Cycle Criteria for Detection of Camouflaged Targets

Barbara L. O'Kane, Ph.D.
US Army RDECOM CERDEC NVESD
Ft. Belvoir, VA 22060-5806
UNITED STATES OF AMERICA

Email: okane@nvl.army.mil

Gary L. Page
Booz Allen Hamilton
Arlington, VA 22203

David L. Wilson, Ph.D.
US Army RDECOM CERDEC NVESD
Ft. Belvoir, VA 22060-5806

David J. Bohan
US Army RDECOM CERDEC NVESD
Ft. Belvoir, VA 22060-5806

SUMMARY

The interplay between sensors and camouflage has long presented a problem for modeling target acquisition performance of human-in-the-loop thermal sensors. For instance, ACQUIRE, a commonly used target acquisition model, is relatively more sensitive to target size than target contrast. The result is that ACQUIRE generally predicts that low contrast targets will be detected at ranges similar to baseline targets. Thus ACQUIRE has had limited success for camouflage evaluation, since it is known from field studies that lowering contrast has a significant effect on detection range.

One ad hoc solution often used to overcome this limitation has involved adjusting the model resolution criterion (ACQUIRE's N_{50}) in accordance with available data for the vehicle of interest. However, this method has the disadvantage of requiring a system/sensor combination to be assessed in the field, before modeling, with the attendant costs and time requirements. In addition, since field tests are required, the method lacks predictive value.

A re-examination of ACQUIRE revealed a straightforward association between the inherent thermal contrast of a camouflaged target and the appropriate resolution criterion. This new resolution criterion determination method is being used in current analyses. One significant advantage of the approach discussed in this paper is that the historical use of ACQUIRE for standard targets is not changed, but fidelity of ACQUIRE for uses involving camouflage is enhanced.

1.0 BACKGROUND

ACQUIRE is the target acquisition prediction model that is used to predict range performance for thermal sensors in the US Army. It has a long history that began with the "Johnson Criteria," developed by John Johnson in 1958 [Johnson 1958] to predict target detection range performance of night vision goggles. In 1975 an updated version was released which accounted for the sensor parameters in thermal sights of that time and was known as the Static Performance Model [Ratches 1976]. In 1990 another release was issued

Paper presented at the RTO SCI Symposium on "Sensors and Sensor Denial by Camouflage, Concealment and Deception", held in Brussels, Belgium, 19-20 April 2004, and published in RTO-MP-SCI-145.

as "*ACQUIRE*" and was able to account for the new developments in sensors including two-dimensional aspects of the sensor and target.

The *ACQUIRE* model up to this time was used only for comparing sensors. The target was described in very simplistic ways and was used as a nominal target to compare the range performance of sensors to one another. However, as time passed, sensor and target camouflage developers often used *ACQUIRE* for other purposes, including the prediction of how well a camouflage treatment would reduce detection. The model did not pass the adequacy test in that application. It was to address that problem that we have developed and are using *ACQUIRE-LC (ACQUIRE for Low Contrast Targets)*, which was designed specifically for camouflaged targets.

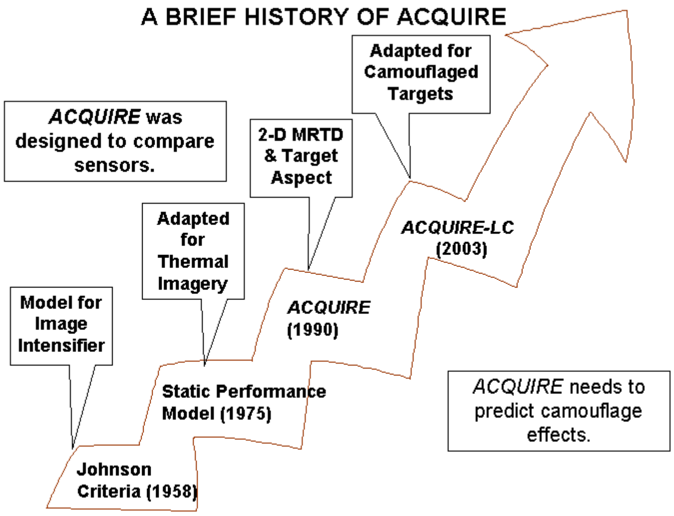

Figure 1. Historical development of *ACQUIRE* and where *ACQUIRE-LC* fits into this history.

