AUTOMATED SPACE SURVEILLANCE USING THE AN/FSY-3 SPACE FENCE SYSTEM [1]

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1. ABSTRACT

The AN/FSY-3 Space Fence System is a highly automated space surveillance system enabled by a service-oriented, net-centric architecture and an advanced situational awareness user interface. The large radar power aperture, coupled with mission processing, automation and advanced visualization, permits rapid space catalog build-up and provides space object event alerts to operators in near-real time. Operator burden is minimized with intuitive three-dimensional track displays, simplified radar tasking and control, and orbital mechanics processing driven by the US Air Force Space Command (AFSPC) Astrodynamic Standards Software.

2. INTRODUCTION

The U.S. Air Force (USAF) is developing the AN/FSY-3 Space Fence System (SFS) as part of its Space Surveillance Network (SSN) to provide unprecedented detection sensitivity, coverage and tracking accuracy. The Space Fence Program was initiated by the USAF in 2005 to develop a system of geographically dispersed S-Band phased array radars which provides 24/7 un-cued capability to find, fix, and track small objects in Low Earth Orbit (LEO). After several trade studies, the concept was expanded to increase flexible sensor coverage across the LEO, Medium Earth Orbit (MEO), Geosynchronous Earth Orbit (GEO) regimes while simultaneously supporting cued search requests. The system replaces the now decommissioned very-high frequency (VHF) USAF Space Surveillance System (AFSSS). In June 2014, the Lockheed Martin industry team was awarded the contract for the Engineering, Manufacturing, Development, Production and Deployment (EMDPD) of the SFS. Two Space Fence sensor sites are planned; sensor site #1 in the Kwajalein Atoll and sensor site #2 in Australia as shown in Fig. 1. A Space Fence Operations Control Center (SOC) will be sited on the Redstone Arsenal in Huntsville, AL.

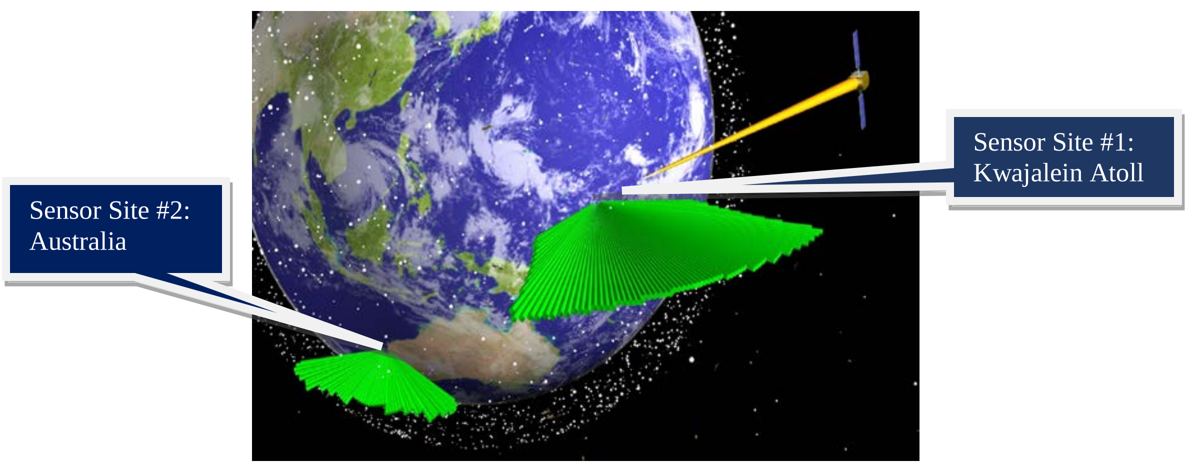

Fig. 1. Space Fence System Sensor Sites

[1] Cleared for public release by 66ABG PA, Case Number: 66ABG-2016-0144

Lockheed Martin's Space Fence System solution is a result of extensive cost-schedule-performance studies conducted during multiple concept and design phases. The design was shaped by the need for flexible sensor coverage and affordability through use of digital array technology that employs element-level Digital Beam Forming (DBF) and is capable of many independent beams to support simultaneous functions. The design leverages Gallium Nitride (GaN) high power amplifier technology for use in the transmit array to provide high power long pulses needed for space operations, and high efficiency for low operating costs. The radar is matched with a commercial off-the-shelf (COTS)-based, net-centric enabled Mission Processing Suite. Mission Processing forms observations from radar measurements, monitors space events and provides internally and externally-available data services.

