# Electro-Optic Identification Research Program: Probability of Identification and Performance Modeling

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Document Number: N0001402WX20822

## LONG-TERM GOALS

The overall goal of the Electro-Optic Identification (EOID) Research Program is to support the performance of EOID sensors transitioning to the fleet. EOID is used in the identification of Mine Like Objects (MLOs) and is a pressing need for Mine Countermeasures (MCM) operations. The EOID sensors include the Streak Tube Imaging LIDAR (STIL), which is transitioning to the AN/AQS-20A and the WLD-1 (Remote Mine-hunting System) programs, and the Laser Line Scan (LLS), which has been delivered to the Fleet in the form of the AN/AQS-14A(V1) program. Through these transitions, EOID will be a key element in implementation of Fleet plans for a robust organic MCM capability. The EOID Research Program will begin to provide the tools to meet specific Fleet needs and capabilities, which include:

- Perform mission planning, real-time performance assessment, and post-mission analysis
- Flow down Fleet identification requirements to the system and operational parameters
- Develop Computer Aided Identification (CAI) algorithms to aid in the operator identification of mines
- Develop Autonomous identification capability for future systems
- Assess and evaluate alternate designs for future systems

## OBJECTIVES

The primary objective of this phase of the program is to validate existing performance prediction and simulation models and to develop and test Automatic Target Recognition Algorithms (ATR) for electro-optic identification (EOID) systems.

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| **Report Documentation Page** | *Form Approved*<br>*OMB No. 0704-0188* |

| | | |
|---|---|---|
| 1. REPORT DATE<br>**30 SEP 2002** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2002 to 00-00-2002** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Electro-Optic Identification Research Program: Probability of Identification and Performance Modeling** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Coastal Systems Station,,6703 W. Highway 98,,Panama City,,FL, 32407** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT

**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

**The overall goal of the Electro-Optic Identification (EOID) Research Program is to support the performance of EOID sensors transitioning to the fleet. EOID is used in the identification of Mine Like Objects (MLOs) and is a pressing need for Mine Countermeasures (MCM) operations. The EOID sensors include the Streak Tube Imaging LIDAR (STIL), which is transitioning to the AN/AQS-20A and the WLD-1 (Remote Mine-hunting System) programs, and the Laser Line Scan (LLS), which has been delivered to the Fleet in the form of the AN/AQS-14A(V1) program.**

15. SUBJECT TERMS

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|---|---|---|---|---|---|
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **7** | |

## APPROACH

To have a true performance prediction model, two components must exist. There must first be a component that accurately predicts the sensor output for a given set of environmental conditions. There must also be a component that relates the sensor output to real performance parameters for the Mine Countermeasures (MCM) task. This program dealt with both components.

The performance parameters for MCM mission are Measures of Performance (MOPs) and Measures of Effectiveness (MOEs). The two Measures of Effectiveness (MOEs) for MCM operations are time and residual risk. A given area is said to be cleared of mines to a certain confidence level based on the search effort and the search results. A more confident declaration of a cleared area requires more time and assets to be applied in the operation. To calculate the MOEs, Measures of Performance (MOPs) must be established to quantify the individual system contribution. Some of these MOPs may seem familiar like Probability of Detection, others like Probability of False Identification ($P_{\mathrm{Fid}}$) and Time to Identify ($T_{\mathrm{id}}$) may not. All the MOPs must be defined in order to calculate the MOEs of time and residual risk. To get to the MOPs, it is necessary to relate the performance back to sensor and environmental parameters. The goal of this work is to determine Probability of Identification ($P_{\mathrm{id}}$) as a function of sensor and environmental parameters.

In real world operations, the overall MCM MOE is sensitive to identification. Search systems provide large lists of mine-like contacts that will form the basis of prosecution lists for identification assets. Objects positively identified as mines can either change the ship operations area or call for neutralization assets to clear the mined area. The time required to identify the objects can be significant.

Performance models are being developed so operations can be planned using water clarity measurements from oceanographic databases. The best water clarity data comes from sensors in the operation area during the operation. The Streak Tube Imaging LIDAR (STIL) system is using a water clarity measurement to suggest an operational altitude during the sortie. Models have also been suggested to show reference targets as they would be seen through the current water conditions. Ideally, the warfighter would be able take whatever information is known of the environment, input those parameters into a mission planning tool, and determine the expected performance, or $P_{\mathrm{id}}$, to estimate the effectiveness of the EOID sensor for that mission on that day with that target. Figure 1 illustrates this need.

