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A SHIPBOARD MULTISENSOR SOLUTION FOR THE DETECTION OF FAST MOVING SMALL SURFACE OBJECTS

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Abstracts Detecting a small threat object either fast moving or floating on shallow water presents a formidable challenge to shipboard sensor systems, which must determine whether or not to launch defensive weapons in a timely manner. An integrated multisensor concept is envisioned wherein the combined use of active and passive sensor is employed for the detection of short duration targets in dense ocean surface clutter to maximize detection range. The objective is to develop multisensor integration techniques that operate on detection data prior to track formation while simultaneously fusing contacts to tracks. In the system concept, detections from a low grazing angle search radar render designations to a sensor-search infrared sensor for target classification which in turn designates an active electro-optical sensor for sector search and target verification.

Keywords Detection,Multisensor,Integration,Classification,Tracking,Data-Fusion

1. INTRODUCTION

This paper concerns the system design overview required of a synergistic use of sensory data from multiple sources to extract the greatest possible amount of information for the detection, classification, and tracking of a fast moving small object. Detection of a small object on ocean surface in general is a formidable problem because of (1) the target's low signal-to-noise ratio (SNR) and short observation time, and(2) the target is buried in a highly structured clutter background reproducing a potentially high false alarm rate. As shown in Figure 1, the ownship's objective is to combine the nonacoustic data with prior knowledge to provide a search and track capability against threat targets and other extendables in the region of interest for ship survivability.

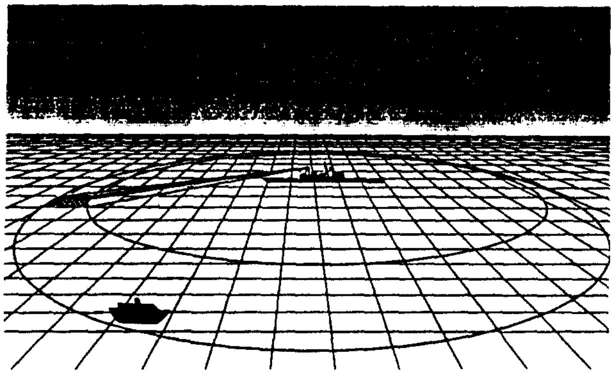

Figure 1

The detection and classification of low observable targets present a formidable challenge to standalone sensors. In fact, the next generation tactical missions required for defensive littoral warfare capability against conventional naval vessels such as submarines or fast boats cannot rely on standalone sensor information alone without stretching beyond prevailing technologies as well as physical and cost limitations. These threat vessels diminish the effectiveness of standalone sensors which typically depend on limited sectors of the electromagnetic spectrum, yielding a low density of "observables" to exploit about targets of interest. Moreover, individual sensor systems currently operational in naval platforms probably do not meet the projected minimum performance requirements for the expected mission environment since they were not designed to detect small but fast moving object in the first place. Therefore, in addition to the need for the individual sensor's performance improvement, new systems must rely on an integrated, multi-sensor approach for maximum information extraction while avoiding unacceptable physical and cost problems.

Because each sensor in the multisensor system measures dissimilar physical phenomena in different spectral regions over diverse spatial volumes with distinct measurement characteristics , this process is complex and adaptive. The conversion of the pixelated data(image, time-frequency lines, and physical shapes or textures) into a meaningful perception of the environment in the form of a contact report requires a large number of distinct intelligent process and a database sufficient to interpret the meaning of the properly combined data.

In recent years, many automated systems have been designed and developed to intelligently combine data from multiple sensors to derive meaningful information not available from any individual sensor. This process of combining data has been referred to as multisensor fusion[1,2,3,4]. Perhaps the most comprehensive definition of multisensor fusion in the navy context is a multilevel, multifaceted data fusion process dealing with the detection, association, correlation, estimation, and complete and timely assessments of situation and threat. The multisensor integration then is the multisensor fusion process which optimally utilizes multiple sensors through appropriate sensor management. These definitions focus on three central aspects of fusion:

.The process is performed on multiple data at the pixel level and at the report level each of which represents a different level of abstraction of data.

.The process includes detection, association, correlation, estimation, and combination of data

.The outputs include stat estimates and classification. The combined information will be used to establish an overall tactical picture and situation assessments for appropriate combat reactions.

The basic objective of multisensor integration, then, is to derive more information, through combining and designating, than is available from any single sensor. This is the effect of synergy: the enhancement of the sensor system's effectiveness by taking advantage of the cooperative and joint operation of the multiple sensors. The purpose of this paper is to discuss these issues and elements associated with a possible multisensor integration conceptual approach from the perspective of accomplishing the fast-moving-surface-object detection task from surface shipboard platforms.