The Space Fence design includes two minimally-manned radar sites with complementary coverage and the Space Fence Operations Center (see Fig. 2). Each radar site features closely-spaced, but separate, transmit and receive arrays that are mission-optimized for high availability and low lifetime support costs, including prime power. Coverage is optimized to provide assured coverage at Initial Operational Capability (IOC) down to 800 km altitude with the Kwajalein Atoll site and improved lower altitude assured coverage to 550 km at Full Operational Capability (FOC) with the addition of the Australian site. Both sites provide cued tasking support to all altitudes including GEO. The SFS is net-centric (interconnected by the Global Information Grid (GIG), more recently referred to as the Department of Defense Information Network (DoDIN)) and will seamlessly integrate into the existing SSN, providing services to external users—such as the Joint Space Operations Center (JSpOC)—and coordinating handoffs to other net-centric SSN sites.

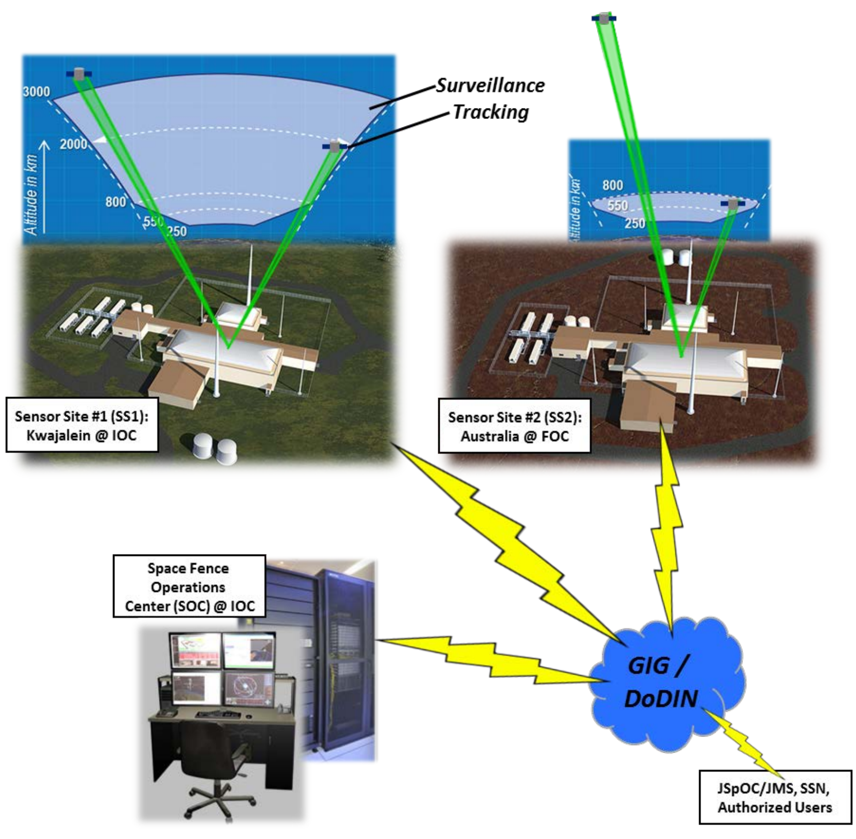

Fig. 2. Space Fence System Architecture and Coverage

The layout of a sensor site is depicted in Fig. 3. The system architecture permits tremendous user-defined flexibility to customize volume surveillance and track sectors instantaneously without impacting routine surveillance functions. Arrays are built with scalable building block sections and Line Replaceable Units (LRUs). Array electronics can be serviced from beneath while arrays are operating, permitting high system availability as shown in Fig 4. Liquid cooling enables high performance and reliability. Radar control, signal and data processing, and Mission Processing are hosted on COTS processing within the operations building. A portion of this processing is dedicated to automating many of the SFS functions, such as space object observation generation and system status monitoring.