1.1 ACQUIRE Methodology

The *ACQUIRE* model has three important components which drive the predictions [O'Kane 1995; Howe 1993]:

1. ΔT_{RSS} of the target: If a particular scene is available, the target is segmented from the background in a calibrated image as shown in Figure 2. A rectangular bounding box is also drawn to encompass pixels falling outside the target box √2 times the maximum extent in the height and width dimensions, respectively. ΔT_{RSS} for the apparent signature is calculated from the signature of the target at range by the following formula:

$$\Delta T_{RSS} = \sqrt{\left(\mu_{tgt} - \mu_{bkgd}\right)^2 + \sigma_{tgt}^2} \qquad \text{(Eq. 1)}$$

where μ_{tgt} is the mean target temperature, μ_{bkgd} is the mean background

temperature, and σ_{tgt} is the standard deviation of the target temperature [O'Kane 1993].

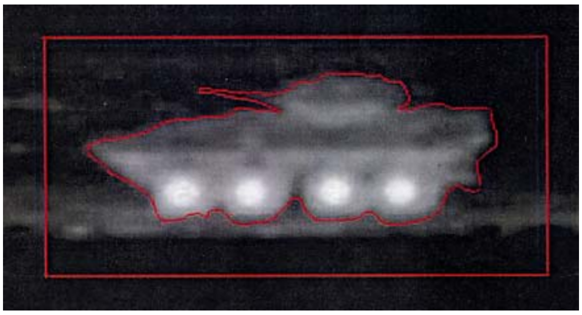

Figure 2. ΔT_{RSS} **of the target.**

2. The thermal contrast value then is used to enter The Minimum Resolvable Temperature Difference (MRTD) curve for the sensor, which relates the ΔT or ΔT_{RSS} required to see the four-bar line pattern of a given spatial frequency [Vollmerhausen 2000]. A notional MRTD curve is shown in Figure 3.

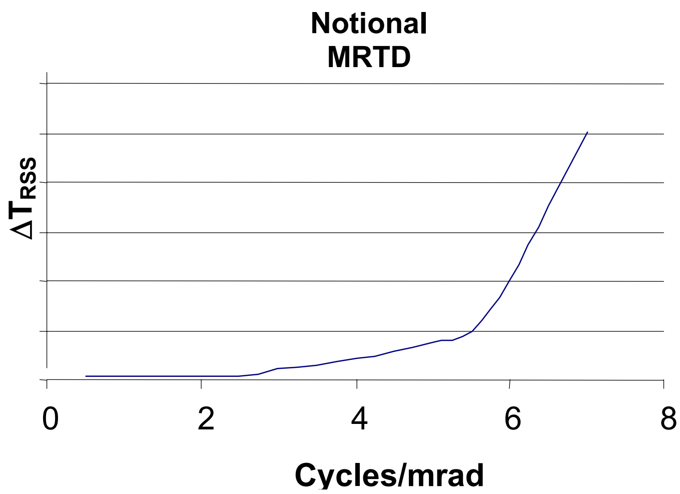

Figure 3. Notional MRTD curve showing the relationship between a given thermal temperature difference and the spatial frequency visible in a four bar pattern for a given sensor and field of view.

3. Cycles on target (N) is calculated from this spatial frequency and the projected size of the target at a particular range by the following formula:

$$N = \frac{f_{res} \cdot \sqrt{A}}{R} \qquad \text{(Eq. 2)}$$

where f_{res} is spatial frequency resolvable (cycles per mrad) from the MRTD with the target's thermal contrast, A is the projected area of the target (m^2), and R is the range (km).

Finally, the probability of detection is calculated from the cycles on target by using the Target Transform Probability Function (TTPF):

$$P_d = \frac{\left(N / N_{50} \right)^E}{1 + \left(N / N_{50} \right)^E} \qquad \text{(Eq. 3)}$$

where

$$E = 2.7 + 0.7 \cdot \left(N / N_{50} \right)$$

The only parameter in the TTPF (Eq. 3) that is not physically measured is known as "N_{50}", or the "cycle criterion". This number is used as the test for the cycles on target value to make the prediction. In the *ACQUIRE* User's Guide, the value of N_{50} for detection varies with subjective clutter, 1.5 for moderate clutter and 0.75 for low clutter backgrounds. The choice of N_{50} can have a significant impact on range performance, as shown in Figure 4, where the low clutter and moderate-high clutter curves are plotted. At a particular range, for example, the probability might be 0.9 for a low clutter and 0.25 for a moderate clutter.