2. SURFACE SHIP SENSOR REQUIREMENTS FOR PERISCOPE DETECTION

The multisensors envisioned in the conceptual approach include a variety of radar(RF), infrared(IR), and electro-optic(EO) sensors for surveillance, search, and tracking tasks. Each of these tasks essentially requires involved sensors to preform detection function. High-resolution radars with high-speed scanning antennas, either surface objects in sea clutter by decorrelating the clutter echoes[5]. Although offering good probability of detecting the target, radars covering 360 degrees often demonstrate unacceptably high false alarm rates. High resolution laser based active electro-optical(EO) systems offer promise, but may be ineffective as a searching sensor without being designated by other sensors for capturing maximum direct target reflections. Passive IR sensor systems with high sensitivity may provide the capability to examine a potential periscope at high resolution but probably at the price of physically large optics and cost. Operating in conjunction with a high resolution radar, however, passive IR sensors at an appropriate resolution and sensitivity may assist to categorize the contact as either a confirmed target or clutter with a significant improvement in the overall system level false alarm rate. Conceptually, the passive IR detectors will provide single or dual band information about the temperature statistics on a particular bearing. These detectors will provide added imaging information on a designated basis. Given the fine spatial resolution of the radar, passive IR, and laser systems, a geometric and time correlation may produce a very accurate classification of coherent point returns even though the duration is fairly short and modulated by the ocean surface. However, only when the individual sensor characteristics are fully optimized based upon the performance requirements for the fused system, will the benefits of sensor fusion be fully realized. In order to optimize the integration algorithms and sensor control strategies for optimal system performance, it is essential to carefully specify the requirements and characteristics of the sensor themselves. Here, we discuss some specifics of the target and the individual sensor requirements with respect to the target detection capability.

3. RADAR

The threat target is envisioned to be physically small when exposed it extends above surface anywhere between 0 to 5 feet from the mean sea level. Given a detection by any sensor, the system requires the associated resolution (spatial/temporal) to be granular. This granularity requirement implies large bandwidth transmitters and receivers. Also, desired angular resolutions require very narrow beamwidths. In order for classification to occur via spatial/kinematic techniques, the required resolutions may push all known radars in bandwidth and beamwidth. The body of targets (or other extendable) appears for short durations and is buried in sea clutter. Actual exposure times will depend on several factors including the experience and vulnerability perception of the threat vessel commander, microwave(RF) detections by mastmounted Electronic Support Measures(ESM), and sea state/weather conditions. Additionally, the surface ship application only allows for sensor mounting heights up to the ship's existing mast height. This mast height factor corresponds to surface grazing angles of much less than 1.0 degree for any plausible detection range. These conditions create clutter properties which are very unique and poorly characterized. For a fully developed sea, the sea surface spectrum can be represented in terms of the Pierson-Moskowitz spectrum [6]. From the analysis shown by Tonkin and Dolman [7], a shadowing effect causes the fluctuations in the radar cross-section, making performance predictions particularly difficult. As described in Reference 7, the mean height relative to the mean sea level $\langle h* \rangle$ of the lowest visible point on the target for each wave train may be found as a function of the grazing angle. The numerical approximation to the resulting mean lowest visible height is

$$\langle h* \rangle = 0.26\ h^{1/3} \exp(-85\psi)$$

where ψ is the grazing angle (measured in radians from the ship) and $h^{1/3}$ is the significant peak-to-trough wave height. In addition, radars operating at low grazing angle exhibit extremely nonlinear relationships in backscatter returns, correlation statistics, and specular multipath. These relationships all yield very low signal to clutter ratios and clutter statistics that yield false alarm rates that can be fairly significant. In addition to strong nonlinear clutter returns, the atmospheric propagation effects including ducting condition are expected to vary, causing fluctuations in effective tactical ranges.

4. PASSIVE IR

This sensor provides passive IR imaging information (elevation and azimuth of a target) in a search sector. Each detector element maps an instantaneous field of view and a collection of these elements maps the entire field of view. Thus, a vertical array of individual elements occupies the field of view the optical aperture with an azimuth coverage equivalent to the azimuth coverage of a single element and the elevation coverage equivalent to the sum of the elevation coverage of all elements stacked in the array. If scanned, the sensor will extend the azimuth coverage from one instantaneous field of view to the entire scanned sector. If starting, as in a focal plane array(FPA)[8], the sensor has the search sector(which is the field of view) covered without scanning. This sensor is expected to be designated primarily by a radar and will in turn designate an active EO sensor for finer localizations of targets and classification verification. Since the atmospheric propagation characteristics vary with spectral band, multispectral IR needs to be considered.

