Moving Target Indicator (MTI) Applications For Unmanned Aerial Vehicles (UAVS)

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KEYWORDS

Unmanned Aerial Vehicles, UAVs, Moving Target Indicator, MTI, GMTI, MMTI, AMTI, UAVB, Battlelab, DoD, Synthetic Aperture Radar, SAR, TESAR, JEFX, JSTARS, Cross-Cueing, situational awareness, Predator.

Abstract -- **This paper provides an overview of Moving Target Indicator (MTI) applications and employment on DoD Unmanned Aerial Vehicles (UAVs). The ability to receive MTI data on ground, maritime/littoral or aerial moving systems significantly enhances the ability of a UAV to locate, track, classify, and identify enemy targets or platforms of interest. An overview of the United States Air Force (USAF) UAV Battlelab's (UAVB) initiatives utilizing MTI applications is discussed. Results from these demonstrations and tests are presented including a synopsis of warfighter comments and requirements. An overview of the capability to utilize collaborative or situational awareness (SA) tools/systems in the management and dissemination of this information/data is also presented. Additional discussions surrounding other UAV systems and their mission applicability are presented and include ground, littoral and air MTI applications.**

I. INTRODUCTION

The Unmanned Aerial Vehicle Battlelab (UAVB) is chartered with researching and evaluating innovation as it applies to enhancing the capabilities of UAVs in USAF employment. The UAVB was established in July 1997 to "rapidly identify and demonstrate the military worth of innovative concepts that exploit the unique characteristics of UAVs to advance Air Force combat capability." The UAV Battlelab explores these concepts through demonstrations of innovative technology or the application of existing technology in new ways to UAV operations. Originally viewed as a sensor/surveillance platform, the UAV has reached a new era where it has become not only acceptable, but desirable for the UAV to accept new mission tasks–both combatant and noncombatant-that might be enabled through new technologies and new concepts of operations. Advances in UAV employment must parallel those of other military concepts of operations, platforms, payloads, weapons, systems and technologies. In lieu of these advances, future UAV operations will be required to satisfy the entire spectrum of conflict.

One specific area of interest that has been closely examined by the UAVB has been in the area of cross-cueing applications, with specific interest in the area of Moving Target Indicator (MTI) applications. The capability for any platform or system to successfully locate, track, classify and identify a system of interest is significantly increased when a wide area surveillance system is provided for initial detection and information on the system or platform of interest. Amplifying information about the system such as current location, heading, and velocities all contribute to the success of detecting and locating the system of interest. One specific application of this cross cueing approach takes advantage of wide field of view MTI sensors to cue narrow field of view electro-optical (EO) and infrared (IR) sensors. The MTI sensors provide a wide area search system and coarse information about potential targets sufficient to cue the narrow field of view EO and IR sensors that can continue the process of tracking, classifying, and identifying potential targets.

An overview of two UAVB initiatives utilizing MTI applications is presented in this paper. The first initiative, Joint Surveillance Target Attack Radar System (JSTARS) – UAV Cross Cueing, focused on receiving a satellite downlink of JSTARS MTI data to cross cue a UAV. The second demonstration, MTI Enhancement for Predator, focused on internal cross cueing between the United States Air Force (USAF) Predator's Tactical Endurance Synthetic Aperture Radar (TESAR) and its electro-optical/infrared (EO/IR) sensors. Although the focus of these efforts concentrated on MTI cross cueing applications and the collection, management, display and dissemination of the data, the scope of these demonstrations varied considerably. Primary considerations for the first initiative included cross cueing from secondary sources and also focused uniquely on Ground MTI applications. Primary considerations for the second initiative focused on internal cross cueing and included ground, littoral and aerial applications.

II. MTI APPLICATIONS

In general, the motion of a system of interest, such as a

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
14 APR 2005	**N/A**	**-**

4. TITLE AND SUBTITLE	
Moving Target Indicator (MTI) Applications For Unmanned Aerial Vehicles (UAVS)	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Electronics Engineer ISR Division USAF UAV Battlelab**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001798, Proceedings of the International Conference on Radar (RADAR 2003) Held in Adelaide, Australia on 3-5 September 2003., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

vehicle or a vessel, causes the radar signature of the moving system to shift outside of the normal return of a radar image. This shift in frequency, referred to as Doppler shift, is used to distinguish fixed or stationary systems from moving systems. Radar that utilizes the Doppler shift data is described as MTI radar or pulse-doppler radar. The primary differences between these radars are based upon the range and frequency measurements. In general, an MTI radar has a Doppler frequency measurement that is ambiguous (in which multiple-time-around target echoes occur) with a range measurement that is unambiguous (speeds within expected range gates). With a pulse-Doppler radar, the Doppler frequency measurement is unambiguous and the range measurement may or may not be ambiguous.

