A MIMO Radar Benchmarking Environment

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Abstract—With the growing amount of research being devoted to the concept of multiple-input multiple-output (MIMO) radar, there has been a lack of a common simulation and benchmarking environment for determining the viability and cost-effectiveness of MIMO radar architectures and algorithms. To this end, GTRI has developed a MIMO Benchmark environment to serve this purpose, which is to be made publically available to researchers in order to compare the performance of MIMO techniques with those of more conventional phased array radar systems. This paper describes the problem that the MIMO Benchmark is intended to be used to assist in solving, in the form of a new challenge problem for the MIMO community, as well as providing a summary of the architecture of the MIMO Benchmark infrastructure.[1][2][3]

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1. INTRODUCTION

With the successes in applying multiple-input multiple-output (MIMO) techniques to problems in communications, researchers have turned to the concept of applying similar techniques to radar, with comparisons to traditional phased array radars. While one may assume that the ability to obtain a greater number of degrees of freedom in observing and tracking targets will improve performance in the long run, such assumptions must be tested on a level playing field with existing technologies in order to determine their viability.

Benchmarks have been used to evaluate target tracking algorithms with respect to "real-world" problems such as finite sensor resolution, false-alarms, refraction, etc. GTRI has developed the initial version of a new MIMO Radar Benchmark based on similar radar benchmarking environments that GTRI has developed in the past. This extensible environment allows for the development of new MIMO architectures and algorithms in order to evaluate their respective costs and benefits. This environment has been built by working closely with researchers and engineers through various workshops[1][2][3][4] and conference calls. Researchers will have access to this initial version in order to construct and test MIMO techniques with a common environment and common performance metrics.

This paper is organized into the following sections: detail on the problem that is being addressed, a brief description of the infrastructure of the MIMO benchmark, and sample benchmark results.

2. PROBLEM STATEMENT

In order to provide a point of comparison between MIMO radar and, for example, existing phased array radar, a set of *standard scenarios* and a *challenge problem* should be established in order to place a constraint on what is deemed to be an acceptable solution to the MIMO problem. The MIMO Benchmark includes several practical tracking scenarios that may be used to evaluate the effectiveness of a particular technique or algorithm, as well as scenarios in which objects that can interfere with a particular tracking scenario can come into play.

This section gives a high-level description of the scenarios contained in the MIMO Benchmark, a description of a concept of operations for a MIMO tracker that gives an idea as to a solution for the MIMO problem, and a statement of a challenge problem in order to provide a target for researchers to use as a point of comparison.

Scenario Definitions

The scenarios included with the MIMO Benchmark have up to four ships equipped with S-band tracking radars. As one of the requirements for MIMO radar is the ability for each of the ships to communicate with each other, perfect communications are assumed for the time being. This assumption is in place in order to place focus on solving the initial problems that MIMO puts forward, instead of focusing solely on the communications aspect.

Each of these scenarios can contain up to four fighter planes that fly in formation as the targets that the radars are intended to track; these targets are given the designators F-1 to F-4. Finally, civilian aircraft may enter the picture as well, as up to three civilian airliners may be included within

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[2] IEEEAC paper#1143, Version 2, Updated 2010:12:20
[3] Work supported in parts by the ONR grant N00014-09-1-0054 and the Georgia Tech Research Institute.

a scenario; these targets are given the designators A-C. Table 1 shows how the different scenarios are composed from these sensors and targets.

Table 1 – Scenario Definitions

Number	Targets
1	F-1, A-C
2	F-2, A-C
3	F-3, A-C
4	F-4, A-C
5	F-1, F-2, A-C
6	F-3, F-4, A-C
7	F-1, F-2, F-3, F-4, A-C

The trajectories of the aircraft used in the scenarios as well as the positions of the ships on which the radars are mounted are shown in Figure 1; the particular formation and the intentional crossover of the truth objects is intended to exercise the ability of a MIMO tracker to discern and properly track closely spaced objects. To fully characterize the performance for a single scenario, the MIMO Benchmark allows for the running of a scenario across several Monte Carlo trials, the overall results being the average across all of the runs.

