Night Vision modeling; historical perspective

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Abstract

This is a technical historical chronicle of the past and on-going development of performance models for electro-optical sensors carried out by the U.S. Army CECOM NVESD, the original Night Vision Laboratory. The emphasis has been on thermal imaging models and is also the focus of this paper. The origin of the Johnson criteria is shown and the resulting models that have evolved from the original concept proposed by John Johnson. The present formulations of the models are detailed and the newest developments are introduced. The force that drives the various improvements in the models is the development of more sophisticated thermal imagers whose performance must be described and predicted. Background supporting developments in laboratory measurements and field validation are indicated.

Keywords: FLIR modeling; thermal imagers; Johnson criteria; Minimum resolvable temperature; Minimum detectable temperature; detection; recognition; identification.

1. Introduction

The development and fielding of thermal imaging, or Forward Looking Infrared (FLIR), systems by the U.S. Army over the last 30 years has been led by the development and exercise of validated performance models. These models were and still are being improved by the U.S. Army Communications-Electronics Command (CECOM) Research, Development & Engineering Center's (RDEC) Night Vision & Electronic Sensors Directorate (NVESD) at Ft. Belvoir, VA. This modeling approach has been adopted by the other services, NATO and industry to optimize designs, predict operational performance, select contractor proposals and generate performance specifications. The modeling approach is based upon the unique concept of John Johnson of NVESD that relates a laboratory measurement of "resolvable cycles across a target" to target acquisition performance in the field. This innovative concept when coupled with extensive validation data from the laboratory and the field has provided a powerful tool for the infrared and thermal imaging community. Models have also been developed based on this same principle for other electro-optical imaging systems, such as image intensifiers and television. This paper will concentrate primarily on the FLIR modeling.

2. Johnson Fundamentals

Johnson's[1] original concept was based upon work originally done by Otto Schade[2] with television. Johnson proposed that the ability of an observer to acquire military targets in scenes (detect, determine orientation, recognize and identify) when viewing through an electro-optical device is dependent on how well he can resolve bar patterns of varying frequencies at the same contrast for image intensifiers and television or same temperature difference for FLIRs. A series of experiments was conducted with an ensemble of observers who used image intensifier imagery to determine how well they could resolve bar patterns and also perform the discrimination tasks of detection, target orientation, recognition and identification of military targets. Detection is defined as discriminating the presence of an object of potential military interest from the background, orientation is the determination of the target aspect, recognition is determining the class of the target, e.g. truck, personnel carrier, tank, etc., and identification is the determination of the member of the class, e.g. M60, M48, Stalin tanks. The discrimination level was then related to how many line pairs could be resolved across a critical dimension on the target for the limiting resolution measured with the device-observer combination. The number of line pairs resolvable across a target critical dimension was calculated by multiplying the highest bar pattern frequency that could be resolved at that contrast and observer-device ensemble times a dimension on the target that was assumed needed to be resolved in order to perform the discrimination level of interest. Typically, this was target height for combat vehicles. The Table 1 shown below resulted from these experiments.

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Table 1. Johnson's data relating lines resolved across the target critical dimension to discriminating targets to various levels.

Target	**Resolution per Minimum Dimension**			
Broadside View	**Detection**	**Orientation**	**Recognition**	**Identification**
Truck	**0.90**	**1.25**	**4.5**	**8.0**
M-48 Tank	**0.75**	**1.2**	**3.5**	**7.0**
Stalin Tank	**0.75**	**1.2**	**3.3**	**6.0**
Centurion Tank	**0.75**	**1.2**	**3.5**	**6.0**
Half-Track	**1.0**	**1.50**	**4.0**	**5.0**
Jeep	**1.2**	**1.50**	**4.5**	**5.5**
Command Car	**1.2**	**1.5**	**4.3**	**5.5**
Soldier (Standing)	**1.5**	**1.8**	**3.8**	**8.0**
105 Howitzer	**1.0**	**1.5**	**4.8**	**6.0**
Average	**1.0±0.25**	**1.4±0.35**	**4.0±0.8**	**6.4±1.5**

The original Johnson experiments were run at relatively high contrast on the targets and bar patterns. The extrapolation to any contrast or temperature difference became possible with the definition of Minimum Resolvable Temperature Difference (MRT) in 1969 by Lloyd and Sendall[3] when the limiting resolution of bar patterns became formalized. MRT became the measurement of an observer's threshold in bar temperature difference above ambient for recognizing a 4 bar pattern as a function of the bar frequency. That is, at a given bar frequency determined by the bar spacing (equal to 1/[2 x bar width]), the temperature difference of the bars above ambient was reduced until the observers could no longer distinguish four bars. For image intensifiers and television, the measurement became the Minimum resolvable contrast (MRC) which showed threshold contrast of the 4 bar pattern vs. frequency and parametric in light level. The methodology for getting from MRT to target acquisition performance is the subject of the next section. Much of the following modeling development has been published in the classified literature for infrared, the Infrared Information Symposium (IRIS). The original articles were largely classified due to the validation data sets which indicated performance of new developmental infrared imagers. Most of the referenced articles are today declassified.

