target.
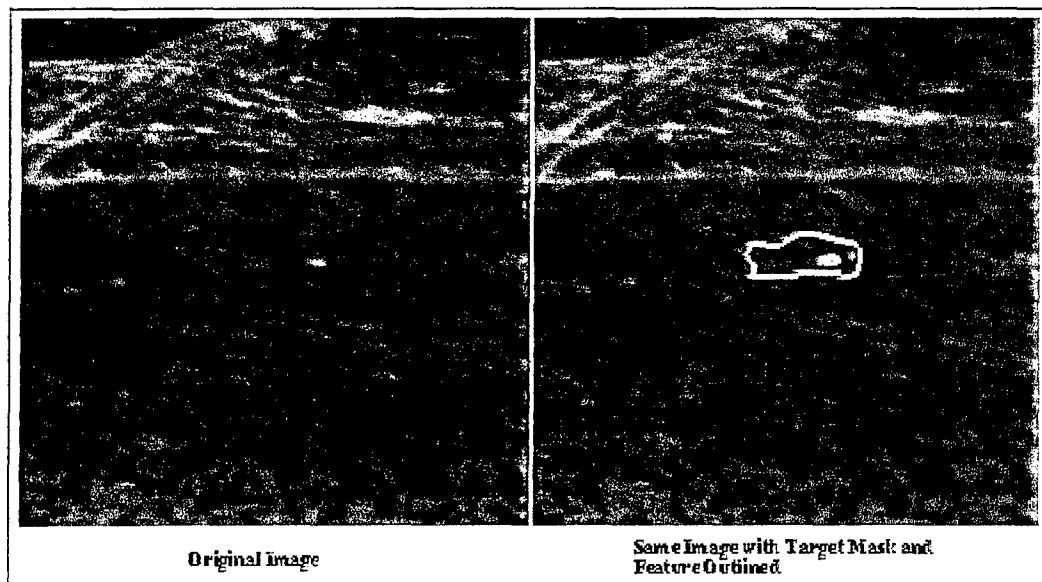

Original Image   Same Image with Target Mask and Feature Outlined

Figure 3-1. Low GLCM TM with Predominant Target Feature, Actual Data

4. DETERMINATION OF FEATURE PREDOMINANCE

     A number of methods were explored to measure the level of target feature predominance that is present within an IR image. This measure would be combined with the classical whole-target GLCM to form a composite measurement. Included in these were the features relative SNR, the area ratio of the feature with the target, the energy ratio of the feature with the target, and many more elaborate formulations.

     The selected implementation was to use the GLCM TM itself as a feature predominance measurement. This new implementation of the GLCM TM is the same as the classical form but with the feature area mask used instead of the whole-target, with the local background area is defined as anything but the feature. The result is a normalized form that

measures the textural content and the intensity of the feature relative to that of its background. In such cases as shown by Figure 4-1 and Equation 4-1 where a small but bright hot spot at an engine port is present, the extracted feature itself has a very different textural composition than that its background. This provides an excellent measure of an internal target component that can be used for tracking and, by the nature of Equation 4-1, is normalized.
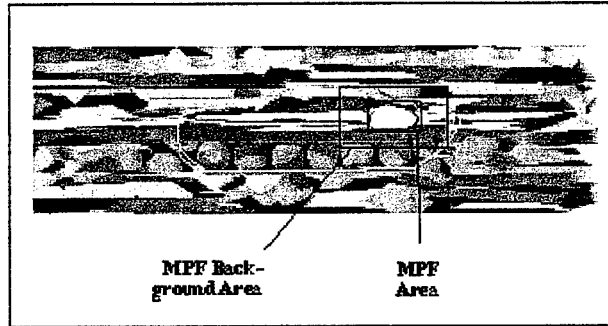

