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Presenter(s): Dr. Thomas Meitzler

Organization Name: U.S. Army TACOM

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Use of a Photosimulation Laboratory for Estimating Vehicle Detection Probability and Comparing Detection Metrics (U)

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Abstract (U)

(U) A method is described for using a photosimulation laboratory environment to compare detection metrics and evaluate the effectiveness of camouflage for military vehicles. There are distinct advantages to acquiring images at the field site and then bringing them back to a laboratory environment for observer testing versus taking the subjects out to the field for estimating detection probability. Laboratory testing using field acquired imagery provides a repeatable, secure, and relatively low-cost way to generate consistent data for the measurement of the effectiveness of camouflage relative to a baseline vehicle, and the calibration and validation of target acquisition models. A laboratory test procedure is described by the authors in which a baseline Light Armored Vehicle (LAV) is compared to a treated LAV in the TACOM Visual Perception Laboratory (VPL) using imagery collected from the field in the manner prescribed by an experimental design.

1 Introduction (U)

The purpose of this paper is to describe a methodology for photosimulation tests in a laboratory environment, for the purpose of vehicle treatment comparison or detection metric trade-off studies, using imagery of the vehicle taken at the field site. Mega-Pixel, high-resolution, digital cameras presently available on the market have come very close to equaling the resolution and color depth attainable with film. Six megabyte CCD imaging chips along with the ability to capture imagery in raw 24-bit format, combined with high capacity, portable, storage devices enable high-resolution imagery to be captured at field site locations and easily delivered back to the laboratory. The time consuming processing loop required with film has been removed. Using high-resolution graphics projectors, the imagery can then be presented in the controlled environment of a laboratory in such a manner as to obtain observer data with confidence levels approaching 99%. The benefits achieved using the repeatability and randomization offered by the lab environment are not available in a traditional field test. The laboratory randomization of the order of the stimuli removes any potential bias introduced by the order of the presentation of the stimuli in a traditional field test where this type of randomization is not practical.

(U) The test procedure described in this report was undertaken as part of the LAV Service Life Extension Program (SLEP). Specifically, the purpose of this experiment was to determine the performance of a camouflage treatment in reducing the probability of detection in the visual part of the electromagnetic spectrum at various ranges, aspect angles and lighting conditions. Only the unclassified baseline results will be described in this report.

2 Experiment (U)

(U) A full-factorial test matrix was developed and 24-bit color imagery of the vehicles was collected at the field site using a Kodak 460 digital camera. The images taken at the field site were prepared for the laboratory photosimulation test and then presented to thirty subjects. The experimental factors and levels with their values are shown below in Table 1. The photosimulation test in the lab was arranged so that the pixel Instantaneous Field-Of-View (IFOV) subtended by the monitors was less than one minute of arc and the displayed image represented a unity magnification or 1X representation to the subject. The first test was meant to emulate naked-eye vision. Prior to the actual test, the subjects were instructed on the purpose of the test and given a pre-test in which they could become familiar with the imagery and software. None of the pictures used in the pretest were used in the actual test, however, the images were from the same set. The test protocol was to display an image with a time-out of thirty seconds. The imagery was cropped so that no scrolling was required. The target can appear within one of five possible regions. The soldier must use the mouse to "click-on" what he or she thinks is a target, based on the training. The tests are done in a dark room in which the subjects are 'dark-adapted' to maximize contrast differences in the images.

(U) Analysis of the first test showed most subjects obtained a score of only 20 % detection. This is not unreasonable given the difficulty of the imagery. The ranges are not unusual for such a test, however the high degree of clutter, and in particular, the height of the grass on the terrain makes it difficult for the unaided eye to detect common cue features of the vehicle. A second test was arranged to simulate closer ranges. The ability to resample the imagery is a feature of lab testing that would not be available on the field. Another benefit of the laboratory environment is that atmospheric effects can be added to the imagery for a more controlled simulation of atmospheric effects. Additional atmospheric effects were not added in this particular experiment, however, the capability does exit. The imagery from the field was of sufficient resolution so that there was no noticeable increase in pixelation of the imagery. The software used linear interpolation to zoom in on the selected imagery. The presentation in the lab was randomized for each subject.