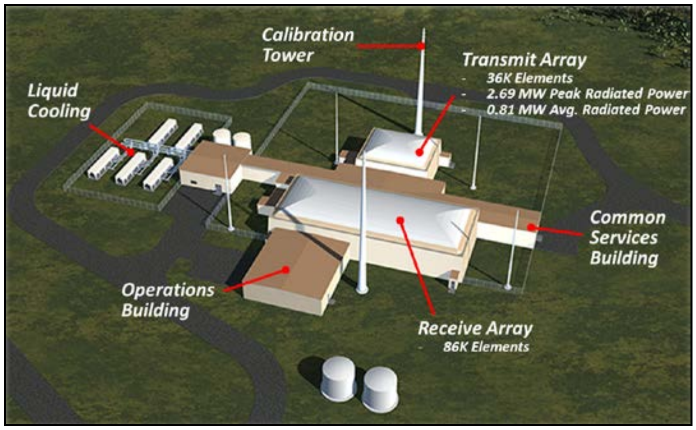

Fig. 3. Space Fence Sensor Site Overview

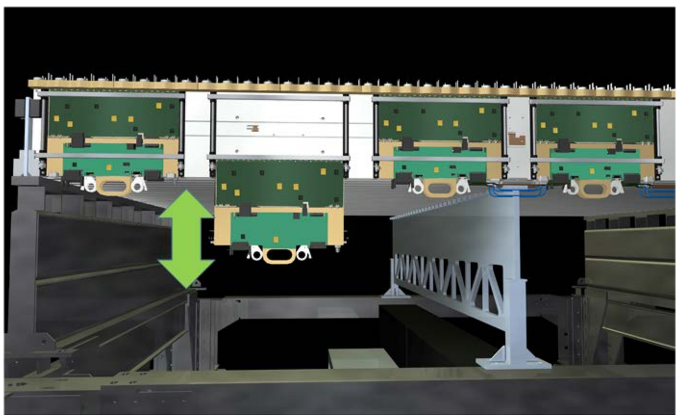

Fig. 4. Array Electronics Serviceable From Beneath Array While Operating for High Availability

Use of element-level DBF permits Space Fence to maintain persistent surveillance while tracking hundreds of simultaneous objects detected in the fence. The system automatically manages resources by performing long-arc tracks on Un-Correlated Targets (UCT) to support accurate initial orbit determination (IOD) (See Fig. 5).

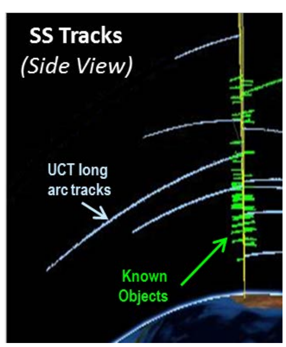

Fig. 5. Element-Level DBF Enables Long Arc Tracking Simultaneously With Un-cued Surveillance

For high-interest objects, a "mini-fence" can be electronically constructed to gather more track data, focusing radar resources specifically on that object, providing more timely and accurate information. Scheduling of the mini-fences is automated and based on orbital algorithms and system parameters. System resource control automatically adjusts the number of beams and range extents to cover the required volume of the mini-fences. Use of element-level DBF allows Space Fence to support cued tasks without interrupting un-cued surveillance.

The SFS, and in particular, Mission Processing, provides efficient sensor control, automated data processing and operator friendly interfaces that enable the operator to focus on the mission instead of the volume of data typically available from a large sensor system. A system this powerful, in terms of sensor coverage, data throughput and high-technology components, requires automation to allow the system to be operated and managed with a minimally-sized staff.