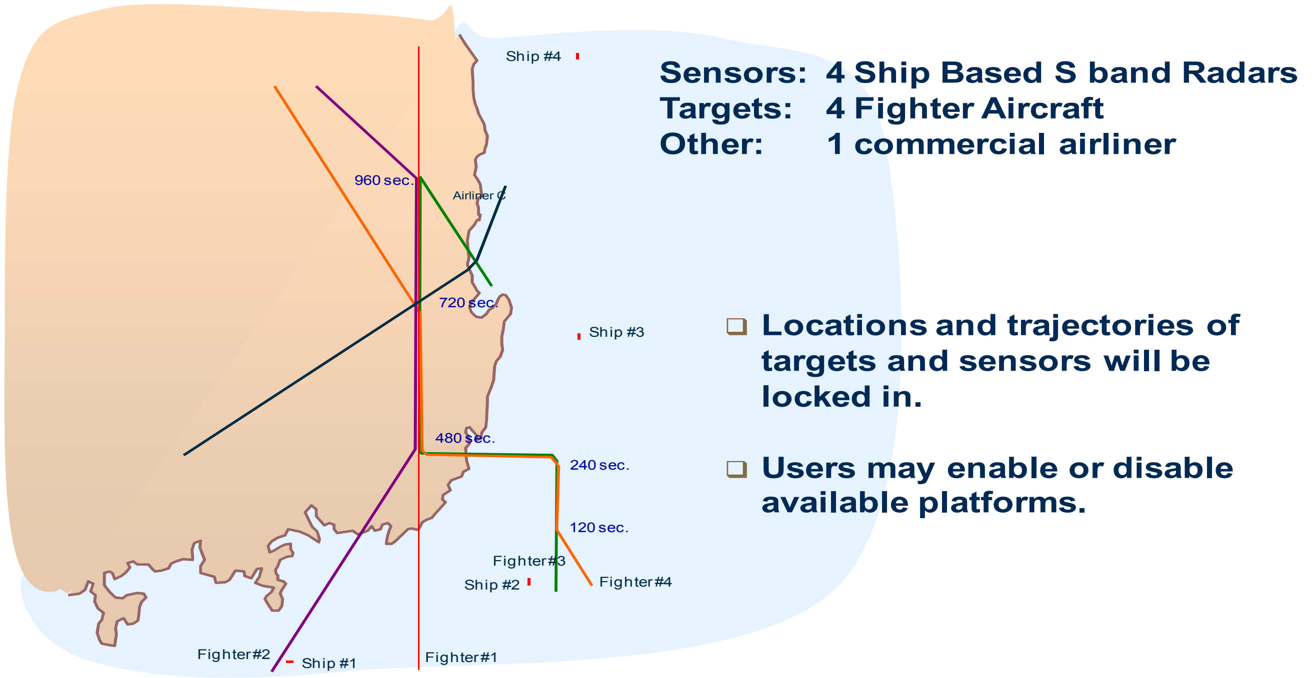
MIMO Tracker Concept of Operations

It is useful at this point to define a concept of operations for a general MIMO Tracker, based on the idea that, at its core, the concept of MIMO radar itself is "merely" a coordinated series of networked radar installations that are jointly illuminating a volume using orthogonal waveforms, and processing the returns more or less simultaneously. The device that is actually performing this processing is what is referred to as a MIMO Tracker.

Before target acquisition, each of the radars in the network will perform a monostatic search in order to locate targets. The results of the search, in the form of radar measurements, are sent to the centralized MIMO Tracker. The MIMO Tracker then processes these measurements in order for it to determine whether or not to initiate and maintain tracks based on them.

In order to update the tracks, the MIMO Tracker will initiate a synchronized *MIMO dwell* for the networked radars. This dwell will instruct a group of the networked radars to transmit a specific orthogonal, waveform at a specific time, while simultaneously instructing another group of radars (which may include the transmitters) to prepare to receive the bistatic returns. As with search, once measurements are processed from these returns, they are sent to the MIMO Tracker for track updates.

By default, when radars have nothing to do, e.g., the MIMO



Sensors: 4 Ship Based S band Radars
Targets: 4 Fighter Aircraft
Other: 1 commercial airliner

- **Locations and trajectories of targets and sensors will be locked in.**
- **Users may enable or disable available platforms.**

Figure 1 – Target Trajectories for Benchmark Scenarios

Tracker is busy with another group of radars, the radars' local processing will automatically place search dwells into their command queues. This will allow for the automatic acquisition of measurements which can also be sent to the MIMO Tracker for further processing.

Challenge Problem

With the scenarios and a concept of operations defined, a challenge problem[4] that can be investigated using the MIMO Benchmark can now be formally stated:

Given a scenario with a certain number of truth objects and a certain number of sensors, a specific MIMO tracker must maintain a 98% track completeness ratio, while minimizing energy consumed and dwell time by the sensors during runtime.

The *track completeness* metric is the ratio of targets tracked to the total targets present in a scenario; this can vary throughout the course of a run due to tracks being dropped, or targets simply not being tracked at all. Minimization of energy consumed and dwell time is purposely left vague in order to allow for proper exploration of the problem space; the challenge problem in sum allows for a great deal of novel approaches to be considered.

3. BENCHMARK INFRASTRUCTURE

The MIMO Benchmark infrastructure is similar to the infrastructure of past GTRI radar benchmarks, with some key differences; one of which is the internal operation of the sensor models. This section describes each of the components of the benchmark and how they interact and operate.

System / Sensor Architecture

The radars that are included in a specific scenario are simulated as multiple instances of a single, generic radar simulation. Like the other components in the MIMO Benchmark, the simulation instances handle communication and data updates using a queue of events that is populated by a variety of sources. In regard to radar operation, a particular radar dwell is represented by an *event object* that eventually leads to a beam of energy pointed at an area of the sky; as a result, range bins are then filled with returned energy; and subsequently *detection voltages* and then *measurements* (a type of aggregated detection) are generated from the returns. The measurements will eventually lead to a track being formed via a tracking method of some kind.

These operations may be summarized by the following steps that are executed by the radar model each time it processes a dwell request:

1. The positions of truth objects are transformed from a global reference frame, to target positions relative to bistatic steered beams.

2. The relative positions are combined with monopulse antenna positions and target signatures to generate complex I and Q voltage samples per resolution cell, which referred to as the raw *detection voltages*. For the monopulse radars in the MIMO benchmark, there are six of these voltages: sum-channel in-phase (I) and quadrature-phase (Q), azimuth-difference-channel I and Q, and elevation-difference-channel I and Q [5]. The symbols *I* and *Q* themselves refer to the real and imaginary parts of the output of the receiver; i.e., one should always remember that the detection voltages are complex values.

3. The detection voltages are converted into sine-space *detection primitives* through the use of monopulse direction of arrival estimation. The primitives are further converted into measurements through additional processing (clustering and centroiding); these measurements possess additional properties that may be used in track formation and update.

4. The measurements are passed to a "MIMO tracker" in order to estimate the states of the targets and form and update tracks. The behavior of this tracker is unspecified as it is up to the application developer working with the MIMO Benchmark.