(U) At this point, it's instructive to digress for a moment to emphasize the rationale for using the type of design methodology described by the authors in this paper. Statistically based, experimental design is a strategy of designing experiments in such a manner as to develop a robust test plan. In other words, a test plan that is minimally affected by external sources of variability. What makes vehicle detection experiments so challenging is that there are many variables that are present and must be accounted for. In addition, the variables interact with each other. The correct approach to working with several factors is to conduct a factorial experiment. A factorial experiment is an experimental strategy in which the factors are varied together, rather than one at a time. The factorial experimental design concept is extremely important and powerful when used correctly. There are many classical and standard books on experimental design such as *Analysis of Variance*[1] by Scheffe and *Experimental Designs* [2] by Cochran and Cox. A contemporary textbook by Montgomery, *Design and Analysis of Experiments* [3] has many useful examples contained in it. For these type of vehicle tests, it is unwise to leave out points in the data matrix in the hope of making the test plan more expedient unless one is doing a well designed fractional factorial.

(U)When making inferences about differences in a factor in a perception experiment in the laboratory we want to make the experimental error as small possible. This requires that we remove the variability between subjects from the experimental error. The design we use to accomplish this is a factorial experiment run in a randomized complete block. By using this design with the subjects as blocks we form a more homogeneous experimental unit on which to compare different factors. This experimental design improves the accuracy of the comparisons among the different factors by eliminating the variability among the subjects. Within a block, the order in which the treatment combinations are run is randomly determined. In other words, for each subject, the order of the presentation if the imagery is different. It is usually not practical to implement this experimental design in the context of a traditional field test.

(U)Table 1 below shows the factors that were decided to be the most important for the test on the vehicle detection in the field. The chosen factors are; 1) Region of the field-of-view (FOV) in which the vehicle is present, 2) the range from the vehicle to the sensor, 3) the type of vehicle, 4) the aspect angle relative to the observer, 5) the lighting condition indicated by the position of the sun, front lit or back lit, and finally, 6) the general condition of the sky, clear or cloudy. In the vehicle type category, SLEP means the Service Life Extension Program, ADCAM is the trade name of the camouflage.

(U)

Region	
1	Top-Left
2	Top-Right
3	Lower-Left
4	Lower-Right
5	Center

Range (km)	
1	1
2	1.5
3	2
4	2.5
5	3

Vehicle Type	
1	Baseline (old LAV)
2	SLEP + ADCAM
3	SLEP + ADCAM – ADCAM bowplane

Aspect angle	
1	Front
2	30 degree
3	Side

Lighting	
1	Front Lit
2	Back Lit

Weather condition	
1	Clear
2	Overcast

Table 1: Factor matrices for the visual detection test (U)

(U)The pictures below in Fig. 1 and Fig. 2 were used for training observers as to what kind of vehicles they would be looking for in the test and also indicate some of the variables in the experiment such as vehicle type, treated or untreated, and aspect angle.

(U)