3. FLIR Systems & Models: The Past

During the late 1960's early 1970's, thermal imaging technology matured to the point that viable systems could be proposed for engineering, production and fielding. A performance model was needed which could relate FLIR design parameters to field performance by the soldier using the device. In addition in order to optimize the design and choose the best contractor candidate, a method was needed to relate, quantitatively, system parameters such as detector sensitivity, detector MTF, optical F/#, optical MTF, electronics MTF, display MTF, etc. to how well a soldier could acquire targets. Although each contractor had its own model to perform the trade-offs, the contractor model frequently did not cover the wide range of system concepts being considered. For example, various scan formats for linearly scanned arrays of infrared detectors were being considered, such as serial scan, parallel scan and circular scan. The scan formats are shown in Figure 1. The government needed a more general model than was available at the time from any other source.

During the same time frame, there was an enormous amount of activity by the atmospheric science community in trying to understand and model atmospheric propagation in the infrared region. Major organizations involved were NVESD, the Institute for Defense Analyses, and the Air Force Geophysics Laboratory. Measurements were conducted on fogs and hazes in order to characterize aerosol scattering. A landmark set of data on atmospheric propagation through fogs and hazes was performed by NVESD at Grafenwoehr Germany and Fort A.P. Hill, VA. This set of data became the GAP model[4]. Major modifications to the standard atmospheric model LOWTRAN[5] were made in this regime and in the water vapor continuum for the 8-12 micrometer spectral region. With the definition and development of the Common Modules for FLIRs, there was a hot bed of realistic field trials that would provide the necessary validation for the performance models developed during this time.