Other specific attributes of MTI radars depend on the type of radar itself, whether it is stationary or in motion, the environment, and other similar attributes. For apparent reasons, the detection of a moving target is more difficult for a radar in motion, or airborne radar, than for a stationary radar. Other factors such as the speed of the target in reference to the environment (clutter), size, radar cross section, etc. all contribute to the types of requirements and methodologies used in MTI applications.

In the past, a vast majority of MTI applications have been primarily associated with Ground MTI (GMTI) applications. However, recent advances in the areas of maritime/littoral and aerial/airborne MTI applications have been developed and continue to be refined and applied to UAV concepts. Specific applications relative to GMTI include locating, tracking, classifying, and identifying moving vehicles based upon the augmenting data obtained by the radar. Amplifying data such as speed and heading provide indicators to operators about projected paths or roadways used by the vehicles of interest. Additional target 'profiling' can be accomplished based upon this amplifying data. For example, vehicles traveling in excess of 80 k/h would not be representative of tanks.

Specific applications relative to maritime missions include locating, tracking and identification of boats or vessels of interest. Possible candidate targets of interest may include military vessels, drug-carrying boats, refugees or enemy special forces. As indicated by the breadth of these candidate targets, the type of mission may vary significantly for maritime moving target indicator (MMTI) applications. Similar to GMTI profiling, MMTI profiling may be accomplished and may include the monitoring of routes, methods of operations, speeds, etc. Based upon these factors, assumptions governing the type and intent of the vessel may be determined.

A variety of techniques and systems have been developed to automatically detect moving targets and to extract this amplifying information such as location, speed, size, and Radar Cross Section (RCS) from targets of interest. Two specific platforms of interest, the JSTARS side-looking phased array radar and the Predator TESAR radar, both provide multi-mode MTI wide area surveillance and synthetic aperture radar (SAR) capabilities. These radars, which were the primary radars used in the UAVB demonstrations, are able to collect the amplifying information described above and use it in the process of locating, tracking, classifying and identifying targets of interest. The following sections describe the use of this data in the areas of MTI applications for UAVs.

III. JSTARS – UAV CROSS CUEING

A. Scope

The main objective of the JSTARS-UAV Cross Cueing initiative, demonstrated by the UAVB, was to evaluate the military worth of transmitting JSTARS GMTI data to a Predator UAV Ground Control Station (GCS) to rapidly locate, track, classify and identify mobile ground targets of interest. The demonstration was accomplished by transmitting via satellite JSTARS GMTI data to a Predator GCS. In the GCS, the GMTI cross cueing data was overlayed, in real-time, on a three-dimensional terrain visualization tool, to allow UAV operators to rapidly locate a target and then slew the Predator's EO/IR sensors to the mobile ground target of interest. In support of this effort, the demonstration utilized a commonly used visualization tool, *PowerScene*, augmented with standard national imagery products. The combination of the cueing data and the national products in a fused environment provided a robust environment for UAV operators to locate, track, classify, and identify targets of interest.

B. Approach

This initiative was accomplished in a multi-phased approach that included: Phase I – Laboratory Demonstration, Phase II – Functional Flight Phase, Phase III – Demonstration Execution Phase and a Modeling & Simulation Phase. The initial phase of this effort consisted of conducting a laboratory demonstration to ensure compatibility of the Predator exploitation support data (ESD) and JSTARS MTI data into the *PowerScene* system. The preliminary requirements of this effort consisted of developing interface software to read and format MTI data into compatible formats.

Phase II of this effort demonstrated the end-to-end system and architecture functionality check as shown in Figure 1. This phase consisted of a direct down-link (DDL) demonstration and exercise participation events that included dedicated live-fly flights by participants to validate the concepts of operations (CONOPs), communication interfaces and to develop a baseline system architecture.

