

Evaluation of the AN/SAY-1 Thermal Imaging Sensor System

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Abstract—The AN/SAY-1 Thermal Imaging Sensor System (TISS) was developed to provide surface ships with a day/night imaging capability to detect low radar reflective, small cross-sectional area targets such as floating mines. Through field testing and laboratory measurements, the performance of the imaging sensors of TISS has been evaluated. The objective of this paper is to present program history, performance evaluation of TISS, and future considerations of the TISS program.

Index Terms—Infrared imaging, detection of targets, minimum resolvable temperature differences (MRT), performance prediction

I. INTRODUCTION

The initial requirement for the AN/SAY-1 Thermal Imaging Sensor System from herein referred to as TISS, was developed from operational experience to effectively detect, identify targets in a passive mode in the Arabian Gulf, North Arabian Sea, Persian Gulf, and the Caribbean. Surface ships operating in the littorals can be faced with threats such as floating mines and fast small craft, which are difficult to detect due to low radar reflectivity and small cross-sectional areas. The problem of detecting potential threats becomes even more complex due to sea surface clutter, operating in small patrol areas, requirements to operate at night and with poor visibility, and in Emission Control (EMCON) conditions. Electro-optical (EO) sensors such as thermal imaging sensors, visible imaging sensors, and laser rangefinders provide additional situational awareness to complement current shipboard radar in a manner to overcome the issues of detection and identification of small surface targets. The TISS incorporates the above-mentioned EO sensors into a single stabilized gimbal platform with a suitable size and weight that allows mounting of the sensor onto the deck or mast of surface ships. With its suite of EO sensors, auto-tracking capability, and accurate stabilization, the TISS has demonstrated the ability to support other roles such as navigation, suspect ship boarding, and air defense. The Surface Multi-Sensors Branch of the Night Vision and

Electro-Optics Department at the Naval Surface Warfare Center Crane Division serve as the In-Service Engineering Agent (ISEA) whose duties include the task of ship installation, engineering support, field service support, and overall logistics of the system.



Fig. 1. AN/SAY-1 TISS installed on the LHD-6.

II. PROGRAM BACKGROUND

In December of 1989 due to an emergent need for floating mine detection in the Persian Gulf region the Chief of Naval Operations (CNO) directed an initial procurement of seven of the Army's Mast Mounted Sights that were originally designed and installed on the OH-58 Kiowa Warrior Helicopter. In the previous year, the USS SAMUEL B. ROBERTS (FFG-58) was severely damaged when it collided with a mine while operating in the Persian Gulf region. The seven systems were delivered in the fiscal years of 1989 and 1990 and installed and cross-decked on a total of seven ship classes. The system was designated as the AN/SSQ-119 Navy Mast Mounted Sight (NMMS).

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Fig. 2. AN/SSQ-119 NMMS installed on a FFG-7 class of ship.

In the fall of 1990, Operation Desert Shield created the need for additional NMMS systems. A letter contract was signed to procure eight additional NMMS from McDonnell Douglas (original OEM) for a total of fifteen units procured for operational use in the Persian Gulf Region. The shipboard electro-optic Mission Need Statement (MNS) was drafted in 1992, the Cost and Operational Effectiveness Analysis (COEA) followed in 1994, and the Operational Requirements Document (ORD) SER 410-86-95 was approved in 1995. A competitive contract award was given to then Boeing (who had since acquired McDonnell Douglas) for the production of TISS units. The TISS engineering test unit (ETU) completed DT II-A onboard the Shelf Defense Ship (SDTS) in June 1996 and completed DT-IIB on the USS TICONDEROGA (CG-47) in August 1996 while supporting counter drug operations that lasted until December of that same year. The decision to move forward with the low rate initial production of TISS was also made in August 1996 with the Production Milestone III being reaching in April 1997. The first Phase 2 (Prime Mission Equipment) installation was completed July 1998 on the USS HAYLER (DD-997). The first SCN permanent installation was completed August 1998 aboard the USS BONHOMME RICHARD (LHD-6). A vertical cut in the out year funding for TISS in 1998 limited the procurement to only twenty-five systems instead of the planned ninety systems. TISS is scheduled to replace the NMMS units with the policy change in 2001 of cross-deck to permanent installations. TISS is currently installed aboard fifteen OLIVER HAZARD PERRY- class guided missile frigates, two WASP-class amphibious assault ships, one HARPER'S FERRY-class dock landing ship, and one SPRUANCE-class destroyer.

III. SYSTEM OVERVIEW

TISS is comprised of a stabilized Optical Sight located above deck, a Control and Display Panel (CDP) located in the Combat Information Center (CIC), and System Support Electronics (SSE) located below deck.