Figure 4-1. Feature GLCM Trackability Metric, Measure of Feature Predominance

$$TM_{MPF}\left(\ell_\theta^{MPF},\theta\right) = 1 - \frac{\sum\limits_{a,b=0}^{L-1}\left[\hat{G}_{a,b}^{MPF}\left(\ell_\theta^{MPF},\theta\right)\cdot\hat{G}_{a,b}^{bkg}\left(\ell_\theta^{MPF},\theta\right)\right]}{\sqrt{\sum\limits_{a,b=0}^{L-1}\left[\hat{G}_{a,b}^{MPF}\left(\ell_\theta^{MPF},\theta\right)\right]^2}\cdot\sqrt{\sum\limits_{a,b=0}^{L-1}\left[\hat{G}_{a,b}^{bkg}\left(\ell_\theta^{MPF},\theta\right)\right]^2}} \qquad \left(0 \le TM_{MPF} \le 1\right), \qquad (4\text{-}1)$$

where

MPF	=	the Most Predominant Feature of the target,
$\hat{G}_{a,b}^{MPF}$	=	$G_{a,b}^{MPF}\left(\ell_\theta^{MPF},\theta\right)*K_{\Delta_a,\Delta_b}^{unc}(t)$, the convolved MPF GLCM,
$\hat{G}_{a,b}^{bkg}$	=	$G_{a,b}^{bkg}\left(\ell_\theta^{MPF},\theta\right)*K_{\Delta_a,\Delta_b}^{unc}(t)$, the convolved background GLCM,
$G_{a,b}^{MPF}$	=	the GLCM of the MPF area in the current frame,
$G_{a,b}^{bkg}$	=	the GLCM of the local background in the current frame,
$K_{\Delta_a,\Delta_b}^{unc}$	=	the truncated uncertainty kernel for the current frame,
ℓ_θ^{MPF}	=	the MPF's structure length along the current direction
Background	=	Every thing in the local area except the MPF.

5. COMPOSITE TRACKABILITY METRIC

A rational solution for a composite track metric (TM_{COMP}) is the normalized Root Sum Square (RSS) value of the whole-target track metric (TM_{tgt}), which is the classical form shown by Equation 2-2, and the feature-only track metric (TM_{MPF}) as is shown by Equation 4-5. This formulation takes into account the special problem scenario exhibited in section

3. When the GLCM-based TM algorithm is invoked using only the MPF as the target mask in such cases, the feature area is so much *unlike* the surrounding background that a relatively high value of TM_{MPF} is measured. With this type of case, TM_{COMP} would take into account the fact that the whole target would be difficult to track utilizing a multi-feature based tracker. It would also consider the fact that a portion of the target *could* be tracked but by ignoring the rest of the target. The normalized RSS combines these two measurements with the proper weighting, never allowing TM_{COMP} to be less than TM_{tgt}. In situations for which the whole-target structure very closely resembles the background and no predominant feature exists, TM_{COMP} would be measured as a relatively low value since TM_{MPF} would essentially be zero. The TM_{comp} formulation shown by Equations 5-1 and 5-2, and the properties of which shown by Figure 5-1 exhibit the nature of the composite metric. The *normalized* RSS seems to be the appropriate formulation for the low TM_{tgt} /hot spot condition as compared to a non-normalized RSS formulation, which was tested during algorithm development. The non-normalized RSS, limited to 1 does not achieve the objective since a very predominant hot spot and a low TM_{tgt} results in a saturated value with too much weighting on the feature component. More detail on the implementation and test results can be found in reference 6.

For $TM_{MPF} > TM_{tgt}$, $\qquad TM_{COMP} = \sqrt{1/2\left(TM_{tgt}^2 + TM_{MPF}^2\right)}$ $\qquad\qquad (0 \le TM_{COMP} \le 1), \quad (5-1)$