The prime automation features and enablers of the SFS are:

- Net-Centric, Service-Oriented, Web Standards-Based System Interface
- Client Subscription Framework
- SKIWeb, GeoRSS, and DISA Enterprise Messaging Data Feeds
- Automatic Internal Space Object Catalog Maintenance
- Automatic Orbital Mechanics Processing
- Automatic Command and Control Task Processing
- Operator Visual and Audible Event Cues
- 2D/3D Space Object Visualization
- Web Browser-Based Operator Display Thin Client
- High System Availability and Maintenance Automation

This paper provides insight into these design principles that contribute to the automation of the USAF's newest land-based space sensor.

3. NET-CENTRIC ARCHITECTURE AND SERVICES

The SFS was designed and built with net-centric concepts in mind. Net-centric refers to the use of Internet protocols (e.g. Hypertext Markup Language (HTML), Extensible Markup Language (XML)), Web Service Definition Languages (WSDLs), and other web standards, that serve to remove barriers between networks. This improved interoperability allows authorized users access to both data and mission applications across disparate networks regardless of where they reside. In addition to global access to authorized external users, net-centric web services and displays optimize mission operations and support a rapid operations tempo. The system is designed so that operations can be performed by an authorized operator via the user interface (UI), or be performed (as applicable) by an authorized machine-to-machine client via a controlled set of web service operations.

Using the standards identified above, the Space Fence architecture deploys net-centric capabilities (both machine-to-machine, as well as machine-to-end-user) onto strategically placed servers over high availability robust networks. These servers follow additional net-centric principles including:

a. Support for multiple net-centric dissemination mechanisms to lower the technical barrier of entry for all authorized users (i.e. including users with less robust systems)

b. Leverage of existing net-centric architectures, code, advanced techniques and concepts

c. Utilization of Free and Open Source Software (FOSS), when it is low risk and performs as well as Commercial-off-the-Shelf (COTS) to lower Life Cycle Cost (LCC)

Space Fence implements a net-centric architecture by providing all external interfaces through standard communication mechanisms and its Subscription Framework to process, persist, and publish the data to the appropriate subscribers. In near real time, web services are used to interact with the SFS over machine-to-machine interfaces. These web services employ a set of well-defined interface patterns widely recognized and used by current data sharing networks.

By design, web services are available to external users; however, not all operations provided by the user interface are available through these web services to external users. A balance between the need to disseminate mission, performance, and informational data versus the requirement to maintain control of the SFS by operators was employed. This yielded an information rich and capable data source while not exposing operations that put the system at risk or compromise the Space Fence operator to perform the mission.

The Space Fence Web Services are summarized in Table 1.

Table 1. Space Fence System Services

System Service	Description
Alert	The Alert Service provides operations for monitoring the control of external SFS Alerts. Alerting tolerances and other controls can be obtained through an operation in this web service. The Subscription Service provides the interface to publish alerts to the external user when the subscription filter matches an event detected by the SFS.
Calibration	The Calibration Service provides an operation to obtain atmospheric correction data being used by the SFS calibration calculations.
Catalog	The Catalog Service provides operations to receive incremental updates of JSpOC catalog information. Additional operations allow the external users to receive correlation criteria used to associate observations to objects within Space Fence processing, and retrieve the most current orbit state for a particular Un-Correlated Track (UCT).
Data Store	The Data Store Service provides operations to query data storage. These queries are focused on calibration metrics, performance metrics, and other non-mission data. Mission data is primarily obtained via the subscription service.
Mission Configuration	The Mission Configuration Service provides operations to retrieve available Mission Profile Configuration (MPC) definitions that define the un-cued fence and other mission profile data.
Notification	The Notification Service provides common endpoint for receiving all external notifications into the system. These notifications consist of alerts generated by the JSpOC or notification of various events detected.
Raw Data	The Raw Data Service provides operations for retrieving raw data collection recording settings for SFS radar assets. Certain events can be used as triggers for automatic collection with specification of the time period of data to collect.
Subscription	The Subscription Service provides a mechanism for external users to be notified of changes to specific Space Fence data elements per filters established in the subscription. Filter types are defined in the specific service schemas.
Tasking	The Tasking Service provides operations required for tasking the SFS. Tasking includes legacy capabilities and enhanced tasking by object or volume. The Subscription Service is used to create a subscription to allow external users to receive tasking status updates.