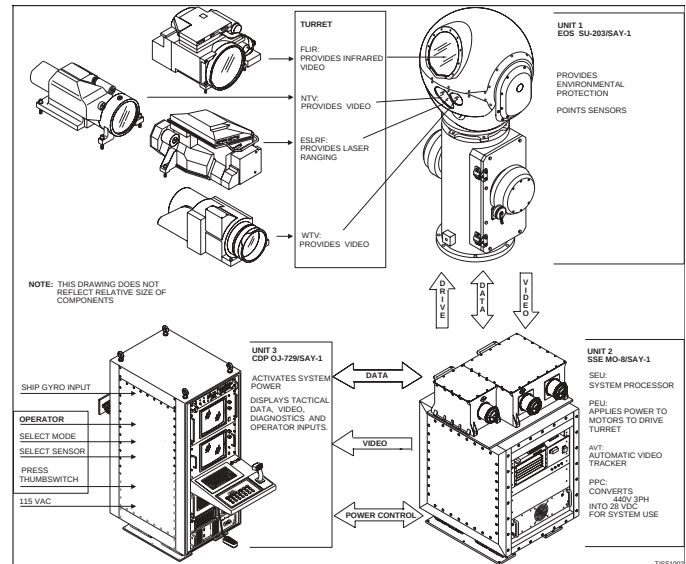


Fig. 3. Above deck and below deck schematic of the TISS components along with information of data flow among the system.

The Optical Sight houses in a two-axis stabilized, environmentally protected turret the TISS sensors, Thermal Control Unit (TCU), and an Optical Boresight Tool (OBT). Stabilization of the optical sight is less than 15 mrad of jitter. Sight coverage encompasses $\pm 270^\circ$ in the azimuth and -30° to $+75^\circ$ elevation, with slew rates of $45^\circ/\text{sec}$ and $30^\circ/\text{sec}$ in azimuth and elevation, respectively.

Using a standard United States Navy (USN) Tactical Advanced Computer (TAC-4) console, the TISS CDP consists of two 15-inch COTS, ruggedized monitors, a COTS industrial personal computer (PC), and an operator control panel. One of the 15-inch monitors is the sensor video display, showing user selectable TV or IR camera imagery. The other monitor is the situational display, giving the ship's heading and position information, and displaying keyboard and pointing device commands.

The operator control panel is comprised of a standard PC keyboard, a handgrip control, and operator selectable panel switches. Most operator functions can be performed using the handgrip control, including selection of IR or TV sensors, selection of FOV, positioning Line of Sight (LOS), and initiation of automatic video tracking.

The remainder of the below deck equipment is the SSE comprised of four main subassemblies - the Pedestal Electronics Unit (PEU), the System Electronics Unit (SEU), the Automatic Video Tracker (AVT), and the Primary Power Conditioner (PPC). The PEU provides stabilization control to the turret, which encases the sensors. The SEU provides system control and power regulation. The AVT features high performance video processing that provides multiple target tracking capability, with the ability to handle small targets, cluttered backgrounds, temporary blockages (i.e. buildings, existing ship structure, clouds) and crossing targets. Finally, the PPC furnishes 2 kW of clean 28 V of power for use in the above deck equipment. These electronics can reside up to 30 m from the turret, and are connected via 106 m of cable to the operator CDP.



Fig. 4, Picture of the CDP within the TAC-4 console with the handgrip, footswitch, two monitors, and the keyboard.

IV. SENSOR OVERVIEW

The sensors include an infrared (IR) camera, two Charge-Coupled Device (CCD) TV cameras, and a long range Eye-Safe Laser Rangefinder (ESLRF).

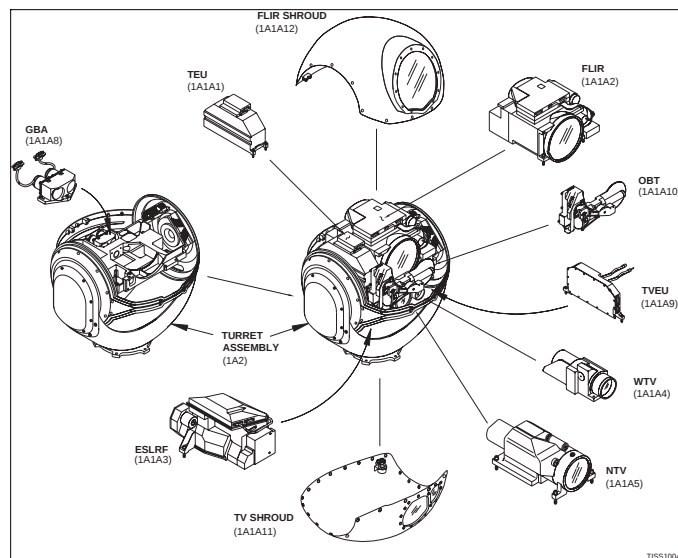


Fig. 5, The TISS turret houses all of the sensors along with the sensor electronics.