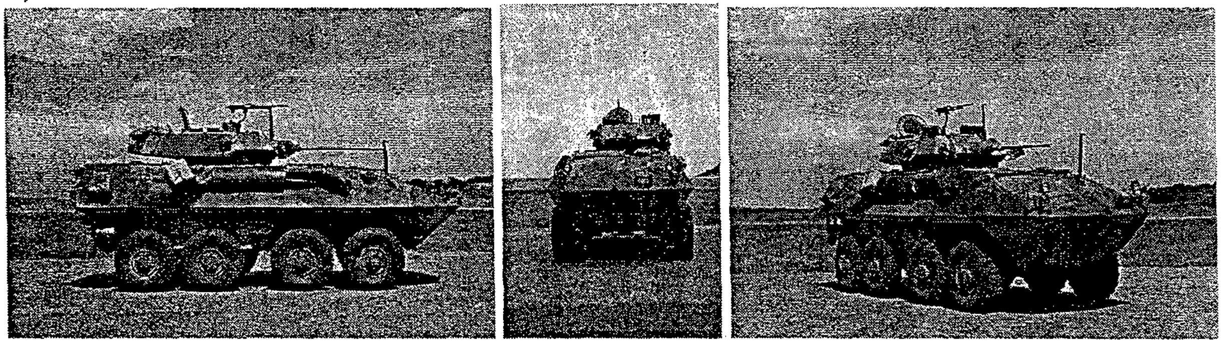

Fig. 1: Sample baseline LAV training images (U)

(U)

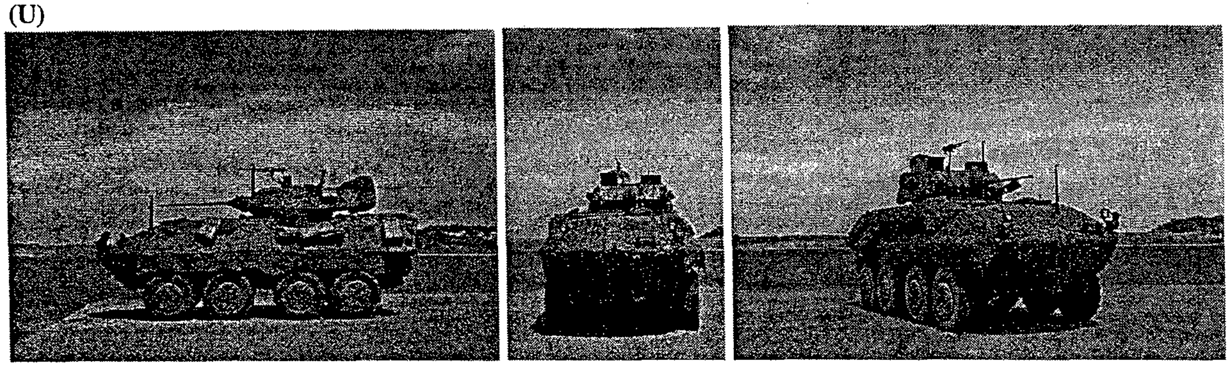

Fig. 2: Treated LAV training images (U)

(U)The figure below is of the background at the field site and does not have a vehicle in it. The picture shows that the grass height was high at the test site. The range of the test field was about 3.5 km and that the grass was high and obstructed the view of the vehicle at large ranges, thus requiring the simulation of powered optics by magnifying the images at certain amount depending on initial range.

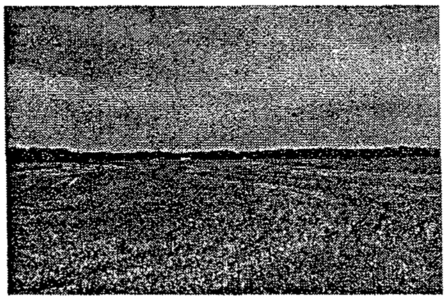

Fig. 3: Background image of test site (U)

(U)The charts in Fig. 4 below show the X and Y chromaticity values of the monitors that were used in the photosimulation test. The color chromaticity values were measured in the lab using a spectrophotometer. The values measured as projected on the monitors were compared to photometric standard values and found to be virtually identical. Based on the similarity of photometric measurements between standards in the field and displayed on two identical SONY the monitors, the authors are confident that the color fidelity is accurate. The primary physical difference of field versus lab tests is the level of luminance in the lab as compared to the field setting. The use of low light cancels out the effects experienced in the field such as glare and pupil size.[6] Typically when detection tests are done in the laboratory environment, the subjects are dark adapted and the tests are run under very dim lighting.