For $TM_{MPF} <= TM_{tgt}$, $\qquad TM_{COMP} = TM_{tgt}$ $\qquad\qquad\qquad\qquad (0 \le TM_{COMP} \le 1), \quad (5-2)$
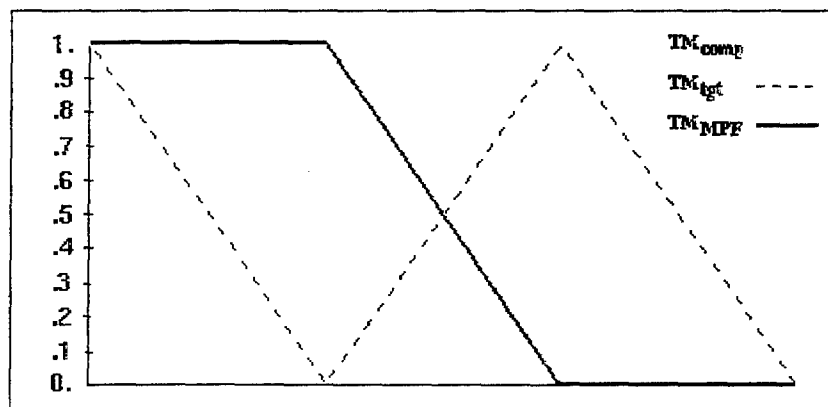

FIGURE 5-1. Composite GLCM Trackability Metric Properties

6. GLCM TM SENSITIVITY TO GROUNDTRUTH

Exact ground-truth is available for synthetic image sequences, but is not available for captive flight data. In order to analyze tracker performance against captive flight data, the ground-truth data must be generated by hand. This manually generated ground-truth data is obviously not as accurate as it would be if it had come from a simulation. The first questions become, how does human error in the ground-truth data affect the TM and can one ground-truth an image sequence well enough to get reasonable TM values? Once we have these answers, we must develop and provided a tool and technique for ground-truthing that reduces the workload enough to make the TM a usable product.

The ground-truth can have many sources of inaccuracy. Some of the sources noted in the past have been the inclusion of background pixels in the target definition, the omission of some of the target pixels from the target definition, and target definitions consisting of a rectangular box approximation of the target instead of an accurate segmentation. These inaccuracies are always a direct result of the labor and time intensive Groundtruthing process. Shortcuts are required to allow the TM to become a cost effective tool.

7.0 TRACKLAB GROUND-TRUTHING TOOL

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The ground-truthing capabilities of TrackLab were enhanced with the inclusion of three-dimensional models of a T-72 main battle tank and a BMP2 armored personnel carrier. This greatly reduces the amount of time required to ground-truth captive flight test (CFT) data. Keyboard commands where added to TrackLab to control the position, scaling, and rotation of the models. Figure 7-1 shows a MICOM IR Seeker Analysis Tool (MIRSAT) seeker image with an overlay of the 3-D target model.
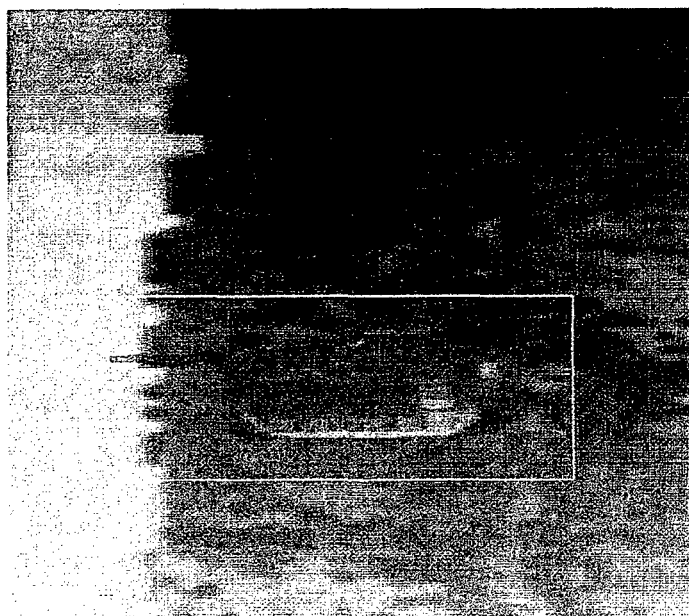

Figure 7-1. 3-D Target Model Overlay.