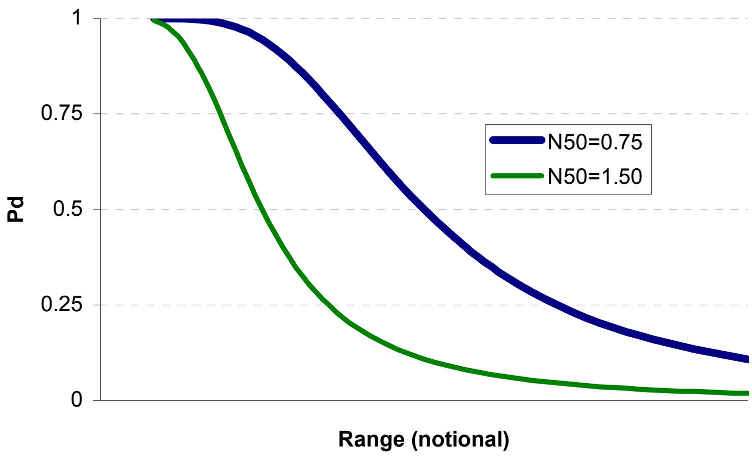

Figure 4. Notional curves showing the significance of the N_{50} term in the TTPF equation (Eq. 4). A lower N_{50} gives greater range predictions for a given probability of detection (low clutter). Conversely a higher N_{50} gives a lower range prediction for a given probability of detection (moderate-high clutter).

2.0 PROBLEM ADDRESSED BY *ACQUIRE-LC*

Lowering ΔT_{RSS} in *ACQUIRE* produces little effect on predicted range. Range predictions are almost entirely dominated by target size. Most camouflage developers do see effects of camouflage on range performance. Therefore, the model requires adjustment for camouflaged targets to better account for effect of lowering thermal contrast on range performance.

A formula was developed which solved the problem for predicting lower contrast targets which had been deliberately reduced in cues. This formula was based upon the finding that the lower the ΔT_{RSS}, the higher

N_{50} had to be to represent effects of camouflage. The equation for moderate to high clutter environments is a power law with offset and is given by:

$$N_{50} = \frac{6}{\Delta T_{RSS}^2} + 1.50 \quad \text{(Eq. 4)}$$

where the ΔT_{RSS} of the target at about 1000 meters is used and the atmospheric attenuation is considered through Beers Law. In this way, the target has an so-called "inherent" ΔT_{RSS}, which is used in the *ACQUIRE-LC* (Eq. 4 and 5) .

For a bland background, the curve for the required N_{50} is lower but of the same shape as given below:

$$N_{50} = \frac{0.75}{\Delta T_{RSS}^2} + 0.75 \quad \text{(Eq. 5)}$$

As seen in Figure 5, the two curves asymptote to the traditional cycle criterion, 0.75 and 1.5, for low and moderate/high clutter backgrounds, respectively.

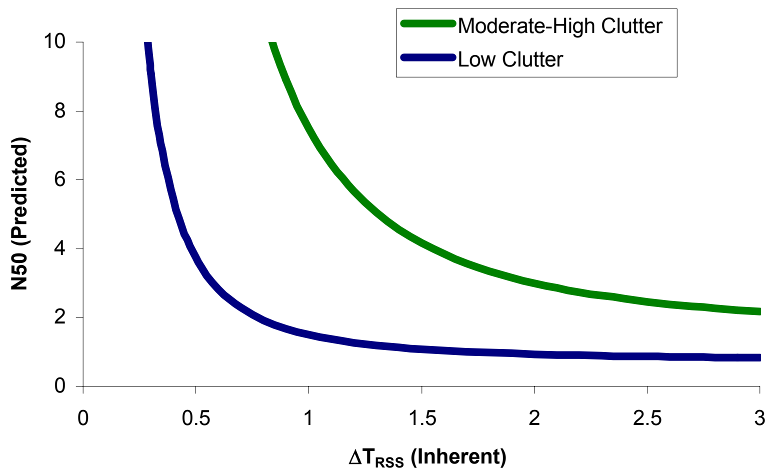

Figure 5. The *ACQUIRE-LC* curves that predict the appropriate cycle criterion (*N_{50}*) for use in the two environments to predict the detection of camouflaged targets.

2.1 Procedure for Using *ACQUIRE-LC*

ACQUIRE-LC provides an enhancement of *ACQUIRE* by providing the appropriate N_{50} for use in the model when predicting probability of detection as a function of range for camouflaged targets. The procedure is straightforward.

GIVEN:

Inherent ΔT_{RSS} of the target at the aspect of interest, and

Target size (square root of the projected area), Target range,

Atmospheric transmission in the appropriate thermal band,

Sensor MRTD.