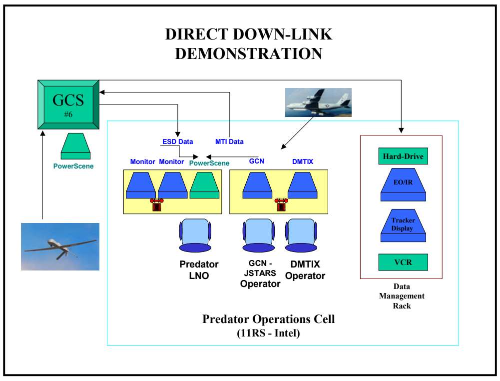

Fig. 1 JSTARS – UAV Cross Cueing Architecture

As part of this effort, GMTI data from JSTARS was fused into a *PowerScene* system in the Predator GCS. As part of this fusion process, *PowerScene* ingested MTI data from JSTARS and overlayed this data into a fused picture with amplifying products. These products included standard National Imagery and Mapping Agency (NIMA) products such as Digital Terrain Elevation Data (DTED) and Controlled Imaged Based (CIB) data. A sample Power Scene display with fused MTI data is shown in Figure 2. As shown, the MTI data, as expected, lines up with the roadways on the CIB data. This provides a direct Area Of Interest (AOI) cue for the UAV operator. This phase, and the subsequent demonstration phase, was executed on the Nevada Test and Training Range Complex with dedicated flights and flights flown as part of USAF Green Flag exercises.

During this phase of the initiative, architecture and system functionalities were evaluated and adjusted as appropriate. For example, data rates, sampling size, fusing approaches, mapping options, and operator interactions and tasks were evaluated. Feedback from operators on techniques and procedures were received and a standardized CONOPS was developed in preparation for the Phase III demonstration.

The operational utility of this initiative was primarily demonstrated and evaluated through Phase III operations. The Phase III effort, which was conducted on the Nevada Test and Training Range Complex during Joint Expeditionary Force Experiment 2000 (JEFX 00), evaluated the utility of GMTI cross cueing with *PowerScene* (including NIMA products) by UAV operators. This robust experiment environment, which included hundreds of live participants, allowed the operational utility to be examined as part of real-world architectures, and operations. A key aspect of this experiment, and of our evaluation criteria, focused on Time Critical Targeting (TCT) CONOPs. The capability to rapidly locate, track, classify, and identify time critical targets was key to evaluating the overall initiative.

The final assessment phase of this effort included a modeling, simulation, analysis and post-assessment effort based upon findings and processes developed and documented from previous phase efforts. The scope of this effort included a comparison of a baseline scenario, in which no JSTARS MTI cueing for UAV platforms occurred, versus an enhanced scenario, in which cross cueing occurred. Primary modeling aspects focused on the cross cueing processes and the interaction among participants of those processes. The effort was conducted utilizing the U.S. Army Space and Missile Defense Command's Extended Air Defense Simulation (EADSIM) model. A South-West Asia (SWA) scenario based upon the Defense Planning Guidance (DPG) Major Regional Conflict – East (MRC-E) was used.

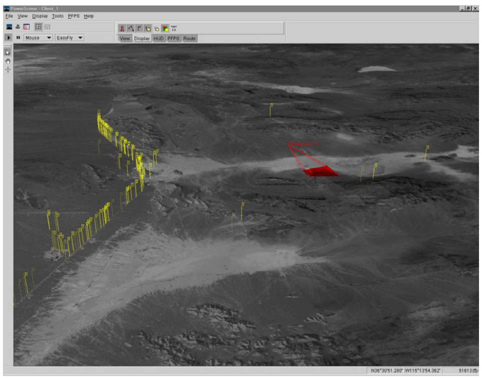

Fig. 2 PowerScene with MTI Data

C. Objectives and Results

As previously mentioned, the overall objective of this effort was to evaluate the utility of using GMTI data from JSTARS to cross cue a UAV to locate, track, classify, and identify targets of interest. In doing so, the primary factors used in evaluating this utility included understanding and assessing the processes, timelines and requirements associated with locating, tracking, classifying, and identifying targets. Included as part of the simulations were the communication and mission requirements associated with UAV operations.

In evaluation of this effort, various objectives and measures of interest were developed, evaluated and used to determine the utility associated with MTI cross cueing. In doing so, specific objectives and measures of interest varied among the phase activities. Phase III demonstration objectives included technical and operational objectives and the measures associated with accomplishing those objectives in an operational exercise and experimentation environment. The modeling and simulation phase objectives, which differed significantly, were focused upon determining the overall utility of cross cueing UAVs in a mission-level environment. This assessment, which provided a forum for examining factors associated with cross cueing, and supporting the contention of cross cueing among platforms, in general, is beneficial. The following sections provide a series of tables and figures that summarize the objectives and results of Phase III demonstration and modeling and simulation effort.