Note that there is no mention of track formation per sensor; in the MIMO Benchmark; while the local sensors may form and maintain their own tracks; the MIMO tracker has the option at any time to force the sensors to halt tracking. The MIMO tracker then maintains individual tracks for each of the targets that it discerns. This MIMO tracker is a user-defined code module, further described in the section on Test Articles.

Figure 2 shows a diagram of the process by which the radar returns eventually become tracks. Note that the only segment that is exclusively a part of the MIMO tracker is the Track Filtering step.

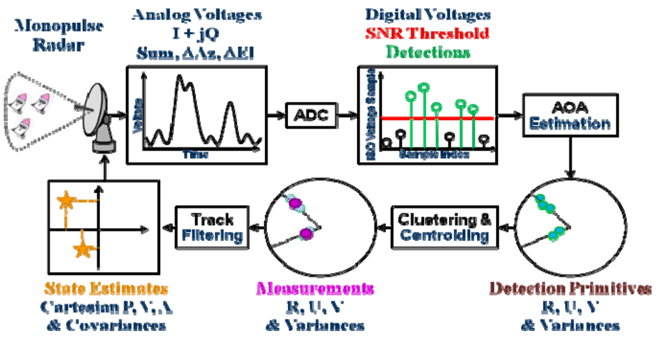


Figure 2 – Radar Model Infrastructure Overview[4]

The first step is accomplished by applying a series of coordinate transforms to a reference point in space with respect to truth, and generating a "beam position" in space relative to the bistatic steered beams of the radars. In the nomenclature of the MIMO Benchmark, this beam position is referred to as a *beam point*. This beam point is then used to locate a target on the radar's receiving face, as well as where it appears in the incident electric field's coordinate frame.

The second step generates the complex I and Q detection voltages as a result of the simulation of the range bins being filled by a target scattering the energy emitted by the radar. Figure 3 shows the relationships between the gains and the target's radar cross section (RCS) that are used to compute these complex voltage values.

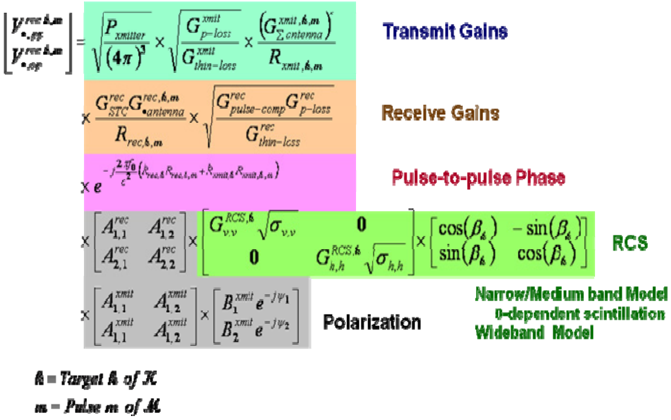


Figure 3 – Transforming Beam Position into Detection Voltages

The resulting sine-space detection primitives are then generated from the detection voltages by using a maximum likelihood monopulse direction of arrival algorithm.[6]

The final step, creating the measurements, is accomplished by first performing clustering and centroiding on the detection primitives. Clustering attempts to extract a single object from a clump of detections, while centroiding forms a measurement based on clustered detection primitives that may span range bins. In general, only two spanning detection primitives are considered when trying to determine if primitives across range bins are part of the same measurement. Once both processes have been completed, the potentially large number of detection primitives has been culled down to a more manageable number of measurements.

Finally, prior to sending the measurements to a tracker, they are optionally corrected for refraction and biases; note, however, that in this initial version of the MIMO Benchmark, this correction is not currently being performed. The measurements may then be fed into a MIMO tracker which may be using some type of filtering scheme in order to maintain tracks; for example, an extended Kalman filter (EKF)[6][7][8] or an interacting multiple model (IMM) filter[9].

Test Article

The users of the MIMO Benchmark require a method by which they can integrate their own tracking and signal algorithms and evaluate their performance using the sensor models; e.g. build the MIMO Tracker described in the Concept of Operations. To facilitate development of such a tracker, the MIMO Benchmark allows for an additional, user-defined module that fits alongside the other components of the infrastructure. This module is known as a "test article" or TA. Just like the sensor models and other parts of the benchmark system, the TA receives events and can also post its own events. The events that a TA typically receives include radar measurement and track information. Figure 4 shows how the TA is integrated into the logical flow of the other components of the benchmark.

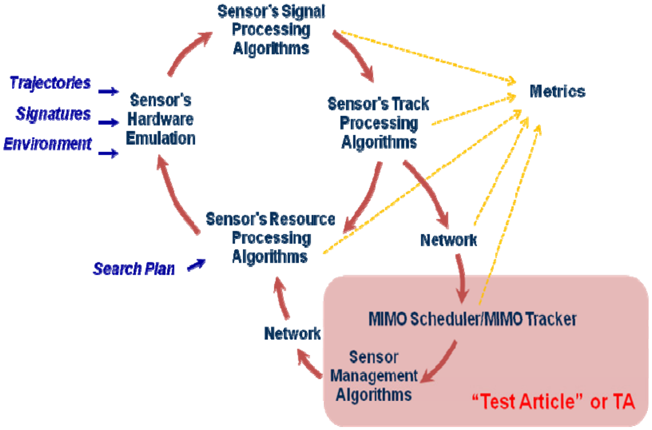


Figure 4 – MIMO Infrastructure Data Flow

As stated in the previous section, the sensor is run in an event loop and the results are passed down to the TA via messages which the TA can then interpret. The TA also has the ability to schedule a MIMO dwell event on the main

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[4] Missile artwork provided by Hannah Register.

simulation timeline. The MIMO dwell event results in a combination of a potentially multiple transmit requests and a set of receive requests being scheduled on the event queue. The resulting sensor detection primitives are then passed back to the TA for further processing, allowing the TA to generate its own measurements, and then form or update tracks based upon these measurements.