***Figure 1. Mission Planning Tools. [Block diagram of mission planning tool showing requirements of environmental input and Measures of Performance output]***

Currently, there does not exist an electro-optical system performance model for the design and/or analysis of system performance in the application of mine identification. There are two well-established military imaging models: target acquisition and surveillance/reconnaissance. The surveillance and reconnaissance model approach for mine identification would require the development of a National Imagery Interpretability Rating Scale (NIIRS) scale for mines and the development of a general image quality equation (GIQE) for mines. In addition, the GIQE has four parameters that must be calibrated for the equation. In contrast, the target acquisition model has been shown to be successfully applied to various targets, and the only calibration requirement for application to underwater mines is the determination of a fifty-percent probability of identification cycle criterion ($N_{50}$). This criterion, coupled with a Minimum Resolvable Contrast (MRC) model for the electro-optical system, allows the probability of mine identification to be calculated for any electro-optical system. Therefore, given the $N_{50}$, any electro-optical system to be used for mine identification can be evaluated for mine identification in various environmental conditions.

## WORK COMPLETED

Two tasks were completed under this part of the EOID Research Program. First, the underwater imaging model, IMPERSonator, was completed and prepared for delivery. Also, using the contrast imagery only, an experiment was conducted to determine the expected $P_{id}$ performance for these sensors.

The primary purpose of the $P_{id}$ experiment was to determine the $N_{50}$ requirement for the identification of underwater mines. The identification target set is shown in Figure 2. The probability of identification performance is the ability of an observer to distinguish one of these targets from the other eleven targets.

The target set was developed at NAVSEA Coastal Systems Station, Panama City. The target set includes 12 targets in 9 orientations with a nadir illumination source (obliques and cardinals). The targets were chosen for their relative confusability and tactical significance. Degradation such as blur was applied to these images to simulate various sensor and environmental effects. The mine and non-mine target images were developed using 3 dimensional models that were textured and inserted onto a real background image. For the experiment, the images were converted to 12-bit grayscale. All image sizes were 400 x 400 pixels. The target images shown were processed with various levels of blur.

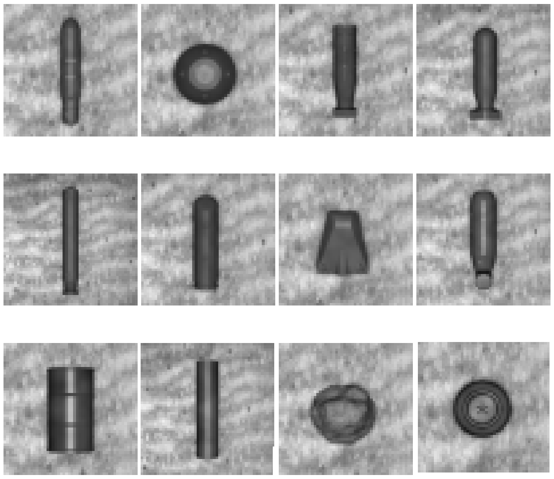

*Figure 2. Mine Target Identification Set. [Sample target set includes cylinder shapes, truncated cones, and trapezoidal shapes against a sand-rippled background]*

The experimental design is outlined in Table 1. From the pristine image sets of Figure 2, 12 targets with 9 orientations (108 images total) were distributed evenly across the cells in the table shown. The targets were then distributed across the cells a second time. This distribution allowed for three of the same target image in each cell and four different targets of the same aspect in each cell resulting in 36 pristine images associated with each cell. The 36 images were processed with a prescribed blur. In the column labeled "10," 36 pristine target images were blurred with a 10-pixel blur and placed in cell "A." The equation for the blur was where *b* is the blur in display pixels.

$$h(x) = \frac{1}{b} e^{-\pi\left(\frac{x}{b}\right)^2} \tag{1}$$

This Gaussian blur h(x) was to be applied to the image by a convolution. The total blur presented to the observer included a combination of the blur given in equation 1, the blur of the display, and the contrast threshold function of the observer.

| Blur(Pixels) | 10 | 20 | 30 | 40 | 50 | 60 |
|---|---|---|---|---|---|---|
| Cell | A | B | C | D | E | F |

***Table 1. Experimental Design. [Experimental design showing the cells (A-F) and the accompanying pixel blur number (10-60)]***

After blurring, the images were combined into one set of 216 total images for the experiment. Observers were trained to identify targets with a minimum 95% proficiency (for unblurred images) prior to participating in the experiment. Each observer attempted to identify all 216 images. The images were randomized in order to vary the level of target identification difficulty. The image sets had equivalent contrast and similar size characteristics. The contrast was described with the root sum squared (RSS) metric

$$C = \frac{\sqrt{\sigma_{tgt}^{\,2} + \Delta G^2}}{2 Avg_{sc}} \tag{2}$$

where $\sigma_{\text{tgt}}$ is the target signal standard deviation (within the target), $\Delta$G is the difference in average signal between the target and the background, and $Avg_{sc}$ is the average scene signal. The target characteristic dimension in display pixels is the square root of the target area.