Table 1 provides a summary of the flight operations (Phase III) technical results. As indicated, all objectives associated with technical merits associated with flight operations were accomplished. Specific objectives such as ingesting and overlaying MTI data, and utilization of these products by UAV operators in the locating, tracking, classifying, and identification process provide a technical assessment of the feasibility of the Cross Cueing CONOPS. However, these only provide an assessment of the technical feasibility, not the operational (user) utility.

As shown in Table 2, a summary of the operational objectives and measures of effectiveness provide a more robust measure of the utility of these combined concepts. As indicated, the overall effectiveness of these concepts were rated effective.

OBJECTIVES	RESULTS
1. Demonstrate the ability to overlay JSTARS MTI radar data into PowerScene.	Green •
2. Demonstrate the ability of the Crew to utilize the combined picture to locate, identify, and track targets.	Green •
3. Demonstrate utility of high-speed ESD for data correlation and position accuracy.	Green •
4. Demonstrate utility of video imagery and *PowerScene* precision targeting.	N/A
5. Demonstrate Predator's capability to provide timely and accurate data to C2 sources.	Green •
6. Demonstrate the utility of using collaborative white board.	Green •
7. Demonstrate JSTARS-UAV cross cueing efforts for third party usage.	Green •
8. Evaluate JSTARS-UAV-*PowerScene* concept with ISR Battle Manager.	Green •

Table 1 - Flight Operations Summary

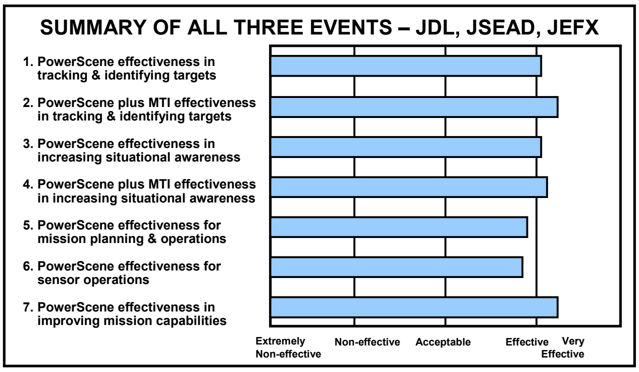

Table 2 - Operational Summary

In determining the objectives and measures of merit associated with the modeling and simulation effort, emphasis was placed on those measures that provide an opportunity to evaluate the utility of cross cueing benefits for a specific and predefined mission. In doing so, the measures emphasized in this analysis were more 'bottom-line' type measures, which focused on attrition, engagements and detection measurements. The following tables provide a comparison between the baseline (no cueing) scenario and the enhanced (cross cueing) scenario results. Obvious objectives associated with this effort include minimizing friendly (blue) attrition, maximizing hostile (red) attrition, etc. As shown in Table 3, and as expected, the enhanced scenario cases afforded additional engagement opportunities and attrition of hostile forces by friendly forces. Additionally, the overall number of detections by blue forces and UAVs were increased as shown in Table 4.

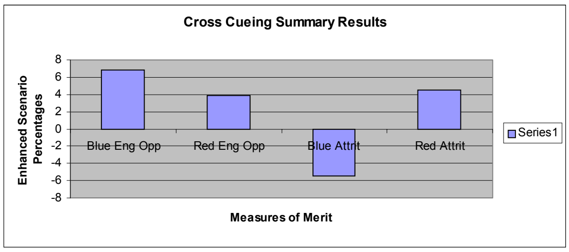

Table 3 - Offensive Summary

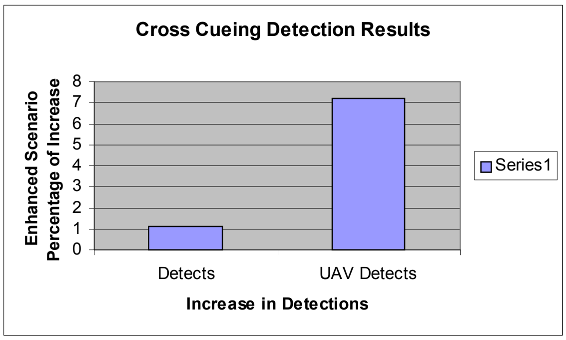

Table 4 - Detection Summary

In summary, this initiative through demonstrations and modeling, simulation and analysis was able to demonstrate and prove that the cross cueing, integration and displaying of JSTARS' GMTI data in a visualization environment improved the capability of UAV operators to locate, track, classify, and identify mobile targets of interest.