The MIMO Benchmark will provide a "default solution" that both illustrates how to create one of these TAs and how to approach solving the MIMO problem using the MIMO Benchmark.

Metrics

The MIMO benchmark allows the computation and plotting of some fairly standard tracking metrics along with some additional metrics for further characterizing radar usage and performance. This section describes the metrics in general, and how the usage and performance metrics are computed.

Air Tracking Performance Metrics—As the ultimate goal of a radar tracking network is to maintain accurate and unambiguous tracks of multiple objects, there needs to be a method of measuring how accurate and how pure these tracks are. As such, the MIMO Benchmark includes the ability to compute and plot the metrics [10][11][12]. The goal is for the track picture to have each object of interest to have exactly one track associated with it, with the converse statement that all tracks should map to one object of interest also being true. Thus, the metrics are used to quantify the deviation between reality and what the current track picture shows.

Examples of the air tracking metrics include:

- Track Completeness Ratio
- Redundant Track Ratio
- Spurious Track Ratio
- Cumulative Track Breaks
- Cumulative Track Switches
- Track Accuracy

Usage Metrics—Usage metrics are defined for radar dwell time spent and energy emitted. Note that both of these are only defined for transmit dwells; no official metrics for characterizing the costs as a result of receive dwells are currently in the MIMO Benchmark. They are computed by analyzing and extracting the relevant information from the dwell requests provided to the running instances of the radar models. Like the other metrics in the MIMO Benchmark, these metrics are collected over the times when tracks are scored (referred to as *scoring times)*; they are then normalized by the number of *scorable objects* (i.e. targets). Finally, they are averaged across all Monte Carlo runs. These operations are encoded in the equations to follow.

There are three different classes of performance metrics: per scoring interval, per sensor, and cumulative. As the names suggest, the latter two are power and time for the entire run for each of the sensors and for the entire run over all sensors. Note, however, that cumulative metrics are computed per scoring interval. Ultimately, the final two types are computed from the discrete scoring interval metrics, which are computed from the dwell requests. The following equations define the dwell time and energy emitted for that case:

$$T[m,j] = \frac{1}{N_{MC}} \sum_{k=1}^{N_{MC}} \left(\frac{1}{N_{SO,k}[j]} \sum_{i \in I_k[m,j]} \tau_{dwell,k}[m,i] \right) \quad (1)$$

$$E[m,j] = \frac{1}{N_{MC}} \sum_{k=1}^{N_{MC}} \left(\frac{1}{N_{SO,k}[j]} P_{m,k} \sum_{i \in I_k[m,j]} \tau_{pw,k}[m,i] \right) \quad (2)$$

where

$T[m,j]$ = Dwell time for the jth scoring interval for radar m.
$E[m,j]$ = Energy emitted for the jth scoring interval for radar m.
m = Transmitting platform.
N_{MC} = Number of Monte Carlo runs.
j = Scoring time interval index.
$I_k[m,j]$ = Indices of the dwell requests in the jth scoring interval for radar m for run k.
$N_{SO,k}[j]$ = Number of scorable objects in the scoring interval j for run k.
$\tau_{dwell,k}[i,m]$ = Time duration of a specific dwell for run k, dwell request index i, and radar m.
$\tau_{pw,k}[i,m]$ = Pulse width for run k, dwell request index i, and radar m.
$P_{m,k}$ = Peak power for radar m for run k.

After the discrete scoring interval metrics have been accumulated, the sensor total and cumulative metrics can then be computed. The sensor total metrics are defined by the following formulas:

$$T[m] = \frac{1}{N_{MC}} \sum_{k=1}^{N_{MC}} \sum_{i=1}^{N_k[m]} \tau_{dwell,k}[m,i] \quad (3)$$

$$E[m] = \frac{1}{N_{MC}} \sum_{k=1}^{N_{MC}} \left(P_{m,k} \sum_{i=1}^{N_k[m]} \tau_{pw,k}[m,i] \right) \quad (4)$$

where

$T[m]$ = Total dwell time for radar m.
$E[m]$ = Total energy emitted by radar m.
m = Transmitting platform.
N_{MC} = Number of Monte Carlo runs.
$N_k[m]$ = Number of dwells by radar m.
$\tau_{dwell,k}[i,m]$ = Time duration of a specific dwell for run k, scoring interval i, and radar m.

$\tau_{pw,k}[i,m]$ = Pulse width for run k, scoring interval i, and radar m.
$P_{m,k}$ = Peak power for radar m for run k.

Finally, the cumulative metrics can be computed using the previous results; they are defined by the following equations:

$$T[j] = \frac{1}{N_{MC}} \sum_{k=1}^{N_{MC}} \sum_{m} T_k[m, j] \qquad (5)$$

$$E[j] = \frac{1}{N_{MC}} \sum_{k=1}^{N_{MC}} \sum_{m} E_k[m, j] \qquad (6)$$

where

$T[j]$ = Cumulative dwell time for scoring interval j.
$E[j]$ = Cumulative energy for scoring interval j.
j = Scoring interval index.
m = Index of transmitting platform.
N_{MC} = Number of Monte Carlo runs.
$T_k[m, j]$ = Dwell time for the jth scoring interval for radar m for run k.
$E_k[m,j]$ = Energy emitted for the jth scoring interval for radar m for run k.