The position, scaling, and rotation values for the model are stored as a keyframe and are interpolated in between keyframes. The user then has the option of initiating a Minimum Absolute Difference (MAD) correlation to accommodate minor jumps in the imagery. A new reference image is captured every five frames, or whenever a keyframe is reached.

With the assistance of the TrackLab tool, an experienced user can ground-truth an image sequence in a respectable amount of time. The image sequence represented by the image in Figure 7-1 contained 1150 images and was ground-truthed in approximately one hour. There were 81 keyframes defined during the process. The operator identified the key frames when there was visible error in the target model placement and the target in the image. The operator, while trying to do a good job, was instructed to "hurry" in order to reduce the time required for Groundtruthing as much as possible. The tradeoff for accurate TM measurements is time and money for the ground-truthing process.

TM Groundtruthing Trade Study

This study was undertaken to determine how sensitive the GLCM TM is to the accuracy of the ground-truth data. The first step in this study was to use a synthetic sequence, which included "perfect" ground-truth data. The rows of ground-truth data were then shifted up by one, two, and three rows. The GLCM TM was then run using the original ground-truth as well as the shifted versions. Figure 7-2 shows the results.
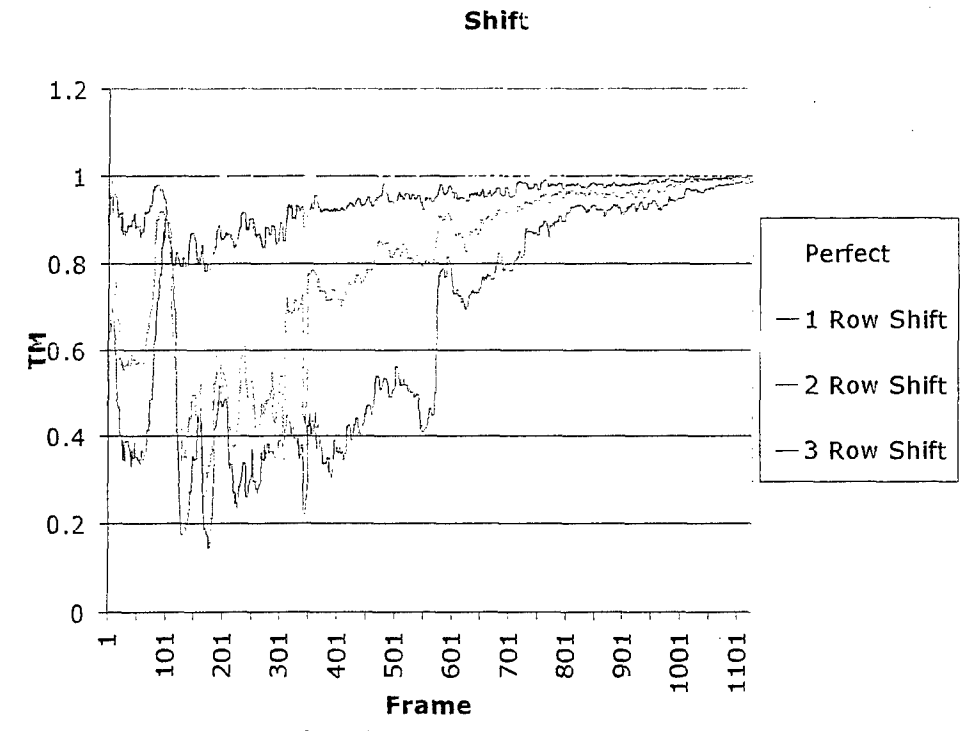
Shift

Figure 7-2.