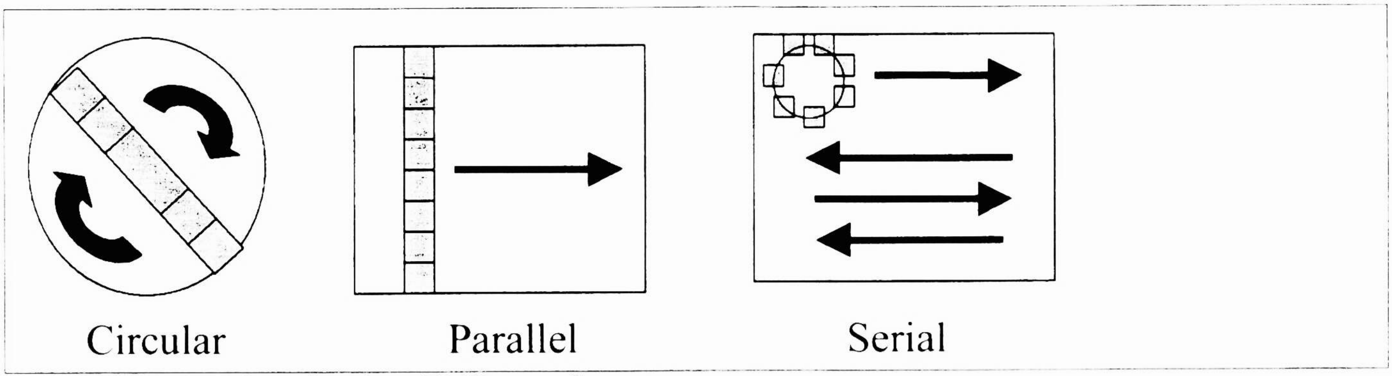


Figure 1. Examples of various FLIR scan formats

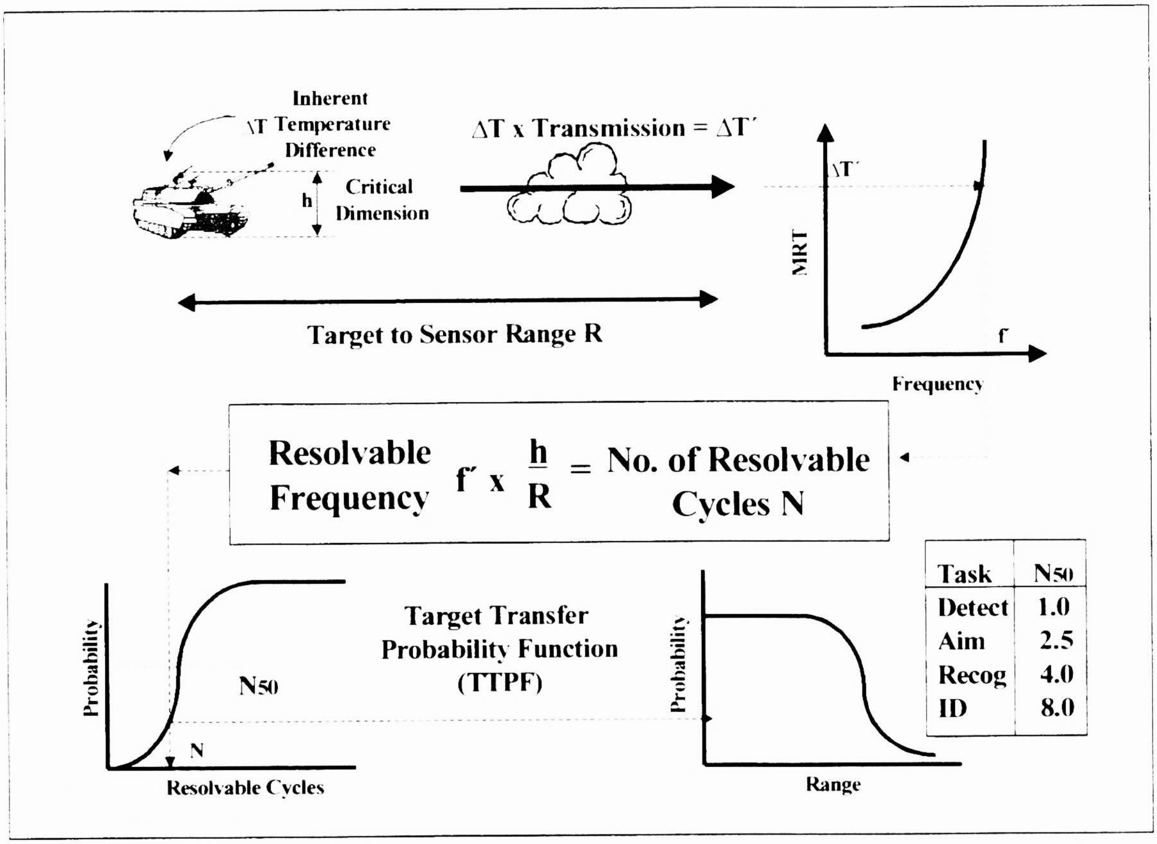
Two sets of field trials were performed in 1968[6] and 1971[7] in Warren Grove, NJ. Both of these tests had the objective of establishing the baseline performance for the electro-optical imagers. The performance data, along with target signatures and atmospheric transmission measurements, were taken so as to validate performance models. In 1975 two competitive field evaluations for contractor proposed night sights for the TOW missile system[8] and the M60 tank[9] were conducted in a similar scientific manner so that the data could be used for model extension and validation. Also in 1975 an airborne FLIR test[10] was conducted at Fort Polk, LA and provided model validation from an airborne platform. In the winter of 1975-1976 a major exercise was performed in Grafenwoehr, Germany[11] in order to demonstrate if the US Army had made the right decision in developing LWIR for target acquisition sights as opposed to other technologies, such as pulse-gated TV. Finally, in 1978 another Grafenwoehr test[12] was conducted in order to show the effects of battlefield debris from artillery barrages and vehicle movement on thermal imaging performance. As in the previous tests, scientific observer performance data was obtained along with highly calibrated target signature and atmospheric propagation data. The result of these realistic field trials was a set of scientific data that provided the necessary information to build and validate an engineering model based upon the fundamental concept generated by Johnson. This field data along with the extensive use of the performance model described in the next section were major factors contributing to the development, fielding and subsequent combat success of the Common Modules for First Generation Thermal Imaging on many weapons platforms.

In the late 1960's and 1970's a team of modelers at NVESD led by Dr. Walter Lawson was attempting to build on the work of Johnson to come up with a performance model for FLIR systems. The objective was to generate an engineering model that predicted probability of an ensemble of observes to detect, classify (tracked vs. wheeled vehicle), recognize and identify tactical targets as a function of range, environment and system parameters. A straight forward approach of calculating a signal-to-noise ratio from a target and system representation was abandoned[13] when the concept of Minimum Resolvable Temperature Difference (MRT) was proposed by Sendall and Lloyd[14]. The MRT provided the connection between Johnson's concept of resolvable bars across the target critical dimension and a system level measurement and was a measurement that could be routinely carried out in the laboratory. The MRT measurement also included the observer. Later a Minimum Detectable Temperature Difference (MDT) was defined which would be the connection between signal-to-noise ratio of a "blob" and the ability to detect hot spots without any higher level discrimination. A measurement was performed in which the threshold of an observer was measured for detecting the hot target as a function of target size[15].

The target acquisition performance model that used the Johnson concept and MRT is shown in Figure 2[16, 17, 18]. An inherent target signature in terms of a temperature difference (ΔT) of the target above the local background is attenuated by the atmospheric propagation to give an apparent temperature difference ($\Delta T'$) at the sensor. This $\Delta T'$ corresponds to a bar pattern frequency f' which the sensor-observer system can resolve through the MRT curve. The number of resolvable bar pattern cycles which can be resolved across the target critical dimension h is then given by

f' X h/R = Number of Resolvable Cycles N across Target.