IV. MTI ENHANCEMENT FOR PREDATOR TESAR

A. Scope

The MTI Enhancement for the Predator TESAR initiative demonstrated by the UAVB focused on internal cross cueing between the Predator's Tactical Endurance Synthetic Aperture Radar (TESAR) and its electro-optical/infrared (EO/IR) sensors. The objective of this demonstration was to evaluate the military worth of overlaying real-time internal or local MTI data on a three-dimensional terrain visualization tool, to allow UAV operators to rapidly locate, track, classify and identify mobile targets of interest including ground, maritime/littoral and air vehicles. The main difference between this effort and the previous demonstration, was this effort entirely relied on the UAV's own capabilities and did not require off-board sensors and communication links. The objective was to demonstrate that the much wider field of view of the TESAR radar would greatly enhance the detection capabilities of the Predator crews from their current heavy dependence on the narrow field of view EO/IR sensor.

B. Radar Background

The Tactical Endurance Synthetic Aperture Radar (TESAR) is a strip mapping SAR that provides continuous imagery. The focused imagery is formed on-board the Predator air vehicle, compressed and then transmitted to the Predator Ground Control Station over a KU band data link. There are 2 modes of SAR operation; Mode 1 provides a non-centered strip map mode where the map center moves with respect to the aircraft motion; and Mode 2 is the classic strip map mode where mapping occurs over a predetermined scene centerline, irrelevant of the aircraft motion. In addition to the SAR modes, a MTI mode exists and was incorporated and integrated into the Predator system for the UAVB demonstration. The MTI mode of operation provides for an extended wide area search range capability over the existing EO/IR systems for mobile ground, littoral and low-flying targets. The MTI mode extends the range of the TESAR system out to approximately a 25 km detection range with scan coverage from 45 to 270 degrees. Amplifying characteristics such as minimum discernible target radial velocities, scan rates, etc., are inherent to the MTI data.

Specific advantageous attributes associated with the TESAR radar, as well as with most SAR radars include an adverse weather detection capability. Although attributes such as cloud, haze, rain, smoke and other battlefield obscurants often prohibit the use of standard EO/IR radars, SAR radars are able to successfully handle these factors often times with little to no degradation.

C. Approach

This initiative, nicknamed STINGRAY for the maritime MTI applications, was successfully completed in two phases. Phase I consisted of a risk mitigation phase where a TESAR system was installed on a surrogate manned platform to assess both ground and littoral/maritime mobile detection capabilities. The ground portion of Phase I activities were executed on the Eglin Range Complex and included a robust target set of real-world threat systems. Phase I maritime assessment was performed out of Boca Chica Air Field, FL and included a variety of maritime systems. Phase II, which integrated the TESAR MTI capability into the Predator Air Vehicle and Ground Control Station (GCS), focused exclusively on ground mobile targets and was successfully executed on the Nevada Test and Training Range Complex.

In executing Phase I, the primary focus was to characterize the performance of the TESAR MTI radar and develop a notional concept of operations. This phase was conducted using an RQ-1A Predator TESAR system installed on a Northrop Grumman Britten-Norman BN2B-20 Islander manned aircraft. The Ground MTI (GMTI) assessment missions were flown against a variety of stationary and mobile military targets. Both cooperative and non-cooperative target sets were used and included actual "threat" or foreign system vehicles. The maritime MTI assessment was flown against a variety of stationary and mobile target sets including real world systems of interest. Both cooperative and non-cooperative target sets were also used including a captured go-fast drug boat. During both the maritime and ground assessment phases, positive results were easily achieved and led to a follow-on Phase II execution.

Phase II demonstration assessment consisted of two primary phases, a radar characterization phase and an operational assessment phase. The primary ground mobile targeting scenario of Phase II consisted of two assessment periods, a baseline period, in which no MTI cues were provided, and an enhanced period in which MTI cueing occurred.

Several concepts of operations (CONOPs) for cross cueing were examined during the execution of the demonstration to include visual, verbal and electronic collaboration. Visual cross cueing was executed by utilizing the TESAR Situational Awareness Map (SAM) display which provided not only a visual location of the target of interest, but also amplifying information about the target such as the velocity, radar cross section, heading, etc.

Additionally, visual cueing was provided on a three-dimensional overlay that displayed MTI hits of the mobile targets. Verbal cross cues between the TESAR operator and EO/IR sensor operator, which are used frequently during normal Predator operations, were also used successfully on a number of occasions. However, this method required some tedious interaction and coordination between the sensor operator and the TESAR operator.