The underlying data types utilized by these web services consist of XML-based types vetted through working groups consisting of multiple programs and stakeholders involved with SSN data exchanges. Governance of these definitions is maintained through the Command and Control (C2) Space Situational Awareness (SSA) Community of Interest (COI). This provides a consistent means to exchange data and encompasses the needs of a wide range of sensors, data representations, and capabilities.

Additional dissemination mechanisms include USSTRATCOM's SKIWeb for Space Fence alerts and a GeoRSS feed for authorized recipients desiring geographically enhanced observation data that can easily be placed onto a 2D/3D map/globe or provided to analysis applications.

While web services are the primary access mechanism employed, other commonly used mechanisms are utilized to broaden the availability of Space Fence Data to the SSN community. In order to potentially serve a large number of users without requiring a large bandwidth, the Defense Information Systems Agency's (DISA) Enterprise Messaging service provides a feed of Space Fence observations and alerts that can be disseminated to approved recipients of this data. Because Enterprise Messaging users extract data from DISA's servers directly and not through Space Fence web services, the SFS only needs to provide a connection with a single copy of data to Enterprise Messaging. Enterprise Messaging servers replicate the data to each end user for the subscribed topics.

Key underlying capabilities of the SFS, which feed the data obtained through web services, provide a powerful and automated capability reducing the data exchange bandwidth required between Space Fence and the JSpOC and other potential users. Calibration of data is performed internally to Space Fence through multiple self-calibration mechanisms, potentially freeing analysts from adjusting observations obtained from Space Fence. Catalog maintenance of UCTs is solely contained within Space Fence and requires no interaction by the JSpOC. RSO candidates are automatically calculated and provided to the JSpOC for their consideration after certain criteria thresholds are achieved, thereby reducing the JSpOC's workload. Internal detection and alert dissemination of breakups and maneuvers provide the JSpOC with value-add SSA information. And finally, internal auto-tasking capabilities provide an automatic means of initiating tasks without operator or JSpOC intervention. All these features add a level of automation to reduce workforce manning requirements and adds convenience and user friendliness.

4. AUTOMATED SENSOR CONTROL AND SITUATION AWARENESS

In an effort to increase system automation, especially for routine, labor intensive tasks, Lockheed Martin teamed with the USAF to shape the system UI by hosting several User Evaluation Periods (UEP). The UEPs involved current and previous SSN operators and helped assess the UI design. The operators were provided an environment in which they were able to provide feedback on the display contents and controls, and make requests for new capabilities (see Fig. 6).

Some UEP-driven enhancements included:

- For space objects changes that are reportable, either due to a satellite's attributes or association with an event, can be tailored to include both visual and audible cues that aid operators in understanding each object's space current status
- Ability to rapidly task objects directly from generated alerts
- Visual depiction of object orbit intersections with the surveillance fence
- Quick access to an object's information through hover tips and menu actions directly from the 3D globe view

Fig. 6. User Evaluation Period Environment

The Space Fence display architecture contains a NASA World Wind Eclipse Rich Client Platform Standard Widget Toolkit-based display environment that runs as a Java Web Start Application and is also available without the globe/maps as a browser-based thin client as shown in Fig. 7. This framework is similar to the one used by the Joint Space Operations Center (JSpOC) Mission System (JMS). The Java Web Start Application is accessible from the Space Fence web-based home page. This capability allows properly credentialed operators to be on-site or at a remote location. The built-in Eclipse framework allows for each operator to customize the layout to their preference and is automatically saved for future sessions and can be shared with other operators. The customization capability leads to efficiently completing tasks for the large scale sensor system.