The IR camera, also referred to as a thermal imager or Forward Looking Infrared (FLIR), weighs less than 30 lbs. and consists of a Indium Antimonide (InSb) staring focal plane array (FPA), an integrated dewar and linear Sterling Cooler, and a dual field of view (FOV) optical train. The high resolution FPA operating in the 3-5 μ m of the electromagnetic spectrum consists of a total of 512x484 pixels. The cooler provides a cool down time of less than 10 minutes for the FPA at an operating temperature of 77K. The optics provides a narrow FOV of 2.1° x 1.6° and a wide FOV of 6.3° x 4.7°. The IR camera provides all weather and night time imaging capability. Two fixed FOV Charge Coupled Device (CCD) cameras provide low light and daytime imaging capability with a spectral response of 0.65-0.95 μ m for haze penetration and twilight or dawn operations. The operating sensitivity of the narrow FOV (1.6° x 1.2°) is from 1 lux to 100,000 lux to account for direct sunlight viewing. The operating sensitivity of the wide FOV (6.2° x 4.7°) is 0.5 for low light imaging.

The low light capability is advantageous for viewing of shipboard running lights and lights along the shore during nighttime operations. For determining range of targets, TISS includes an eye-safe laser rangefinder (ESLRF), which provides a +/- 5m range accuracy to targets from 100m to 20,000m from the turret. The sensors with TISS provide a complete visible situational awareness to CIC in day, night, or harsh weather conditions.

V. PRODUCT IMPROVEMENTS

Seventeen engineering change proposals (ECP) have been approved to be incorporated into the TISS production baseline. Two of these ECPs have had a significant impact on improving the reliability of TISS. These ECPs are designated as ECP 00-T-0006 Anodized Heat Exchanger, and ECP 01-T-0016 Linear Compressor Upgrade of which the ISEA at NSWC Crane developed and implemented.

ECP 00-T-0006 affected the TCU which provides the temperature regulation of the optical bench within the turret. The bench is cooled with an ethylene glycol recirculation system driven by a pump, and a liquid-to-air heat exchanger located in the post under the turret.

The original heat exchangers in the TCU of the TISS were chemically film coated per MIL-C-5541. It was determined from fielded units that the chemical film coat does not protect the heat exchangers from corroding in the at-sea, salt environment. The heat exchangers have shown severe corrosion with the fins curling, which is a phenomenon caused by corrosion of very thin aluminum. This type of corrosion reduces airflow through the heat exchanger and reduces the glycol circulation, which in turn reduces the cooling of the sensors. The upgraded heat exchangers are anodized per MIL-A-8625, which states the heat exchanger is to be coated with a clear anodize. The MMS units when fielded aboard ship used the same coating and showed no signs of corrosion in five years of operation.

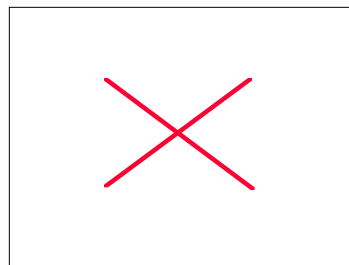


Fig. 6, A chemical coated heat exchanger that shows severe corrosion.

ECP 01-T-016 upgraded the original Raytheon 7050 linear cooler to the US Army Night Vision Lab (NVL) qualified one-watt linear (OWL) cooler. Three cooler vendors have been certified to produce the OWL cooler per the Performance Specification for Long Life, Cooler, Cryogenic One Watt Linear (OWL) PRF-A3165823A. The Raytheon 7050 compressor has an actual mean time between failure (MTBF) of 2092 hours as seen in the field with a predicted MTBF of 4624 hours. The US Army continuously tested the OWL compressors for 5000 hours without a failure. The OWL compressors can also be refurbished twice where as once the Raytheon 7050 compressor fails it becomes a consumable item.



Fig. 7, Original 7050 compressor integrated in the dewar/FPA assembly.



Fig. 8, US Army qualified OWL compressor integrated into the TISS dewar/FPA assembly.

VI. PERFORMANCE EVALUATION

With EO sensors, the basic measure of determining if the system meets mission requirements is to determine the range performance of the sensor. In general, the mission requirements are specified to list targets with critical dimensions and ranges to which the target is required to be detected, recognized, or identified. The range performance can be determined two ways.