The final CONOPs employed during the assessment included an electronic white boarding / collaboration technique utilizing PowerScene, a three-dimensional visualization and situational awareness tool. The PowerScene display, which uses various standard NIMA products, overlays the MTI data onto the graphical environment. It provided a much better visual depiction of where the mobile targets of interest were located. For example, the operator's were able to view the MTI 'dots' or targets as they lined up on the roadways. This clear, visual depiction provided an immediate location to cross cue the EO/IR sensors as shown in Figure 3.

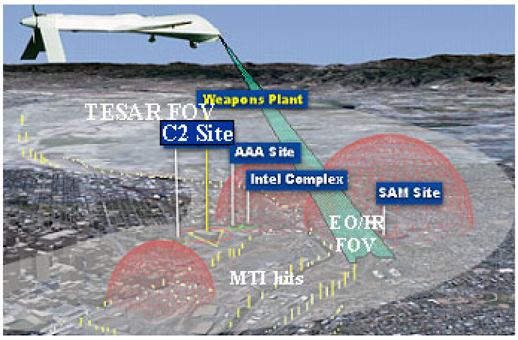

Fig. 3 STINGRAY Situational Awareness Display

D. Objectives and Results

As mentioned above, the overall objectives associated with this initiative included determining the military worth of overlaying real-time internal or local MTI data on a three-dimensional terrain visualization tool, to allow

UAV operators to rapidly locate, track, classify and identify mobile targets of interest including ground, maritime/littoral and air vehicles.

The results of Phase I clearly demonstrated these objectives in addition to providing significant information about the radar and a concept of employment. The qualitative results of Phase one demonstrated the need to proceed to the more rigorous second phase of the initiative.

For phase two, a comparison of the baseline (no cross cueing) and enhanced (cross cueing) was demonstrated over the Nevada Test and Training Range Complex. For both the baseline and enhanced cases, the Predator operators were directed to collect data on static targets with known locations. In addition, they were directed to be alert to any moving targets and that moving targets were their top priority. For both cases, 10 cooperative targets were executing specific paths that coincided with the preplanned Predator flight path. Throughout the baseline assessment, the operator's went after the static target set and collected approximately 75% of the assigned static targets. However, they were unsuccessful in detecting, locating or identifying any of the mobile targets. During the enhanced period, the operator's collected data on approximately 80% of the static target set and successfully detected, located, and tracked the majority of the mobile targets. Specifically, 7 of the 10 cooperative moving targets were detected when the MTI was activated. Compared to zero moving targets detected when the MTI was not activated.

The MTI mode was used for the initial detection of the mobile targets and then passed on to the Predator sensor operator for tracking and for target identification via the EO/IR sensors. Due to the TESAR's significantly larger detection field of view and range envelope over EO/IR sensors, it added a robust wide area surveillance capability to the current Predator system.

Feedback from the operators was very favorable with one indicating that this capability could be a huge help in Operation Southern Watch missions. The overall results of the demonstration clearly indicated that the capability to detect, track, classify and identify mobile targets using MTI mode of the TESAR enhanced Predator's operational capability.

V. CONCLUSION

Both of these demonstrations clearly identify the enhanced capabilities of using relatively wide field of view MTI radar systems to cue relatively limited narrow field of view EO/IR sensors. While each demonstration took a significantly different approach, both approaches drastically increased the situational awareness of Predator crews and enhanced the ISR capabilities of the USAF's Predator.

In current operations, Predator crews have very little awareness of the battlespace outside of what they get from 3rd party voice communications and the view they see from their own EO/IR sensor. The addition of MTI data, from off-board or on-board sensors, on a 3-D graphical software greatly expanded the Predator operator's understanding and awareness of the bigger battlespace. The operator's are able to identify roadways and paths that are or are not heavily used by enemy forces. They are able to identify lone vehicles from major troop movements. They are able to have a much wider field of view sensor provide very informative cues instead of just depending on the soda straw view from the EO/IR sensor in conjunction with the eyesight and training of the sensor operator. For all of these reasons, the success and utility of providing wide field of view cues to the Predator's EO/IR sensor was clearly demonstrated in both the JSTARS – UAV Cross cueing and STINGRAY initiatives.

While both demonstrations clearly enhanced the military utility of the Predator system, they were accomplished with significantly different approaches and each initiative has its own benefits and limitations.