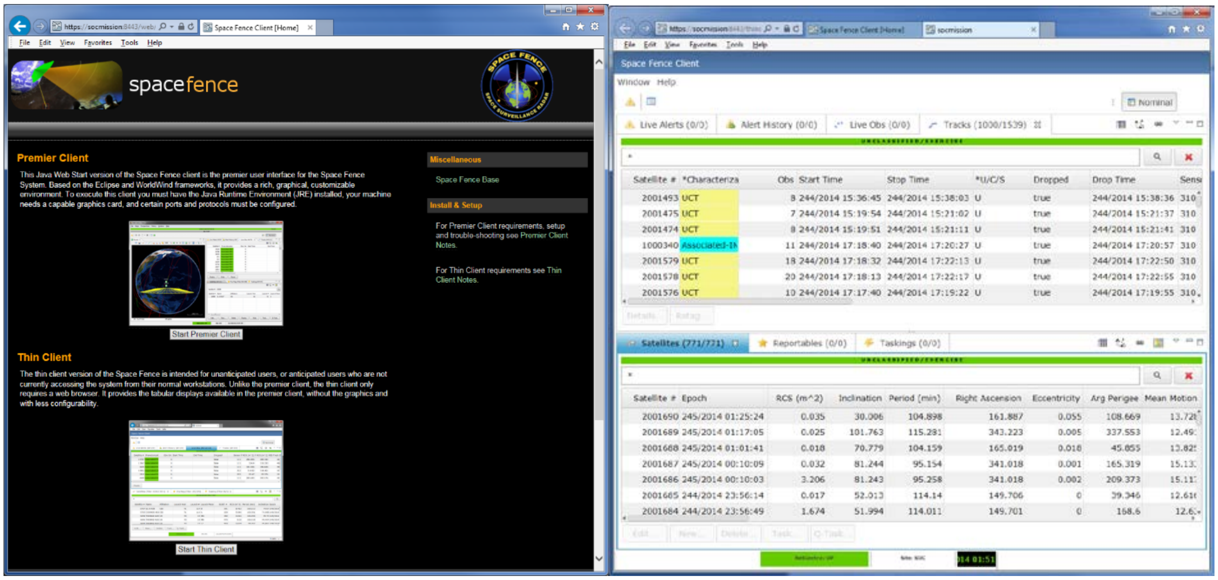

Fig. 7. Space Fence Web Start Application and Operator’s Display

The operator configures the SFS via the UI and receives resource management feedback based on the parameters set lowering the burden of manual parameter optimization. The Space Fence Mission Processing software is designed to run autonomously and is configured to receive and process measurement-level detection reports from the radar. The system currently uses AFSPC Astrodynamic Standards for all orbital mechanics processing on a parallel grid computing architecture, allowing it to handle large amounts of data.

Mission Processing correlates the measurements into tracks and generates smoothed observations. An early observation for a track is then associated against the RSO and internal UCT catalogs using Astrodynamic Standards. If no association occurs, an Initial Orbit Determination (IOD) is performed to construct an initial orbit for the object and is added to the internal UCT catalog. Otherwise, if the track associates to an internal UCT, the orbit state is improved. The system has been designed to automatically recommend internal UCTs that meet a certain criteria for promotion to the JMS maintained RSO catalog through web services. If JMS accepts the recommendation, the system can automatically accept the promotion through web services catalog updates and will retag the observations for the internal object to the RSO object. Processing automatically determines the amount of time to track each object, allowing the system to perform long arc UCT tracking (see Fig. 5). When association is performed on a track, the system automatically determines if the track is part of a space event.

The SFS automatically generates numerous internal and external alerts to keep operators and external users informed of the Space Fence status and detected space events. External alerts are made available net-centrically to authorized clients through its web services. Space Fence is also capable of consuming JMS informational alerts and displaying them on its screens. Additionally, the system provides key alert processing paradigms and controls to the operator. Operators can specify by alert-type if the alert should be auto-disseminated externally via web services or controlled by operators in-the-loop prior to dissemination. The system allows operators to add comments to alerts as well as to change the classification markings on outbound alerts.