STEP 1. Determine appropriate N_{50}:

Apply Equation 4 or 5 for clutter type of interest to predict the correct N_{50} value.

STEP 2. Predict Range Performance:

Use the *ACQUIRE* model to calculate the probability of detection as a function of range using the N_{50} determined in Step 1, atmospheric transmission, etc.

Example:

The camouflaged target of interest has an inherent ΔT_{RSS} of 2°C and is being acquired in a moderate clutter background. Inserting the inherent ΔT_{RSS} into the *ACQUIRE-LC* equation for a moderate clutter environment, Equation 4, we solve for N_{50}:

$$N_{50} = \frac{6}{4} + 1.5 = 3.0 \quad \text{(Eq. 6)}$$

Next, the size of the camouflaged target is determined. It is a front view, 3m by 3m target.

The transmission and sensor MRTD is then inserted into the model and *ACQUIRE* is run straight forwardly using the N_{50} calculated in Equation 6. The probability of detection for the range of interest is then observed in the output of the *ACQUIRE* run.

3.0 DISCUSSION

If one wishes to know why more resolution is required for low contrast targets, the graphics in Figures 6-8 may show some of the rationale. Figure 6 is a three-dimensional representation of a "bland" background with two targets in it that are shown as peaks. The targets can be seen easily, although they really are only one pixel in size, because they rise above the background (noise). Figure 7 is a "moderate clutter" environment and the targets are lost in the clutter, even though they have the same size and ΔT_{RSS} as in the low clutter situation. This would be particularly true of targets in the real world that are relatively low contrast.

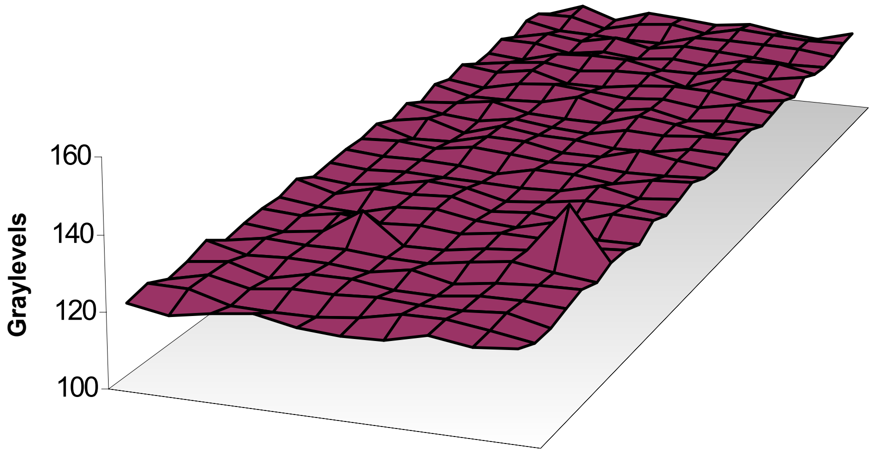

Figure 6. Bland ("low clutter") background with two low contrast targets that are visible as peaks.

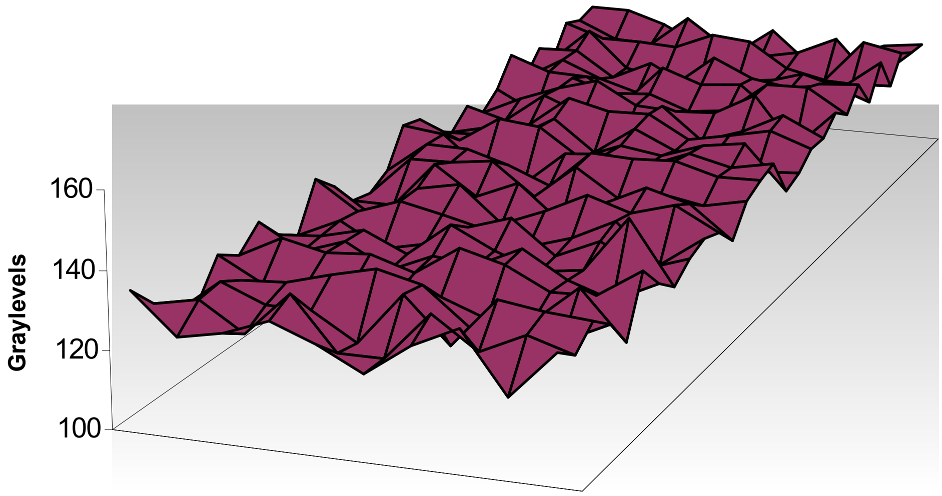

Figure 7. "Moderate clutter" background with two targets. Note how the targets are lost in the scene "clutter."