This number of resolvable cycles N across the target critical dimension could then be related to probability of any level of discrimination through a set of empirically generated curves. These Target Transfer Probability Functions (TTPF) were generated from the field exercises described previously and represent the per cent of the ensemble of observers who could correctly perform the discrimination task, e.g. detection, classification, recognition, and identification[4]. The number N was a function of target signature (ΔT and h), atmospheric propagation, and system parameters through the MRT.



Task	N_{50}
Detect	1.0
Aim	2.5
Recog	4.0
ID	8.0

Figure 2. Model to predict performance based upon Johnson and using system MRT.

The target ΔT was calculated from a measured or predicted signature by calculating the area weighted ΔT for the whole target from the ΔTs and areas of each component of a target signature when broken up into subareas of constant temperature. The critical dimension of the target was usually the height, however, not always as is the case for a man target where the width is used. The choice of critical target dimension for new targets is usually left to a panel of experts with a great deal of experience in the performance of FLIRs. Tables of critical dimensions have been published in the literature on the NVESD model (See reference 25). As was previously mentioned atmospheric propagation is routinely calculated using some standard model, such as LOWTRAN. The TTPF curves were generated from field performance data and one standard free-hand fit was used to match all the levels of discrimination. The one curve was translated horizontally over resolvable cycles and the position of the curve was specified by the N_{50} for 50 per cent probability. The N_{50} then specified the entire curve. For example, the N_{50} for detection, aiming (a missile gunner could put a cross-hairs on the target with sufficient accuracy to fire the missile), recognition and identification were 1.0, 2.5, 4.0, and 8.0, respectively.

The entirely new model that had to be developed in order to implement this modeling approach described in Figure 2 was the MRT (and MDT) model. Trying again the approach of calculating a signal-to-noise ratio for a vertically oriented bar pattern instead of a complex target, yielded quite readily an equation for MRT. The formulation of MRT resulted in a prediction of the ΔT that was a sensor-observer threshold for recognition of the 4 bars as a function of bar pattern frequency. The MRT equation contained sensor and observer characteristics. These included detector noise, optical transfer functions, detector

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[4] The question of false alarm rate is frequently brought up with respect to this performance. However, these experiments were designed such that the false alarm rate was extremely low. The observers were instructed to respond only when they were very confident of their response.

transfer functions, electronics parameters, display characteristics and observer eye integration time[b]. It could be used as a sensor design and contractor sensor selection tool. It was accepted by the community because it was validated to real field data, was well understood and promulgated throughout the national and international infrared community.

At the time of this model development there was a complementary development in the laboratory development community for the measurement of infrared systems[19]. Besides MRT, MDT, optical transfer functions, detector noise, signal transfer function, uniformity, field-of-view, as well as many other system and component parameters were being measured in laboratory facilities. A data base of validation for MRT prediction was generated which gave confidence that the model was accurate. This meant that MRT could be specified in system specifications and verified in the lab. Costly field test verification of military required performance was, thus, avoided and replaced with a relatively simple test that could be done on the production line.

The target acquisition model based on Johnson and using MRT was shown to predict range performance to =/-20% in range. Prediction of targets that were not routine or part of the validation data base had to be done with great care. Often times an "expert" was required to select the N_{50} for a particular task and the target critical dimension. It is interesting to note that the way the Johnson concept was routinely applied as in Figure 2, means that the target whose critical dimension was vertical, conceptually, was stood on its end and compared against horizontal bar pattern frequencies. However, the horizontal resolution was infinitely finely sampled due to the scanning and was significantly better than the vertical resolution since detectors were typically longer than wide and LEDs in the display had similar aspect ratios. All imagers at this time were linearly scanned in the horizontal direction and a vertical MRT was not defined due to the sampling effects. Notwithstanding this ambiguity, the MRT model was used as the basis for field performance predictions. The MRT model was shown to give predictions that were, generally, representative of what was measured in the laboratory for linearly scanned thermal imagers. Typically, the predicted MRT curve crossed the measured system curve at some intermediate bar frequency and was optimistic or pessimistic at low frequency and the opposite at high frequency. In order to extend the MRT model to staring systems, an arbitrary cut-off of the MRT at one-half the theoretical limiting frequency (one over the detector instantaneous field of view) was imposed. This was done in order to account for the fact that a staring imager could not resolve four bars beyond that frequency.