The output displayed has been filtered to make the chart more readable. Figure 7-3 shows the percent errors of the shifted curves with respect to the perfect one. The curves are just what would be expected. At the start of the sequence, when the target is small, minor errors have major effects. And near the end of the sequence, the target is much larger taking up several rows of the image. Therefore, minor errors in the ground-truth placement have little effect.
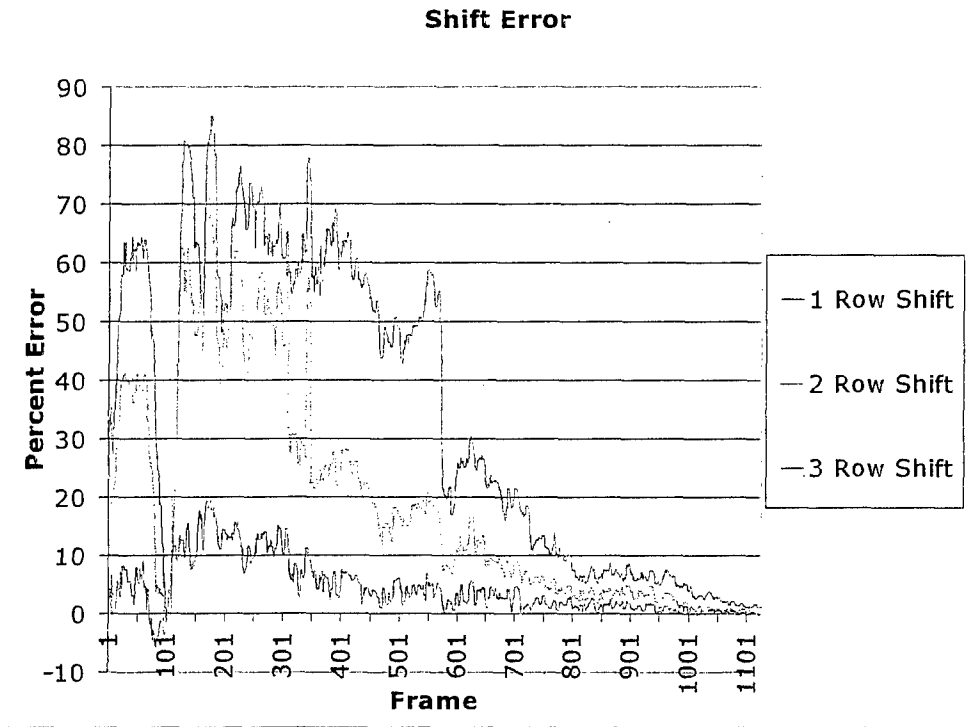
Shift Error

Figure 7-3.