## RESULTS

The experiment was conducted at NSWCDD Coastal Systems Station during the month of July 2002. Thirteen observers were comprised of U.S. Navy Personnel and civilian government employees. The results were reduced for an *ensemble* of observers against an *ensemble* of targets. The probabilities of identification were calculated with all observers against all targets within a cell. The experiment was a forced choice experiment where the observers had to choose an identification choice out of 12 targets.

The probability results were averaged across all observers and corrected for chance. The standard error was calculated for each of the blurs, and the probabilities and error bars were plotted. The limiting frequency was then calculated for the human contrast threshold function, the blur, and the monitor for the given monitor luminance and the target contrast. The limiting frequency was used to determine the number of resolvable cycles across the target dimension, and the corrected probabilities were plotted as a function of resolvable cycles on target.

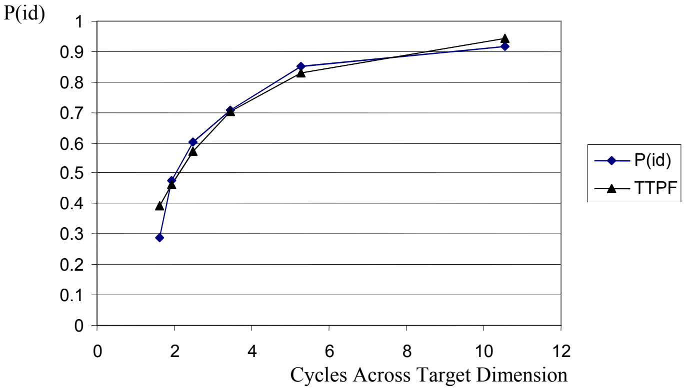

***Figure 3. Probability of Mine Identification as a Function of Cycles on Target. [ Graph: probability is 0.4 with 2 cycles, 0.85 with 6 cycles, and 0.92 with 10 cycles]***

The target transfer probability function (TTPF) is plotted in Figure 3 to show the model fit to the experimental data. The form of the TTPF was taken as

$$P_{ID}(N) = \frac{(\frac{N}{N_{50}})^{1.73}}{1+(\frac{N}{N_{50}})^{1.73}} \tag{3}$$

where this form has been shown numerous times to correspond to various target acquisition observer responses (tanks, trucks, humans, handheld objects, etc.). $N_{50}$ was the number of resolved cycles on target for a fifty-percent probability of mine identification. The $N_{50}$ fit for the mine experimental data corresponded to 2.1 resolvable cycles on target. Note that for a 90 percent probability of mine identification, around 8.5 cycles on target are required. Both 50 percent probability of identification and 90 percent probability of identification are common specification for target acquisition systems.

## IMPACT/APPLICATIONS

The Navy now has a preliminary baseline function for calculating $P_{id}$ both from model output and contrast and resolution measurements taken from actual EOID images. The function was derived for contrast images only. This is applicable for AN/AQS-14A (V1) and the contrast portion of AN/AQS-20A.

A continuation of this study must be done to cover the range imagery and combination of contrast and range imagery. $P_{id}$ should increase with the additional information. Since range and contrast images are not truly independent, the amount of gain is not well understood. There are two areas that experience tells us range will be a major contributor to $P_{id}$. The first is in low to zero contrast situations where there is little information in the contrast image, but the range image is preserved. The second situation is differentiating the tire, rock, and truncated cone. The range images are easier to determine because the targets are different in range, but very similar in contrast.

## TRANSITIONS

$P_{id}$ function will be used in system engineering trade studies and performance prediction models for both the AN/AQS-14A (V1) and AN/AQS-20A. Additionally, the target set generated for the study may be used in operator mine recognition training. Performance models for the Fleet systems are still in development, but the $P_{id}$ function is a critical last step to any performance estimate since the warfighter does not consider Signal to Noise Ratio or resolution a measure of performance.

## RELATED PROJECTS

This $P_{id}$ function is based on a simple display and a human operator making the call using the image only. As advances are made in Computer Aided Identification and display techniques, the $P_{id}$ tests can be rerun to quantify the change in performance against this baseline.

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