At the same time that the NVESD model was being developed, another model was also being developed by Fred Rosell[20] at Westinghouse. This model had a fundamentally different approach to performance modeling. Probability of discrimination was determined by a calculation of signal-to-noise ratio difference (SNRD) based on the target signal propagated through the atmosphere and the system noise level. The $\Delta T'$ at the sensor was compared to the value of the MRT at a frequency corresponding to the number of cycles required to perform a task according to Johnson as in Table 1. That is, if recognition was to be performed, 4 cycles across the target was a threshold value for recognition. The MRT at f' equal to 4 times range/h was divided into $\Delta T'$ and that number compared to a probability of recognition curve that increased monotonically as a function of SNRD and that had been experimentally derived in the laboratory. This compares to the NVESD/Johnson approach which assumes a threshold SNRD for 4 bar recognition and a probability that increases with resolvable cycles. It is assumed that the true model of the world is a combination of the two approaches. However, comparison to field data indicated that the roll off of performance with range was closer to what the Johnson model predicted using a threshold SNRD and a curve for probability vs. resolvable cycles than the SNRD model predicted. The SNRD model gave a much steeper slope of performance vs. range when using the threshold resolvable cycles and a smooth curve with respect to SNRD[21].

4. FLIR Systems & Models: The Present

By the mid 1980's a new generation of thermal imaging was being developed. Linearly scanned two dimensional arrays of detectors and staring arrays were becoming available. Material and growth improvements coupled with the increases in sensitivity to be realized from time-delay-and-integrate (TDI) and staring provided the opportunity for a quantum leap forward in performance for thermal imaging. With the advent of Second Generation scanning systems and staring sensors, shortcomings in the FLIR performance models became critical. System level noise became more important than just the detector noise. Noise introduced by detector-to-detector non-uniformity, the scanning/framing processing, multiplexing, fixed pattern, and electronic processing had to considered in performance models for Second Generation if the noise was to be accurately assessed. The two dimensional scanned and staring arrays were sampled in two directions with electronic multiplexing and vertical resolution approached horizontal.

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[b] There are other observer factors that influence target acquisition performance, such as training, motivation, reward, etc. These factors have never been incorporated into the model.

The other major improvement in Second Generation systems over First Generation was in digitization. The detector array became a focal plane array of IR sensitive detectors with read out circuits bonded to the detector array and multiplexed the signal out of the dewar. This signal could now be digitized with A/D conversion and processed using state-of-the-art digital processing. The major military interest in digital processing was to implement aided/automatic target recognition (ATR) in the sensor package. Second Generation scanned focal plane arrays that are going into the Army's Horizontal Technology Integration FLIR B-Kit were designed to facilitate ATR on weapons platforms. They have nearly isotropic resolution in both dimensions, no interlace, improved signal-to-noise through TDI, and are sampled at greater than once per detector dwell time in order to provide processors the most computer friendly image possible in order to perform automated functions.

The NVESD modeling group was led at this time first by Luanne Obert and then by John D'Agostino and addressed the noise and increased resolution issues directly[22] [23] and implemented improvements with the model FLIR92[24]. D'Agostino hypothesized that the total system noise could be reduced to eight components depending on whether the displayed noise had temporal variation t or spatial horizontal h or vertical v variation in the plane of the display. The standard deviation of each component σ represented a real displayed and measurable noise. Table 2 shows the eight components and their description and potential source for that noise component. The development of digital processing permitted the measurement of each of these components in a system with the digitization and filtering of the noise within the systems. This, in turn, provided the validation for the concept that was implemented mathematically in the MRT equation.

The term σ_{tvh} is the basic detector noise normally characterized by the the NET. σ_{tvh} is related to the actual system bandwidth and not the artificial standard bandwidth used to measure NET. It becomes the NET when multiplied by the ratio of the equivalent noise bandwidth divided by the actual noise bandwidth.

Table 2. Temporal and spatial noise in Second Generation thermal systems.

3-D Noise Component Description		
Noise	**Description**	**Potential Source**
σ_{tvh}	**Random Spatio-Temporal Noise**	**Basic Detector Temporal Noise**
σ_{tv}	**Temporal Row Noise**	**Line Processing, 1/f, Read-out**
σ_{th}	**Temporal Column Noise**	**Scan Effects**
σ_{vh}	**Temporal Spatial Noise**	**Pixel Processing, Detector-to-Detector Non-uniformity**
σ_{v}	**Fixed Row Noise**	**Detector-to-Detector Non-uniformity, 1/f**
σ_{h}	**Fixed Column Noise**	**Scan Effects, Detector-to-Detector Non-uniformity**
σ_{t}	**Frame-to-Frame Noise**	**Frame Processing**
S	**Mean of All Components**	

A second innovation that D'Agostino introduced into the NVESD FLIR and target acquisition models was the use of resolution in both horizontal and vertical directions. Background experiments were performed at NVESD using simulated imagery which showed that more accurate performance predictions were made when resolution in both image directions was included. In order to preserve the existing well understood Johnson concept for imaging and to have as little as possible impact on the well established approach to predicting field performance from MRT, a two dimensional MRT was defined which was not a physical measurement that could be performed on a FLIR. A fictitious MRT function was defined whose temperature difference value was defined as that value at a frequency equal to the square root of the product of the horizontal and vertical MRT frequencies for the ΔT value measured on the horizontal and vertical MRTs. The prediction of field performance was then identical as that shown in Figure 2, however the critical dimension of the target now became the square root of the target area in order to have a consistent two dimensional approach.[6] Figure 3 shows this two dimensional model diagrammatically. Although, conceptually, one might envision this approach as using "resolvable pixels" on the target, the fundamental metrics are still linear one-dimensional frequencies (square root of horizontal and vertical frequencies) and length (square root of area).