The next step of the study was to use TrackLab to manually ground-truth the synthetic imagery. This was done in a "quick and dirty" manner to give worst-case results. Figure 7-4 shows the TM values calculated using the perfect and manual ground-truth data and Figure 7-5 shows the percent error.
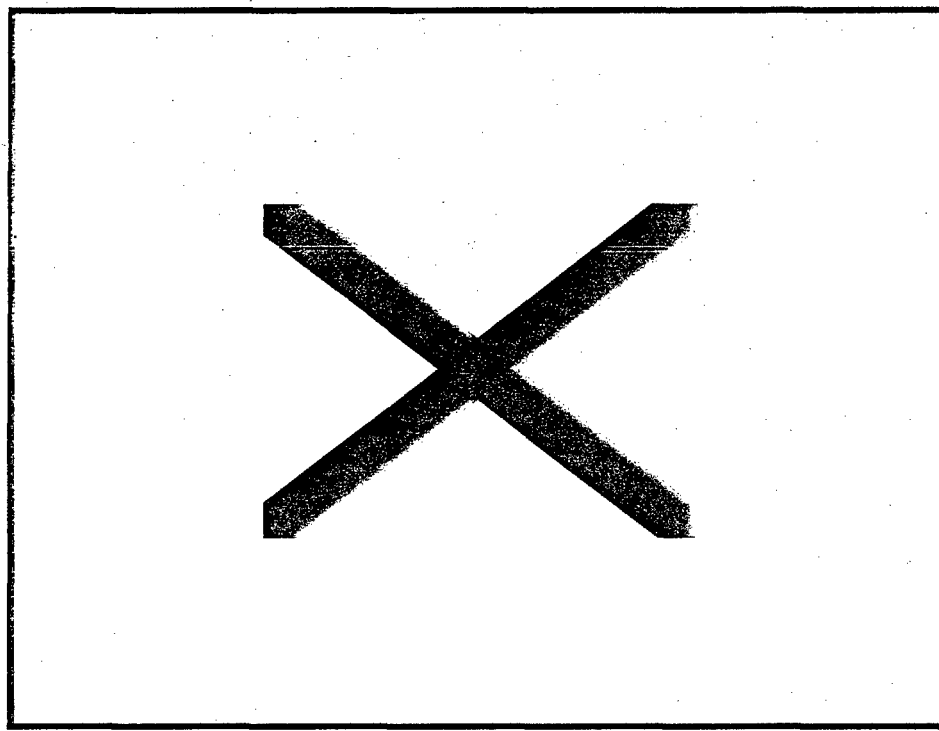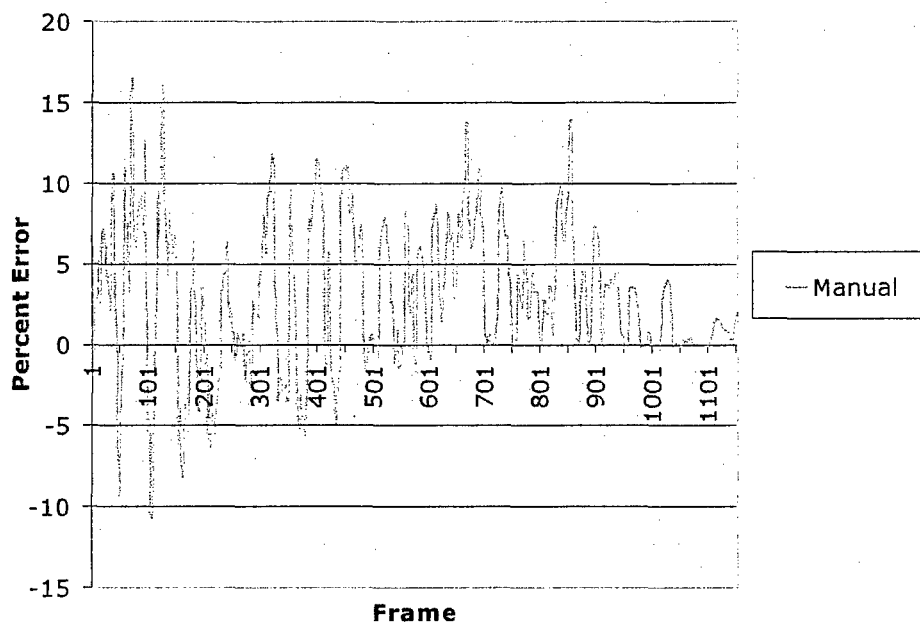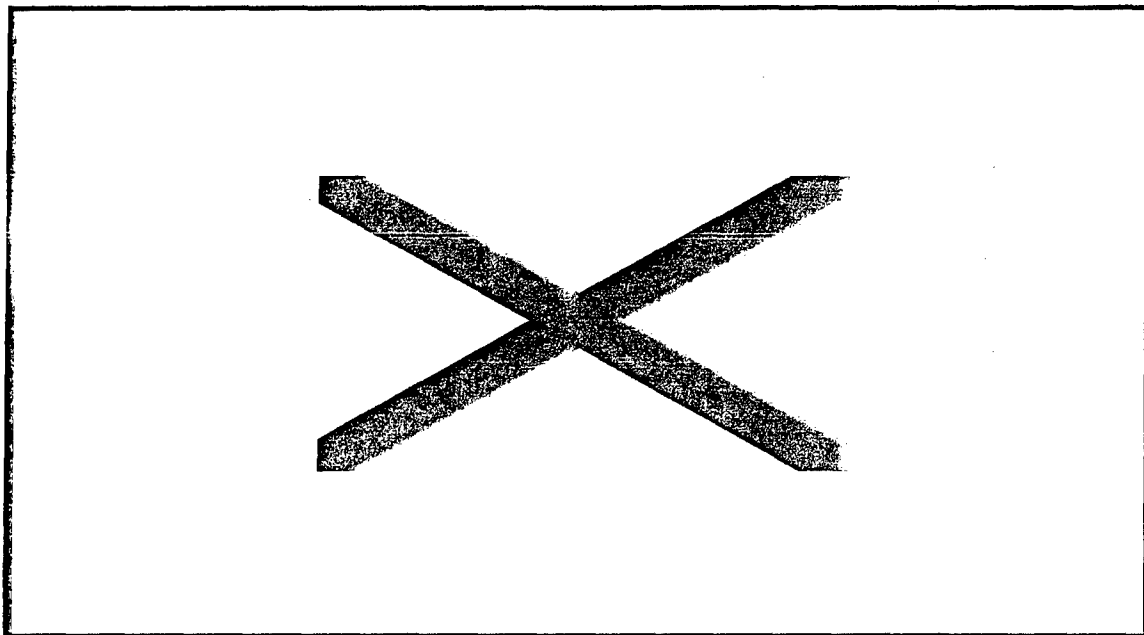