Track Plotter

Tracks, measurements, sensor beam points, and truth data can be examined visually with a tool that is provided with the MIMO Benchmark called the *Track Plotter*. This tool renders a simple 3D image of the earth with appropriate continent mapping, truth objects, and other information displayed as specified by the user. The user may then select objects on the plot using the mouse, in order to display information about the object, for example: its spatial coordinates, its SNR, its covariance ellipsoid, and whether or not the object is part of a track. Additionally, when clicking on a beam point or measurement, a line will be drawn from the transmitting or receiving sensor (depending on what objects are currently being displayed) to the item. For MIMO returns as opposed to a monostatic return, this line will be solid if the sensor was transmitting, or dotted if the sensor was receiving.

Figure 5 shows a theoretical example of how such lines are drawn in the plotter. The circle at the intersection of the lines represents the actual target, while the crosses represent sensor measurements.

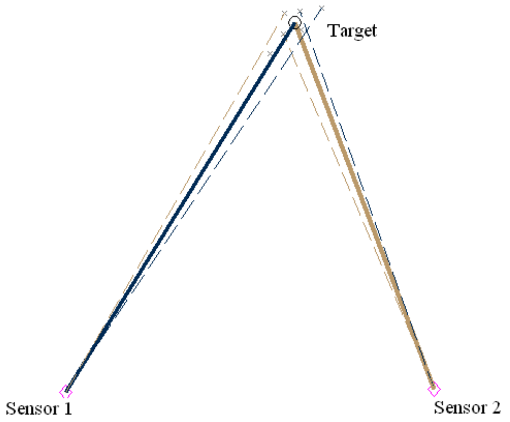


Figure 5 – Visualization of MIMO Event

Furthermore, the outputs of the Metrics application can be compared with the results shown in the Track Plotter in order to provide a correlation between the behavior observed as a result of the use of a particular tracking technique or algorithm.

4. EXAMPLE OUTPUT

The following metrics plots are the result of a set of sample runs performed by the MIMO Benchmark; we present these in order to show how the MIMO Benchmark presents its results, and to give a general idea as to how to interpret them. The scenario used was Scenario 1, shown in Table 1. It contains one fighter (F-1), and two civilian aircraft (A and B). It uses four sensors, identified as R1-R4 in the MIMO Benchmark. The simulations (and as a result, the metrics) were averaged over ten Monte Carlo runs with a total runtime of 1000 seconds per run. The TA used in these runs is the "default solution" that is provided with the MIMO benchmark.

In these plots, we show the track completeness, dwell time, and energy consumed metrics. For simplicity, only sensors 1 and 2 are examined. Note that a trend line has been drawn across most of these plots in order to better visualize what is occurring over the entire run; this is not done automatically by the metrics plotting feature.

Using the Track Plotter, one can correlate the behavior of the TA at specific scoring times with the values of the metrics. This allows the user to perform an effective comparison of the behaviors of different MIMO algorithms. One may note while looking at these plots that the default solution is not terribly efficient with energy; it is not the intention that it is an excellent solution to the problem. Instead, it is just a baseline from which to start working on solutions.

Note that the track completeness remains at 100% during the run, yet at several key points in each of the usage metrics plots, the dwell time and energy drops; this is a result of the targets moving out of the field of view of individual sensors, while other sensors are able to continue providing measurements to the MIMO tracker, which prevents a track break from occurring.

Examining sensor 1 (Figures 7 and 8), according to Figure 8, there are significant drops in dwell time at around 545 seconds and 983 seconds, corresponding to the decay in the energy emitted by the sensor at those points in time, shown in Figure 7. In fact, at 983 seconds, sensor 1 is unable to keep any of the other targets in its field of view, which accounts for the steeper drop in both metrics.

As for sensor 2 (Figures 9 and 10), it has a less severe drop in its usage at similar times, however, unlike sensor 1, it does not completely lose track on all possible targets due to them falling out of its field of view; i.e. we see nothing like dwell times dropping to near zero as shown in figure 8. Instead, at around 850 seconds, it starts tracking one of the airliners, thus boosting its usage metrics near the end of the run.

We can then examine the overall performance of all sensors. The cumulative plots (Figures 11 and 12) allow one to see show when the additional sensors actually begin tracking, and how much time is spent by all sensors dwelling. The overall usage plots instead allow a sensor-by-sensor comparison. As a result of the fact that sensors 3 and 4 always have one of the targets in their fields of view, unlike Sensors 1 and 2, their overall usage metrics consistently rate higher.