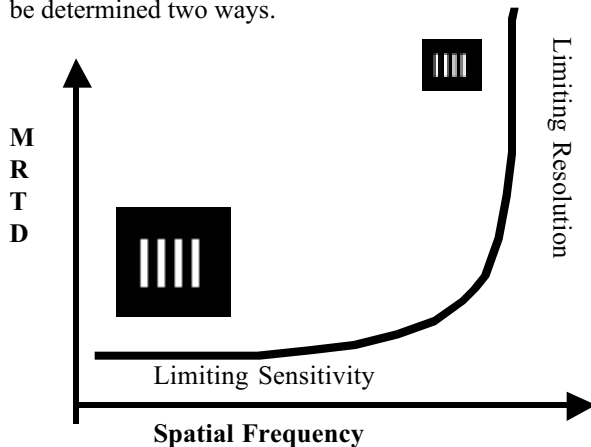


Fig. 9, Pictorial representation of an MRTD curve for a IR camera.

One method is based upon theoretical calculations based upon the sensor design parameters such as the FOV and effective focal length (EFL) of the optics and the number of pixels and pixel dimension of the FPA. Computer models such as FLIR 92 and NVTherm have been developed by the US Army Night Vision Lab to determine the theoretical performance of IR cameras. The output of such programs is a minimum resolvable temperature difference (MRTD) curve. The y-axis of the MRTD curve is the temperature difference between the

target and its background. The x-axis is the spatial frequency of the target in units of cycles (cy) per milliradian (mrad). Knowing the dimensions of the target and the desired standoff range of the target, the target can be represented as a specific spatial frequency. A similar curve called a minimum resolvable contrast (MRC) is used to measure the performance of visible cameras. The difference between a MRC curve and a MRTD curve is the y-axis for a MRC curve is the contrast difference between the target and its background. The discrimination level provides the link between the target angular subtense and the spatial frequency scale on the MRTD curve. The apparent target temperature difference at the system's entrance aperture becomes the threshold MRT. The apparent target temperature is based on the atmospheric effects on the actual temperature difference of the target and its surroundings. Developed by NVL, the ACQUIRE model provides range prediction methodologies for target discrimination levels for both IR and visible sensors. The MRT and MRC abscissa is converted into a range scale using the target discrimination value. NSWC Crane uses these models to predict MRTD and MRC curves as well as developed its own computer model for inputting MRTD and MRC curves for range prediction.

The other method of obtaining MRTD and MRC curves is to perform laboratory testing of the EO sensors using a collimator. Collimator testing incorporates 4-bar targets, which can represent targets at various spatial frequencies, black body sources or visible light sources to illuminate the targets depending upon the testing of an IR or visible sensor, and a parabolic mirror to present the targets to the entrance aperture of the sensor. The Sensor Optical Test Set (SOTS) at NSWC Crane has a 16" aperture collimator with an 80" focal length with the ability to test visible sensors using 3-bar 1951 US Air Force resolution targets at varying contrast levels or 4-bar targets with spatial frequencies out to 16 cy/mrad. The advantage of using collimator testing to obtain the MRTD and MRC curves necessary to determine range performance is the use of an actual observer to resolve the targets at different temperature differences or varying contrast levels.



Fig. 10, SOTS is located at Building 3291 at NSWC Crane.



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REFERENCES

- [1] G.C. Holst, *Electro-Optical Imaging System Performance*, 2nd ed., Bellingham: SPIE, 2000, pp. 412-415.

Fig. 11, TISS being tested using SOTS.

The sensor performance of TISS has been evaluated using both methods of theoretical predictions and actual lab measurements.

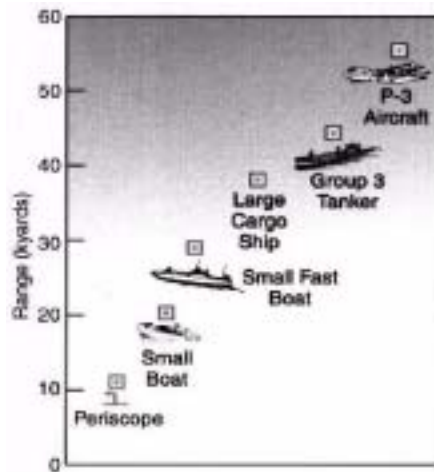


Fig. 12, Unclassified pictorial representation of the typical range performance of TISS for various targets.

VII. FUTURE CONSIDERATIONS AND SUMMARY

TISS is a proven and fielded EO sensor for the USN. It is functional and useful in various environments and conditions and provides early warning detection of threats such as floating mines, fast small attack craft. In addition the usefulness of TISS has expanded into use for Navigation and complimentary target identification with existing shipboard radar systems. Through extensive modeling and laboratory testing the performance of the individual sensors within TISS have been evaluated and characterized in order to ensure their compliance with the desired mission requirements specified within the TISS ORD. The ISEA has implemented engineering change proposals to continue to improve the reliability and maintainability of the system providing the fleet with a higher performance sensor than what might have been originally expected. The TISS Program Office currently has several program objective memorandums (POM) in order to upgrade TISS to increase its value to the fleet as well as to acquire additional systems to meet the Navy's operational needs.

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