The FLIR MRT model with 3D noise and 2D MRT has been released to the community under the name of FLIR92. The calculation of target signature, atmospheric propagation and field performance has been released under the name ACQUIRE[25]. FLIR92 also includes the calculation of MDT and ACQUIRE uses the MDT to compute "hot spot" detection ranges. ACQUIRE contains tables for the area, critical dimension for tactical targets and an analytic curve fit to the Target Transfer Probability Functions. The TTPF N_{50} values had to be changed somewhat in order to validate the model for Second Generation systems and to re-validate the 2D model to the old data base of performance with First Generation FLIRs. The original NVESD model values for N_{50} are shown in Table 3 compared to the new values used in ACQUIRE. Also, the "aim" discrimination level is dropped and a classification level is introduced. The new values for N_{50} brought closer agreement with the values used in image intensifier modeling. This was aesthetically pleasing since it brought the modeling of different EO technologies into closer agreement. Note that image intensifiers have isotropic resolution in all directions and the recognition criterion for them has been N_{50} equal to 3 for many years.

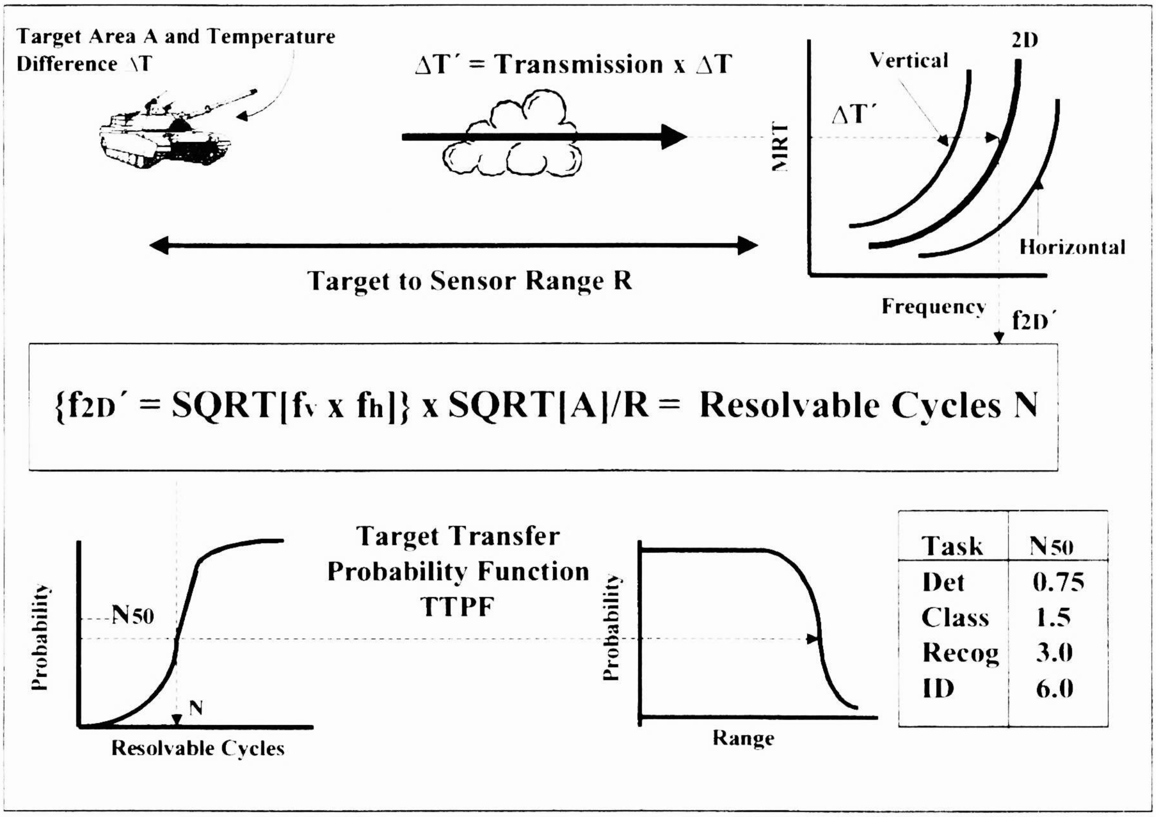

Figure 3. Two dimensional approach to performance prediction.