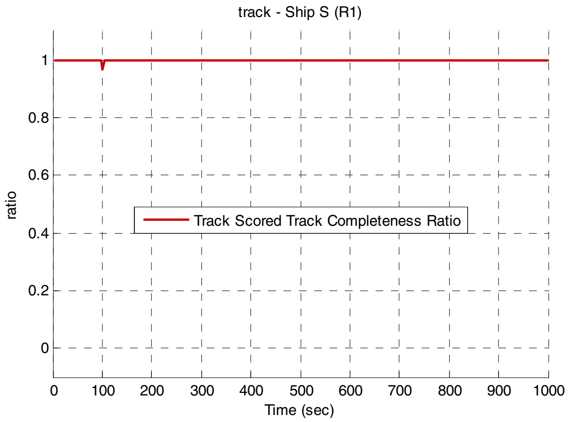


Figure 6 – Track completeness metric

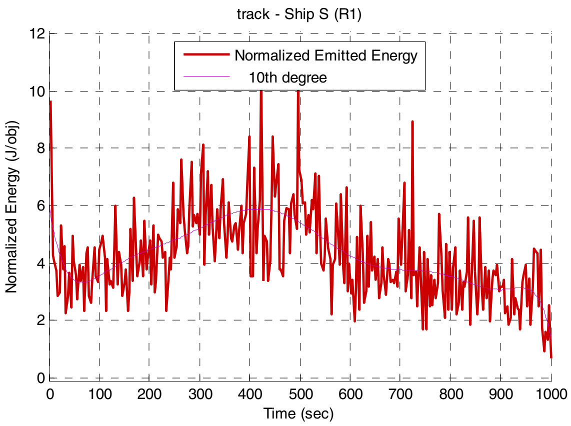


Figure 7 – Sensor 1 Emitted Energy

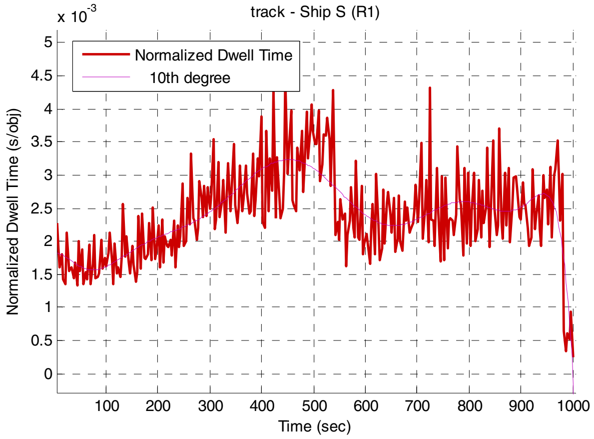


Figure 8 – Sensor 1 Dwell Times

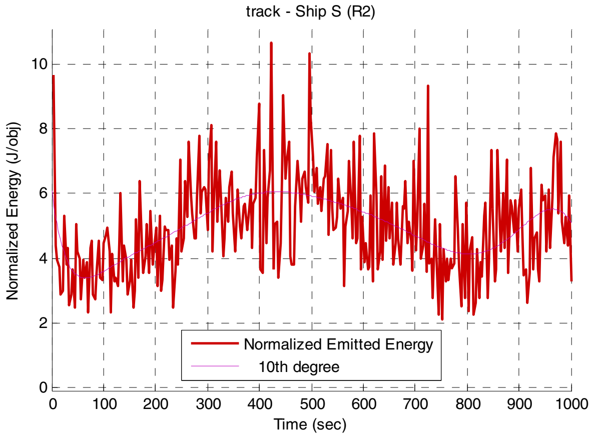


Figure 9 – Sensor 2 Emitted Energy

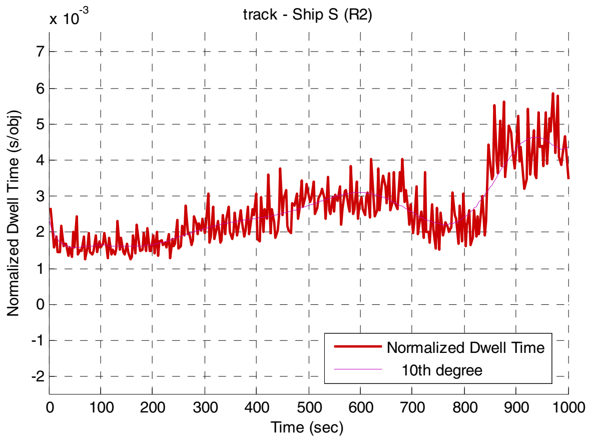


Figure 10 – Sensor 2 Dwell Times

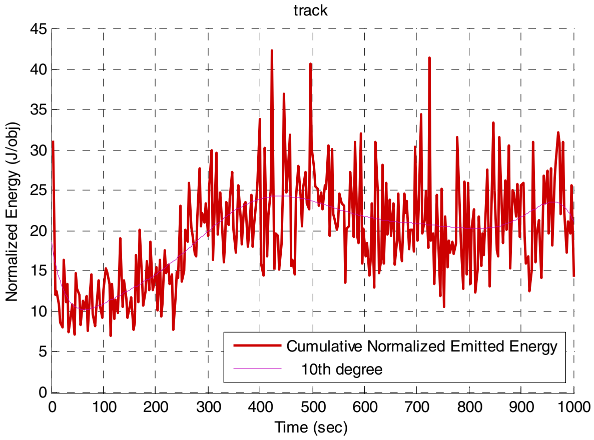


Figure 11 – Cumulative Emitted Energy

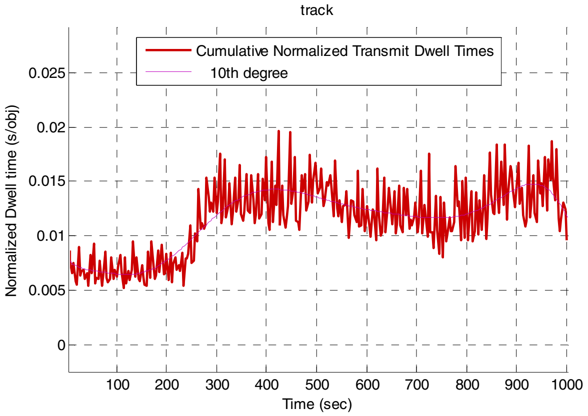


Figure 12 – Cumulative Dwell Times

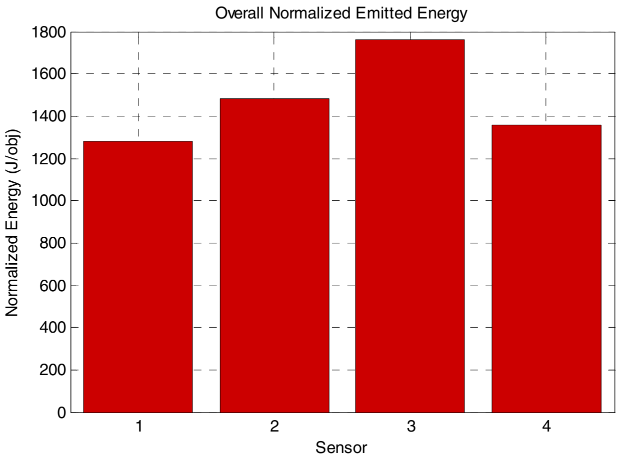


Figure 13 – Overall Emitted Energy (Total Energy per Sensor)

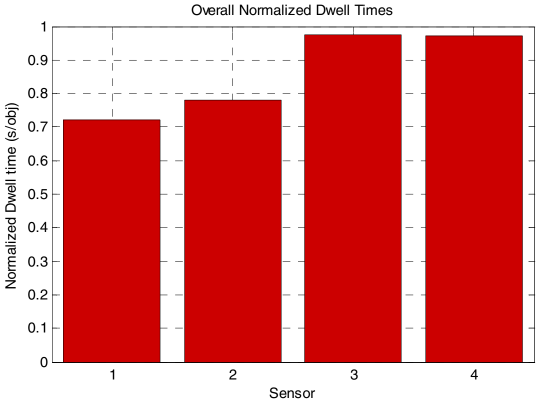


Figure 14 – Overall Dwell Times (Total Dwell Time per Sensor)

5. CONCLUSIONS

A new MIMO radar benchmarking suite and the principles behind its operation as well as a sample run of the suite have been presented. It is our intent that researchers take advantage of this new suite of simulations and use it for their own experimentation with MIMO radar, performing algorithm development and testing using the presented challenge problem as a reference point for desired performance.

REFERENCES

[1] R. Madan and W.D. Blair, editors. *11th ONR/GTRI Workshop on Target Tracking and Sensor Fusion*, Williamsburg, VA, June 2009.

[2] R. Madan and W.D. Blair, editors. *12th ONR/GTRI Workshop on Target Tracking and Sensor Fusion*, La Jolla, CA, July 2009.

[3] R. Madan and W.D. Blair, editors. *13th ONR/GTRI*

Workshop on Target Tracking and Sensor Fusion, Santa Barbara, CA, May 2010.

[4] R. Madan and W.D. Blair, editors. *ONR Workshop on MIMO Radar and Benchmark*, Santa Barbara, CA, May 2010.

[5] M. Skolnik, *Radar Handbook*, New York: McGraw-Hill, 1990.

[6] Blair, W. D., and Brandt-Pearce, M., "Monopulse DOA Estimation for Two Unresolved Rayleigh Targets," *IEEE Transactions Aerospace Electronic Systems*, Vol. AES-37, No. 2, April 2001, pp. 452-469.