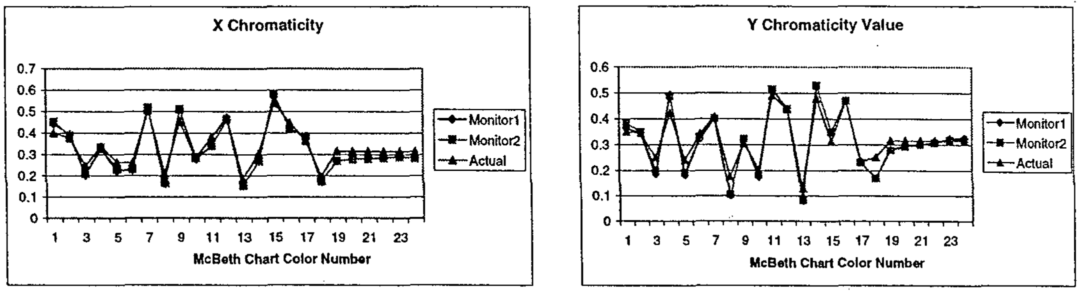

Figure 4 : Laboratory versus field chromaticities (U)

3 - Analysis (U)

(U) Below in Table 2 is the ANOVA table for the baseline vehicle and the other experimental factors. The analysis for the treated vehicle has been excluded because of security classification. The power of the experimental design methodology is shown here in that the significance of individual factors and of their interactions are available for review. Using this kind of a test, one can obtain not only a math model of the detection probability versus any factor in the test, but, one can also obtain the relative importance of the individual factors and their interactions at various powers.

(U) In Table 2, the first column of the table labeled 'source', is the effect or factor(s) in the model, (only first order interactions were considered). The second column shows the type IV sum of squares. Type VI Sum of Squares are used because there are missing cells in our design matrix. The third column, labeled 'df', shows the degrees of freedom for each sum of squares. The fourth column labeled 'Mean Square', shows the mean square of each effect. This is obtained by dividing the sum of squares for each effect by the degrees of freedom for each effect. The fifth column is the F statistic and shows the F statistic for each effect. The F statistic is obtained by dividing the mean square for each effect by the mean square error term listed at the bottom of the Mean Square column. Column six, labeled 'Sig', is the P-value of the F statistic for each effect. The smaller the P-value the greater the importance of the effect. Table 2 shows that the aspect angle was the least important factor in the experiment and that subject, range, sky condition, and the interaction of range and aspect angle.

Tests of Between-Subjects Effects

Dependent Variable: RANK of RESPONSE

Source	Type IV Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	171682105[a]	79	2173191.202	17.177	.000
Intercept	1277408367	1	1277408367	10096.792	.000
SUBJECT	26976158.0	26	1037544.538	8.201	.000
RANGE	116354292	9	12928254.62	102.187	.000
ASPECT	1125275.323	2	562637.662	4.447	.012
SKY_COND	2522624.471	2	1261312.236	9.970	.000
RANGE * ASPECT	5986618.857	18	332589.936	2.629	.000
RANGE * SKY_COND	5272645.363	18	292924.742	2.315	.001
ASPECT * SKY_COND	2248729.330	4	562182.333	4.444	.001
Error	223301195	1765	126516.258		
Total	1966792305	1845			
Corrected Total	394983300	1844			

a. R Squared = .435 (Adjusted R Squared = .409)

Table 2: ANOVA of test factors (U)

(U) Figure 5 shows the model generated logistic curve of the probability of detection versus the baseline LAV. This curve has the effects of all the various factors 'rolled-up' into it. A logistic curve is the standard psychometric function used to model detection data. [8]