5. ACTIVE ELECTRO-OPTICS

This sensor provides target range, azimuth information and/or elevation within the laser beam path. Although various forms exist, the active EO sensor envisioned in the conceptualized system incorporate a high resolution (thus narrow beam) laser as an illustration for discussions. This sensor is expected to be designed primarily by a high resolution passive IR sensor to maximize capturing direct skin reflections. Also called RADAR or laser radar [9], the active EO sensor generates laser beams (either continuous wave (CW) or pulsed) when designated on an area of interest to evaluate a detection event and paints the spatial extent of the laser beam. It is often employed with a single transmitter and receiver located adjacent to each other although up to a four pair system has been marketed. A LASER can be pointed to the direction of interest by means of mirror movements. If mirrors are used for mast weight considerations, the systems's performance may be vulnerable to platform vibrations and limited by the dynamics resolutions of the mechanical subsystems. This sensor may be designed for sensitivity to a particular set of optics such as those contained in periscopes for target feature discrimination. Ceratin features that are representative of subject targets are detectable at various ranges as point source targets while other objects that generate skin reflections may have some spatial extensions. The availability of various discriminating features is determined by the power requirement. the pulse repetition frequency(PRF) requirement, the resolution requirement, target characteristics, atmospheric propagations, and the system stability requirement. In addition, various spatial and kinematic detectors and detection algorithms are critical to the classification problem. An increase in PRF may allow sea-clutter suppression by decorrelation techniques.

6. SYSTEM DESIGN GOALS

Any standalone sensor tasked to resolve and discriminate a target detection from clutter, transients, and false targets will be greatly stressed. Therefore appropriate sensor fusion algorithms need to be developed to permit the use of more technically feasible and affordable sensors. By employing an optimal designation hierarchy among the three sensors discussed, it is possible to perform the geometric and time correlation of point source detections that are consistent and non-extended. An efficient operator and machine interface(OMI), designed to provide store/recall processing for operator interaction with any automatic threat event, will be useful during exercises. Due to the high resolution sensors employed, either mechanical and/or electronic synchronization and stabilization of sensor data may be critical in a dynamic shipboard environment. Consequently, the specific control structures that support synchronization, stabilization and operator interaction will need to be developed. The envisioned system must be capable of day/night target detection in any weather condition under which effective fast boat threat use is possible. The specific mission capabilities include:

(a) Day/night operation under weather conditions allowing tactical advantages.
(b) Automatic detection and classification.
(c) 360 degree azimuth coverage.
(d) High probability of detection.
(f) Low false alarms.

7. A FUNCTIONAL MODEL OF ENVISIONED MULTISENSOR INTEGRATION SYSTEM

The envisioned multisensor integration system assumes three generic shipboard sensors(sensor 1, sensor 2, and sensor 3) that view the same search volume - though not necessarily simultaneously, which contains multiple moving targets of different types(class). Although there are a number of architectural alternatives, we present here the simplest form of a distributed decision structure where a global decision is applied by fusing sensor level decisions.

Figure 2 hows the primary elements of the model and illustrates how the functions of detection, classification, and association estimation form the kernel operations of data fusion. Note that the model distinguishes three levels of processing functions. At the first level, detection processing occurs prior to the central data fusion block. Using a variable threshold setting to filter the raw data, the detection block reduces the maximum number of detections under the prevailing clutter environment(e.g. white caps, solar glint, frolicking dolphins, birds, and some man-made objects). At the second level is the classification function. By cascading a number of discrimination techniques(e.g. track velocity, high range resolution signature, phase and doppler signature, polarization signature, and other advanced techniques) there is good confidence that most background targets such as surfaced but not frolicking dolphins and navigation buoys can be disseminated from periscopes. It will also be possible to avoid throwing-out most periscope detections. The output of the classification block consists of positions, velocities, and classification of targets for associating with existing tracks in the third level processing function. The distributed decision structure implies that spatial and temporal association algorithms are needed wherein a limited amount of individual sensor observations and decisions (intrasensor correlations) are made at the individual sensor level prior to the global observations and decisions made at the system level(intersensor correlations) among employed sensors. By establishing a database from detailed measurements of the treat signature (statistically/dynamically), a series of characterizations can be made to determine the actual signature for each frequency band as a function of the available environment and processing.