It is important to note that FLIR92 does not account for sample data effects any differently than the original model. An arbitrary asymptote is imposed on a staring system MRT at the Nyquist frequency. This is important in the future modeling activity to be discussed in the next section of this paper.

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[6] The target area is the projected area of the target on the display. This means that the area can be different in different spectral regions due to the fact that different components of a target show up differently in the various spectral regions. The canvas of a two and ½ ton truck may be at the ambient temperature and have no temperature difference in the infrared. It would show up in the visible region.

Two complementary developments to the modeling helped enable the significant improvements in the capability of the FLIR 92 and ACQUIRE models. These were the development of an Advanced Sensor Evaluation Facility[26] and the expansion of the applicability and use of perception testing[27] [28]. Laboratory testing of thermal imaging systems was upgraded in order to make use of digital processing. Signal trains in an imaging system could by digitized and processed in order to help characterize the system. Use of such equipment as frame grabbers enabled the isolation of the various noise components which permitted the validation of the noise modeling concepts. In addition, the ability to generate large amounts of simulated targets which could be used as input stimuli to automated perceptual testing enabled the generation of large amounts of target acquisition data. Many independent and dependent variables to observer-in-the-loop performance under controlled conditions could be studied that provided new in-depth understanding and new concepts for advanced models. The results from the perception testing had high statistical significance due to the large number of replications that could be performed under the controlled environments.

Table 3. Changes in Johnson criteria from original NVESD model to ACQUIRE[29].

Resolvable Cycles across Target Critical Dimension					
Task	**Detect**	**Aim**	**Classify**	**Recognize**	**Identify**
Original N50	**1.0**	**2.5**	**---**	**4.0**	**8.0**
ACQUIRE N50	**0.75**	**---**	**1.5**	**3.0**	**6.0**
	N50 for a Man target = 0.75				

5. FLIR Systems & Models: The Future

The future for the next generation of thermal imagers has many possibilities. However, one certainty is that the IR FPAs will be staring. The field of view of the sensor will be filled with a detector array with near unity fill factor. Other possibilities for future thermal imager capabilities are (1) the capability for two or more colors in the infrared; (2) automated functions on the FPA, such as motion detection, cueing, tracking and identification; (3) image enhancements that make the image more friendly for the human observer; (4) 3D imaging with active source laser diodes and detectors on the FPA; and (5) passive millimeter wave imaging on the same FPA with infrared. There are other possibilities that can be envisioned. Depending on the thrust of the Third Generation thermal imaging, models describing some or all of these effects will have to be generated. It is premature to emphasize one over another, except for the staring characteristics. Any new model must address the sample data effects that cannot be ignored in staring sensors.

The NVESD modeling group is now led by Richard Vollmerhausen. Although he has been in that position a relatively short time, he has already made or proposed some significant changes to EO modeling. The first change that has been implemented in the FLIR and image intensifier models is improvements to the eyeball component of the model[30]. The sensitivity of the eye to contrast on the display has been introduced so that poor display contrast can now limit performance. The previous model only limited performance by system noise. Now if an observer uses an image in a darkened room or a sunlit cockpit, the predicted performance will be different if no adjustment is made to the contrast and brightness setting. In addition the threshold signal-to-noise ratio is varied depending on the signal-to-noise regime. That is, if the image is severely noise limited, the threshold will be higher than in high signal conditions. Finally, the spatial integration of the eye is limited at 4 milliradians. In the past model, the eye was allowed to integrate over the spatial extent of the target without limit. This permits better agreement for MRT prediction at low spatial frequencies.

The second major change being proposed by NVESD to FLIR performance modeling has been implemented in a new model called NVTHERM[31] [32], which is in Beta testing and further validation. It attempts to address the critical sample data issue associated with staring imagers. The alaised signal in the post filter pass band is calculated and divided by the integrated band pass. This is called the "spurious response" SR. The effect of the spurious response is to effectively reduce the MTF response of the system or to "squeeze" the MTF. Figure 4 shows the concept graphically. The value of the undersampled system MTF is reduced from the unsampled or oversampled system frequency f_2 to another frequency f_1 given by

$$f_1 = (1.0 - 0.32\ SR)\, f_2.$$

This results is a "squeezing of the system MTF in frequency and is dependent on the amount of spurious response that is a determined by the sampling, among other system parameters. Laboratory tests have been conducted in order to validate this empirical model and comments from the community are being solicited. This model does not calculate any noise alaising contribution to the system total noise.