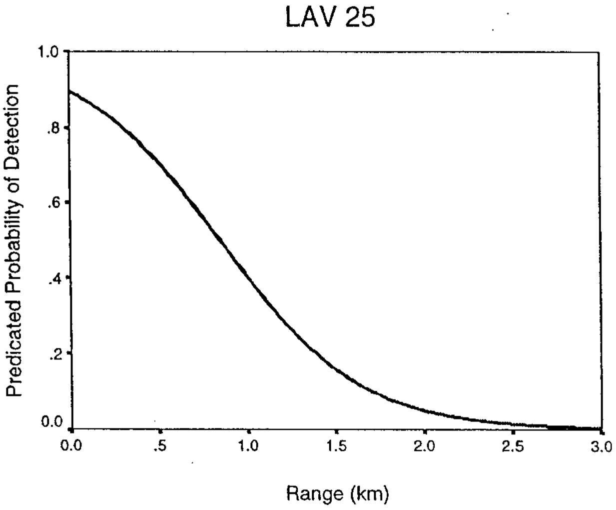

Fig. 5: Logistic fit to the laboratory results (U)

(U) The equation of this curve fit is shown in equation (1) below,

$$\text{predicted probability of detection} = \frac{1}{\left[1 + e^{-(\beta_0 + \beta_1 x)}\right]}. \quad (1)$$

(U) In equation (1), x is the range from the imaging sensor to the vehicle, and the two constants are 2.154 and –2.545 respectively. Fig. 6 is the Normal Q-Q plot of deviance and the graph shows the plot of the quantiles of the deviances from the logistic regression model against the quantiles of the normal distribution. Probability plots are used to determine whether the distribution of a variable matches a given distribution. The points cluster around a straight line if the variable matches the given distribution.

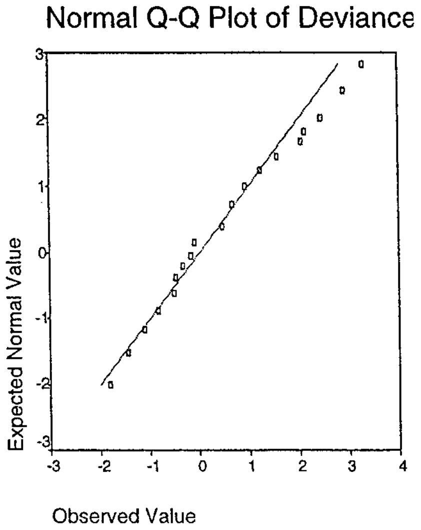

Fig. 6 (U)

(U) In this analysis, cases where the subject did not respond were not considered. A rank transformation was applied to the dependent variable Response. This was done to change our scale of measurement from ordinal to interval/ratio for ANOVA analysis. The linear model for this experiment is:

$$y_{ijkl} = \mu + \tau_i + \delta_j + \beta_k + (\tau\delta)_{ij} + (\tau\beta)_{ik} + (\delta\beta)_{jk} + \gamma_l + \varepsilon_{ijkl} \qquad (2)$$

where,

τ_i represents the range effect,

δ_j represents the aspect angle effect,

β_k represents the sky condition effect,

$(\tau\delta)_{ij}$ represents the interaction effect of range and aspect angle,

$(\tau\beta)_{ik}$ represents the interaction effect of range and sky conditions,

$(\delta\beta)_{jk}$ represents the interaction effect of aspect angles and sky conditions,

γ_l represents the block effect due to the subjects, and

ε_{ijkl} is a normally distributed error term.

(U) The complete analysis of variance for this experiment is summarized in Table 2. All the main effects except for the aspect angle are significant at the one percent level. The interaction terms are all significant at the one percent level.

4 Metric Evaluation of the imagery (U)

(U) The metric evaluated by the authors on this data set were image entropy, defined by equation three below. Fig.'s 7 and 8 show how the entropy metric correlated to range and Pd.

$$H = -\sum_{g=0}^{L-1} p(g) \log_2 p(g)$$

$$\textit{where } p(g) \textit{ is the probability of grey scale value } g, \textit{and the range of } g \textit{ is } [0..., L-1]. \qquad (3)$$