[7] Y. Bar-Shalom, X. Rong Li, and T. Kirubarajan, *Estimation with Applications to Tracking and Navigation*, New York: John Wiley & Sons, pg. 166, 2001.

[8] A. Gelb, Editor, *Applied Optimal Estimation*, The MIT Press, 1974.

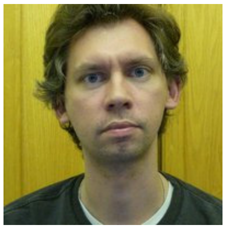
[9] Y. Bar-Shalom and W. Blair, Ed., *Multitarget-Multisensor Tracking: Applications and Advances*, Vol III, Artech House, Norwood, MA, 2000.

[10] R. Canavan, C. McCullough, and W. J. Farrell III, "Track-Centric Metrics for Track Fusion Systems," *Proc. 12th Intl Conf on Info Fusion*, Seattle, WA, July 6-9, 2009, pp. 1147-1154.

[11] O. E. Drummond, "Methodology for Performance Evaluation of Multitarget Multisensor Tracking," *Proc. SPIE Signal and Data Processing of Small Targets 1999*, SPIE, 1999, Vol. 3809, pp. 355-369.

[12] R. L. Rothrock and O. E. Drummond, "Performance metrics for multiple-sensor multiple-target tracking," *Proc. SPIE Signal and Data Processing of Small Targets 2000, Drummond, Ed.,* SPIE, 2000, vol. 4048, pp. 521-531.

BIOGRAPHY



***Richard A. Coogle** is a PhD student at the Georgia Institute of Technology, as well as a Graduate Research Assistant with the Georgia Tech Research Institute. He received his BS in computer engineering (2003) and MS in electrical and computer engineering (2009) from the Georgia Institute of Technology. Prior to returning to Georgia Tech to pursue a PhD and joining GTRI in 2010, he worked for Lockheed Martin Aeronautics, developing simulation and embedded systems software, and for Northrop Grumman Corporation, designing and developing a simulation software platform called the Dynamic Test Stand (DTS). While at Northrop Grumman, he also led the development of an automated test infrastructure to be integrated with DTS. At GTRI, he has contributed to the development of the MIMO Benchmark mainly in the area of sensor usage metrics generation and the event infrastructure.*