Figure 7-4.

Manual vs. Perfect

Figure 7-5.

An interesting point about Figure 7-5 is that most of the TM values generated from the manual ground-truth are within 10% of the values from the perfect ground-truth. In fact, the average error over all frames is 2.96%. Figure 7.6 shows the error and frequency of each key frame entry.

With these respectable results in hand we decided to increase the number of keyframes to see how accurate we could get the TM. In review it took approximately one hour for the initial keyframing exercise, resulting in 81 keyframes. By adding an additional 76 keyframes at a cost of 45 minutes of operator time, the average TM error over all frames was reduced to 2.45%. With the error dropping only 0.5% the added labor cost is hardly worth it.

8. SUMMARY

This paper describes an improvement of the GLCM TM that provides a more accurate prediction in the performance of modern terminal homing missile systems. This improvement consists of a normalized RSS composite metric value that not only measures the structural composition of the whole target compared to that of the surrounding background, as before, but also the most predominant feature on the target, such as a hot spot. The composite metric takes into account the potential for a tracker to track a single feature but with some level of penalization for only tracking a single feature of a multi-featured target. Additionally, the composite trackability metric can be calibrated for specific autotracker systems on the test range for Go/No-go test decisions.

The GLCM TM ground-truth accuracy study performed at MRDEC shows a dramatic change in TM values for a two-row shift or more in the ground-truth. It further shows that the difference between perfect ground-truth and a manual ground-truth aided with the new three dimensional target models in the TrackLab tool averages only three percent. This small loss in accuracy should be acceptable in most applications for the TM.

The TrackLab tools and the GLCM TM executable code are Government owned and available for Technology Transfer to private industry.

9. REFERENCES

1   B. Brackney, M. Helton, and R. Hammon, "Development of the Gray-Level Co-occurrence Matrix Target Trackability Metric for Imaging Infrared Missile Systems", *SPIE Proceedings, Image Processing*, Vol. 3377, 240-254, Orlando, FL. 1998.

2   G. Waldman, J. Wootton, G. Hobson, and K. Luetkemeyer, "A Normalized Clutter Measure for Images," *Computer Vision, Graphics, and Image Processing*, Vol. 42, 137-156, 1988.

3   W. K. Pratt, *Digital Image Processing, Second Edition*, John Wiley & Sons, Inc., 1991.

4   "Trackability Metric Improvement and Validation", Computer Sciences Corporation, N-TR-00-029, April 2000.

5   "Autotracker Design & Analysis", Computer Science Corporation, March 2002

6   "Design Modifications to the Gray-Level Co-occurrence Matrix (GLCM) Based Trackability Metric and the Resulting Performance", *SPIE Proceedings, Image Processing*, Vol. 3340, Orlando, FL, 2001.