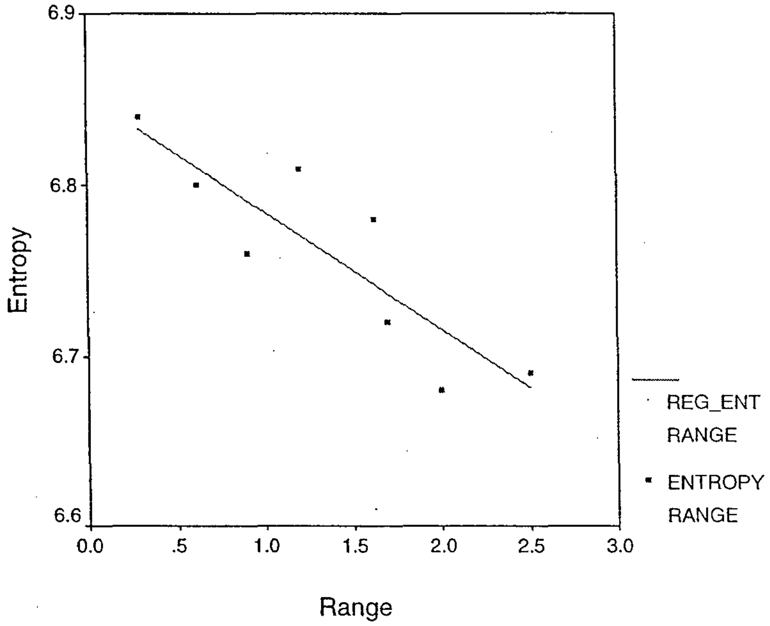

Fig. 7: Image entropy versus target to sensor range (U)

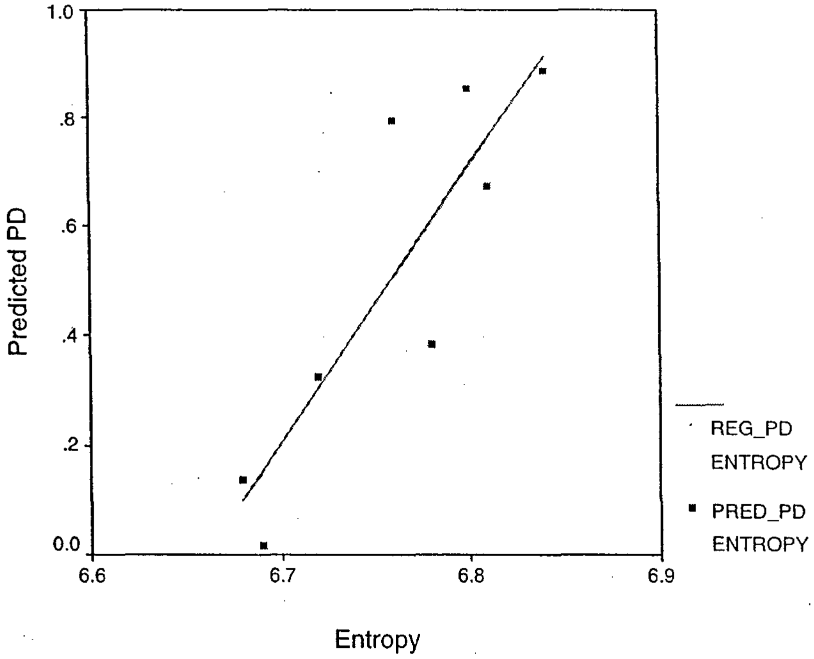

Fig. 8: Pd versus Entropy

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5 Conclusions (U)

(U) In summary, an advantage of using the photosimulation lab environment is that experimenters are able to archive scenes used in the simulation, so that, at a later time it is possible to rerun the same image data set on a different subject pool. The new subjects may have different training and the images may also be modified by either magnification or adding atmospheric conditions. This provides tremendous cost savings since there is no need to pay for another field test.

(U) An experimental design method was used to design an imagery collection test plan and a laboratory photosimulation testing procedure. The probability of detection was determined for the baseline and treated vehicles. A statistical model was made of the laboratory results that gave the probability of detection versus range according to a logistic curve fit and good statistical fits were obtained from the data. A fuzzy logic model was also made from the data that had 0.9 correlation to data not used in the training set.

References (U)

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