***John D. Glass** is a Master's student at Georgia Tech. He received the B.S.E.E from the University of Tennessee in Knoxville in May 2009 (Summa Cum Laude). He has worked several internships with Honeywell Intl. in Clearwater, FL, working on embedded GPS/INS systems, as well as the Y-12 National Security Complex in Oak Ridge, TN, working with amorphous wires. Currently he is a graduate research assistant at GTRI, as a developer for the GTRI/ONR MIMO Radar Benchmark. His current interests lie in the general field of digital signal processing and target tracking. Upon completion of his Master's degree in electrical engineering, John plans to pursue the PhD degree in electrical engineering at Georgia Tech.*

***L. Donnie Smith** is a Research Engineer with the Georgia Tech Research Institute. He received the B.S. degree in Computer Engineering (Summa Cum Laude) from Georgia Tech in 2002, and from June 2003 to August 2005 worked for Northrop Grumman Corporation, designing simulation and test stand architectures. After going back to graduate school in 2005, he accepted a fulltime position at GTRI in February 2007, shortly before earning his M.S. degree in Electrical and Computer Engineering, also from Georgia Tech. As a member of the Georgia Tech research faculty, Mr. Smith has contributed to projects in the areas of target tracking, signal processing, and radar simulation, and these efforts were recognized by promotion to Research Engineer II in July of 2009. He is currently working towards a PhD at Georgia Tech in Electrical and Computer Engineering.*

***Paul Miceli** is a Senior Research Engineer for the Electronics Systems Branch of the Georgia Tech Research Institute. He received the B.S. degree in electrical engineering from Manhattan College and the M.S. degree in electrical engineering from the Georgia Institute of Technology. During his time in graduate school, his research focused on* *the development of signal processing algorithms for the suppression of urban noise in radar warning receivers. Since joining the Georgia Tech research faculty full time in May, 2002 Mr. Miceli has contributed to numerous programs in applications involving target tracking, radar, signal processing, and modeling and simulation. In addition to infrastructure and algorithm development, Mr. Miceli has also long been involved with applied research studies in the fields of multi-sensor fusion and radar performance prediction.*

***Andy Register** earned BS, MS, and Ph.D. degrees in Electrical Engineering from the Georgia Institute of Technology. His doctoral research emphasized the simulation and realtime control of nonminimum phase mechanical systems. Dr. Register has approximately 20 years of experience in R&D with his current employer, Georgia Tech, and product development at two early-phase startups. Dr. Register's work has been published in journals and conference proceedings relative to mechanical vibration, robotics, computer architecture, programming techniques, and radar tracking. More recently Dr. Register has been developing advanced radar tracking algorithms and a software architecture for the MATLAB target tracking benchmark. This work led to the 2007 publication of his first book, "A Guide to MATLAB Object Oriented Programming."*

***Philip West** (SM'99) received the B.S. degree in electrical engineering from The University of Maryland, College Park, in 1983, and the M.S. and Ph.D. degrees in electrical engineering from the Georgia Institute of Technology, Atlanta, in 1984 and 1994, respectively. He is a Principal Research Engineer, a GTRI Technical Fellow, and the Chief Engineer of the Electronic Systems Laboratory at the Georgia Tech Research Institute. He works on problems in the area of multitarget/multisensor tracking for air and missile defense and on emitter geolocation and other passive tracking problems. He is an Instructor in the Georgia Tech Professional Education classes "Basic RF Electronic Warfare," "Advanced Electronic Warfare," "Target Tracking Concepts," "Target Tracking in Sensor Systems," and "Advanced Target Tracking for Ballistic Missile Defense."*

***W. Dale Blair** is a Principal Research Engineer at the Georgia Tech Research Institute in Atlanta, GA. He received the BS and MS degrees in electrical engineering from Tennessee Technological University in 1985 and 1987, and the Ph.D. degree in electrical engineering from the University of Virginia in 1998. From 1987 to 1990, he was with the Naval System Division of FMC Corporation in Dahlgren, Virginia. From 1990 to 1997, Dr Blair was with the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) in Dahlgren, Virginia. Dr Blair is internationally recognized for conceptualizing and developing benchmarks for comparison and evaluation of target tracking algorithms. Dr Blair developed NSWC Tracking Benchmarks I and II and originated ONR/NSWC Tracking Benchmarks III and IV NSWC Tracking Benchmark II has been used in the United Kingdom, France, Italy, and throughout the United States, and the results of the benchmark have been presented in numerous conference and journal articles. He joined the Georgia Institute of Technology as a Senior Research Engineer in 1997 and was promoted to Principal Research Engineer in 2000. Dr Blair is co-editor of the Multitarget-Multisensor Tracking: Applications and Advances III. He has coauthored 22 refereed journal articles, 16 refereed conference papers, 67 papers and reports, and two book chapters. Dr Blair's research interest include radar signal processing and control, resource allocation for multifunction radars, multisensor resource allocation, tracking maneuvering targets, and multisensor integration and data fusion. His research at the University of Virginia involved monopulse tracking of unresolved targets. Dr Blair is the developer and coordinator of the short course Target Tracking in Sensor Systems for the Distance Learning and Professional Education Department at the Georgia Institute of Technology. Recognition of Dr Blair as a technical expert has lead to his election to Fellow of the IEEE, his selection as the 2001 IEEE Young Radar Engineer of the Year, appointments of Editor for Radar Systems, Editor-In-Chief of the IEEE Transactions on Aerospace and Electronic Systems (AES), and Editor-in-Chief of the Journal for Advances in Information Fusion, and election to the Board of Governors of the IEEE AES Society,1998-2003, 2005-2007, and Board of Directors of the International Society of Information Fusion.*