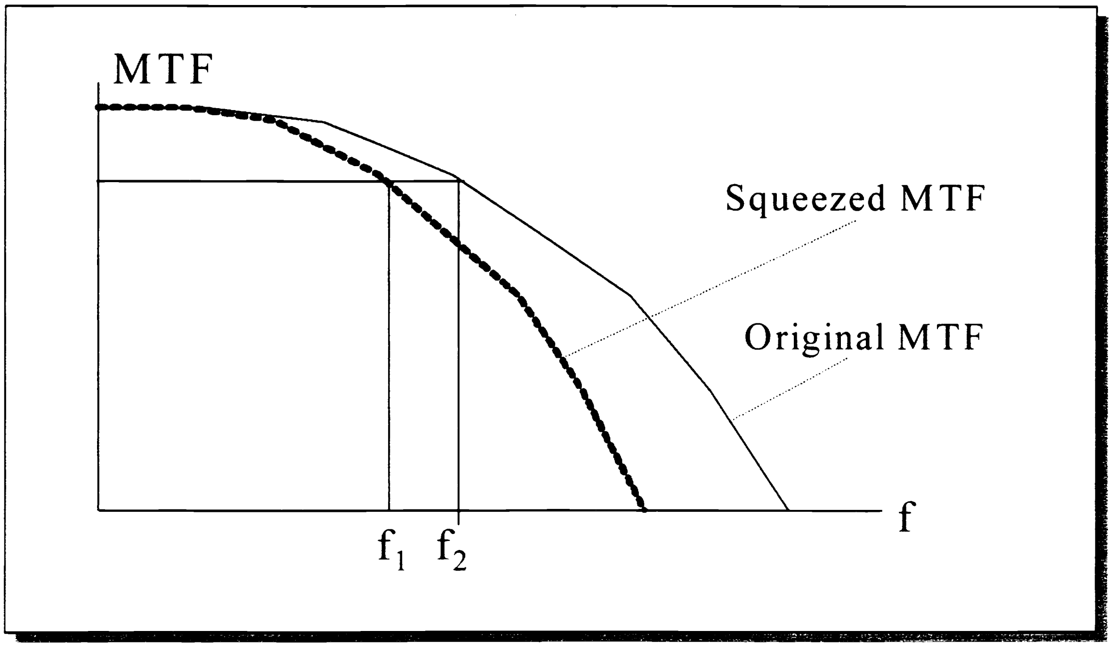

Figure 4. MTF "squeeze" due spurious response in sampled data systems.

Further investigations that are in process have to do with quantifying the improvement in image enhancements on perceptual and automated performance. Other advanced sensor characteristics to be investigated are (1) diffraction and scattering effects at detector sizes comparable to the wavelength of the radiation, (2) degradation in performance due to fixed pattern (coherent) noise, and (3) image based metric for undersampled systems. The NVESD modeling group is charged with developing models for sensor fusion, image fusion, multi-spectral imaging, and extension to SAR imaging. All of these requirements mirror the possible system developments that are being proposed for the next generation imaging sensors.

6. Search

A complete story of the Night Vision performance modeling would not be complete without some mention of the time dependent search modeling. The models described in the paper to this point have been time independent models where the observer has sufficient time to perform the task. Basically, it is assumed that he has infinite time. This is true whether the task is resolving bar patterns or discriminating targets. The Night Vision modelers developed a time dependent search model in the 1970's[33] This simple empirical model for an observer to detect a target in the device field of view while scanning a field of regard in low to medium clutter as a function of time $P_d(t)$ is given by

$$P_d(t) = P_\infty[1-\exp(-t/m\tau)],$$

where P_∞ is approximated by the static probability of detection given infinite time, m is the number of device fields of view in the field of regard, and τ is the mean detection time for all observers who detect the target in a device field of view. Empirical results from various field exercises have given the relationship[34] (See reference 25.).

$$\mathbf{1.7\_< \tau = 6.8/(N/N_{50})\ seconds.}$$

The quantity N/N_{50} is similar to the quantity specifying the TTPF curve of the preceding sections and the N_{50} must today be chosen by an "expert" since it is a strong function of background clutter and we do not know how to quantify clutter.

This model is simple and validated to some extent. The model is not applicable to zero clutter where a visual lobe model is more appropriate. It is also not valid for the unaided eyeball search. The lack of explicit dependence of τ on device field of view is not intuitive, but may be explained by the fact that the validation set consists of electro-optical devices which all have approximately the same field of view in object space. All the search experiments with the electro-optical sensors presented the same level of difficulty for the observers. There is an implicit dependence of τ on resolution through N/N_{50} which, in turn, influences the device field of view.

The search model has provided the systems analyst with a useful tool for assessing time lines with electro-optical imagers. Its limitations, such as mentioned above, have been and still are being addressed. Improvements and extensions of applicability have been reported and work continues to this day on search. Search modeling is an inherently difficult task due, in large part, to a the lack of a quantitative clutter model.

7. Summary

Night Vision Laboratory, now NVESD, has played a major role in development of performance models for electro-optical sensors. This role has covered the years from the 1960's to the present and will continue into the next century. The focus of the model development has always been driven by systems development considerations. The future focus will, similarly, be on the next generation concepts. Those system characteristics with the most near term significance are staring imagers, sample data effects, multi-spectral sensing and aided/automatic performance.

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