In order to detect the low contrast targets at the same level in the high clutter as in the lower clutter, the target must be bigger in the scene, which is equivalent to being closer, as shown in Figure 8.

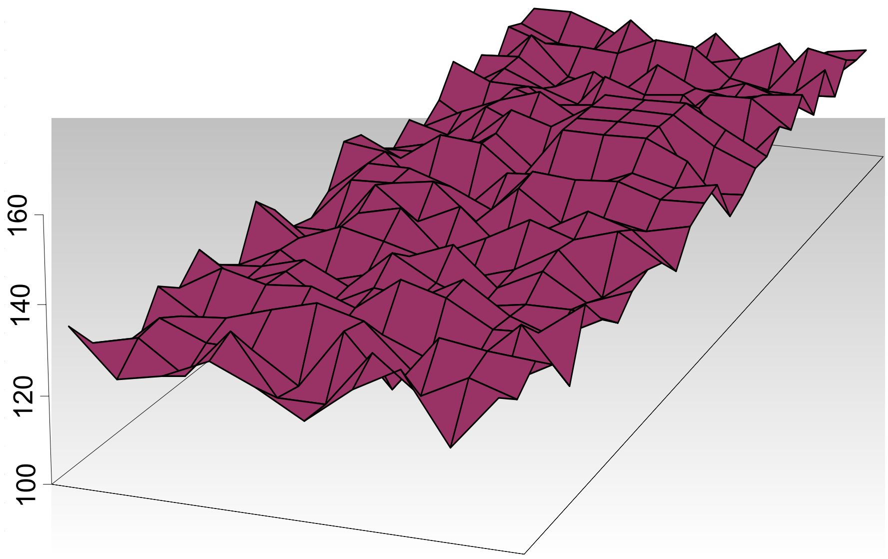

Figure 8. "Moderate clutter" background with a large target of low contrast. Note how the square target in the upper right quadrant is apparent because of its size.

3.1 Caveats

As with any model, proper use is important. Therefore, we recommend adhering to the following guidelines for the use of *ACQUIRE-LC*.

1. Treating the target orientations separately is highly recommended since the N_{50} associated with the average ΔT_{RSS} does not produce the same results as when the orientations are given their respective N_{50}.

2. *ACQUIRE-LC* is to be used only for detection of camouflaged targets in the thermal spectrum, and

3. *ACQUIRE-LC* is not designed to predict recognition or identification range performance.

4. The analyses necessary for application of *ACQUIRE-LC* to desert day and nighttime conditions are continuing. *ACQUIRE-LC* has not been validated for desert conditions.

4.0 CONCLUSIONS

ACQUIRE-LC is a welcome enhancement to *ACQUIRE* for camouflage developers. It is a model that gives the appropriate cycle criterion for camouflaged targets to more accurately predict expected performance in woodland and littoral environments.

NVESD welcomes your use of *ACQUIRE-LC* and your comments and feedback.

5.0 REFERENCES

[Howe 1993] Howe, J.D. Electro-Optical Imaging System Performance Prediction. In *The Infrared and Electro-Optical Systems Handbook, (Volume 4) Electro-Optical Systems Design, Analysis, and Testing,* 1993, ERIM, Ann Arbor, MI, pp. 55-120.

[Johnson 1958] Johnson, J. Analysis of Image Forming Systems. *Proceedings of the Image Intensifier Symposium,* 1958, p. 249.

[O'Kane 1993] O'Kane, B.L., Walters, C., D'Agostino, J. and Friedman, M. Target Signature Metrics Analysis for Performance Modeling. *Proceedings of the Infrared Imaging Symposium on Passive Sensors II,* p.161, 1993.

[O'Kane 1995] O'Kane, B.L. Validation of Range Prediction Models for Target Acquisition with Infrared Imaging Sensors. In *Vision Models for Target Detection and Recognition,* El Peli, Ed.; World Scientific: London, pp.190-218, 1995.

[Ratches 1976] Ratches, J.A. Static Performance Modeling for Thermal Imaging Systems. *Optical Engineering* 1976**, 15**, pp. 525-534.

[Vollmerhausen 2000] Vollmerhausen, R. and Driggers, R. *Analysis of Sampled Imaging Systems.* SPIE: Bellingham, WA. 2000. pp.152-153.