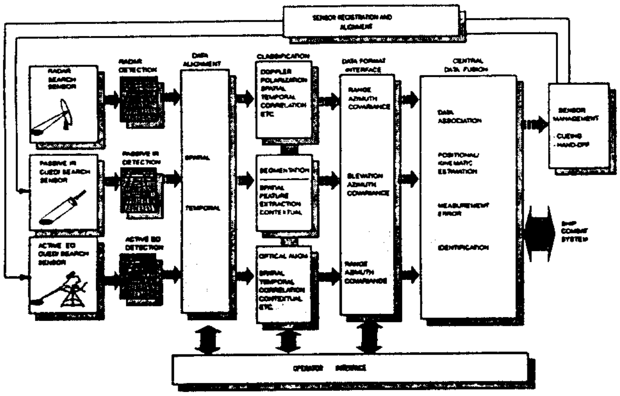

Figure 2

8. CONCLUSIONS

An integrated shipboard multisensor concept involving the fusion of radar, passive IR, and active EO sensor information for the detection of fast-moving small surface object has been discussed. The advantage of this approach follows from the synergistic use of the three sensors against the show moving, briefly exposed, low radar-cross-section(RCS) targets and extendables. The system concept revolves around the radar as the primary search sensor designating a passive IR sensor, and the passive IR sensor then designating the active EO sensor which in turn can look for target specific signatures. A major challenge is the optimal resource scheduling that maximizes detection ranges while minimizing false alarms. Since a finite time will have passed from a designation process, the occurrence of more designations will decrease the designated sensor's time-on-target, potentially diminishing interrogation opportunities. With the short exposure times of subject targets, the individual module's processing time will need to be closely examined. The second element of challenge concerns the data registration. The benefits of integration are fully realized only when the additional sensor information is applied to a common reference frame. Even with the advent of high resolution gyroscopes, the sensors may not be able to mechanically register with a common reference frame due to the insufficient resolution capability of the gyroscopes, the sensor platform's vulnerability to calibration errors and environmentally induced vibrations, and each sensor's unique characteristics including the resolution capability. Therefore, an electronic methodology incorporating various imaging technologies needs to be examined. Third, the benefits of sensor fusion are obtained only when the individual sensor characteristics are fully optimized based upon the performance requirements for the fused system [10]. In order to optimize the integration algorithms and sensor control strategies for optimal system performance, it is essential to carefully specify the requirements and characteristics of the sensors themselves. Another important challenge is the enormous amount of data flowing from sensors to each of the individual processors, including the data fusion processor. The shear amount of detection data will undoubtedly quickly fill the hypothesis generator. Thus, an efficient hypothesis pruning technique will be needed. Again, the overall system should be able to fully process all incoming data and timely generate appropriate command and control information so that a maximum detection range can be achieved against briefly exposed targets of interest.

REFERENCES

[1] Tenney. R and Sandell. R. Jr "Detection with Distributed Sensors" *IEEE Trans. on Aerospce and Electronic Systems,* Vol AES-17, July 1981

[2] Chair. A and Varshney. P "Optimal Data Fusion in Multiple Sensor Detection Systems" *IEEE Trans on Aerospace and Electronic Systems,* Vol AES-22, No 1, january 1986.

[3] Thomopoulos. S, Viswanathan. R, Bougoulias D. "Optimal Decision Fusion in Multiple Sensor Systems" *IEEE Trans on Aerospace and Electronic Systems* Vol AES-23, No.23, No 5, Semptember 1987.

[4] Luo. R, and Kay M, "Multiple Integration and Fusion: Issue and Approaches" *Proceedings of SPIE-Sensor Fusion* Vol 931, Orlando, April 1988.

[5] Croney. J, and Woroncow A, "Radar Polarization Comparisons in Sea-Clutter Supression by Decorrelation and Constant Alarm Rate Receiver" *The Radio and Electronics Engineer,* Vol 38. No 4. October 1969.

[6] Alpers. W, "Monte Carlo Simulations for Studying the Relationship between Ocean Wave and Synthetic Aperture Radar Image Spectra" *J Geophysics Res,* 88C 1988.

[7] Tonkin. S, and Dolman. D, "Sea Surface Effects on the Radar Return from a periscope" *Controller HMSO* London, 1989.

[8] Sribner. D, Longmire. M, and Kruner. M, "Analytic Modeling of Starting Infrared Systems with Multidimensional Matched Filters" *SPIE* Vol.890 Infrared Systems and Components II. 1988.

[9] Yariv. A, Introduction to Optical Electronics, *Holt Rinehard Winston, Inc.,* 1971.

[10]Krueger,K. and Stapleton,R., "A Multisensor concept for Detection of Low-Flying Targets", *NAVSWCDD Technical Digest, Dahlgren,* Va, Sept 1992.