The SFS provides an advanced feature called “alert action-ing”. This feature allows the operator to automatically re-layout the operators screen using the key windows required to monitor and react to an alert condition. Data is automatically filtered to only include the objects involved in the alert condition. Once the operator has completed action-ing the alert, a simple back-button returns the operator’s display to its previous state.

Space Fence has the ability to automatically receive and process Command and Control (C2) tasking. When receiving C2 tasking, the system, without operator intervention, plans a mini-fence in addition to the un-cued surveillance fence to track the object. The system then monitors the mini-fence for success of that volume. The task status and observations resulting from the tasking are sent through web services to the subscriber. Space Fence operators employ two methods to manually invoke tasks: Quick Tasking and Detailed Tasking. Using Space Fence Quick Tasking, operators have minimal entry and interaction and leave the details to Mission Processing. For Detailed Tasking, operators accept system generated plans or use fine grain controls to modify the system generated tasking plan for a satellite. The system provides the capability to establish auto-tasking policies against individual satellites as well as against categories of satellite. The auto-tasking capability automatically and persistently auto-tasks using the settings established by the operator.

The Space Fence display has the ability to view satellite data by both graphical as well as tabular displays. The graphical display can project objects in 2D and 3D (Fig. 8). The situational awareness capabilities include a real-time POS/NEG list that continuously provides the operator important information and allows for efficient responses when off-nominal situations occur. The system also automatically computes and maintains long term trending/performance information that can be graphed and displayed in a tabular format. Data stores are available through the Space Fence machine-to-machine web services and are also available to the human operator on the displays. The operator and external users have the ability to query data by satellite specific properties or track specific properties this allows the operator or external user to quickly find the information they need.

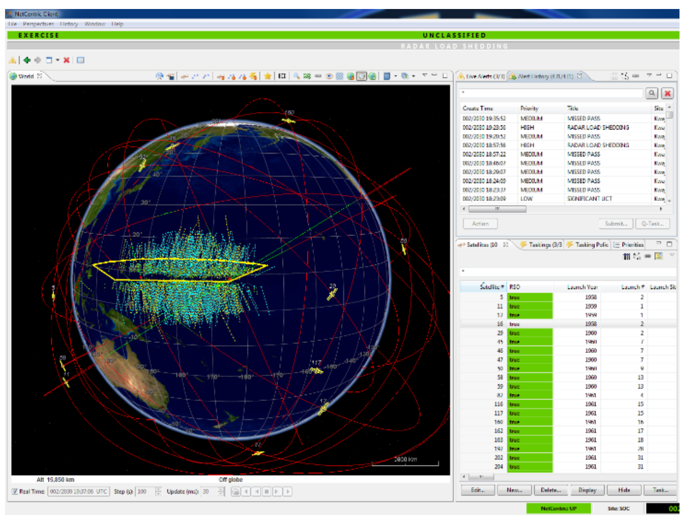

Fig. 8. Space Fence System 3-D Display

SFS high availability and maintenance automation also contribute to the reduced manning required to operate the system. Critical systems are redundant and automatically reconfigure if a failure is detected. Control and status of hundreds of system components are aggregated into a single maintenance workstation and is accessible from within the sensor sites and accessible remotely at the SOC. The Mission Processor continuously computes the system and operational capability as it monitors the status of system components. If a component fails, it is immediately reported to the operator/maintainer. The maintenance action can be immediate or in many cases, deferred to an opportunistic time frame. Most maintenance actions, such as replacing radar transmit and receive assemblies, can be performed while the system continues to operate.

5. PROGRAM STATUS

The Space Fence Critical Design Review (CDR) and 100% Facility Design Review were successfully completed in 2015. These events not only reviewed the design, but also assessed the Technology Readiness Level (TRL) as level 7 and the Manufacturing Readiness Level (MRL) as level 7. During the CDR event an extensive end-to-end prototype demonstration of the system was successfully conducted. A Space Fence Integration Test Bed (scaled down version of the sensor site and SOC) was constructed in Moorestown, NJ and is now operational. Its primary purpose is to provide an environment for early integration and partial system verification prior to on-island installation. Ground breaking for sensor site #1 took place on Kwajalein Atoll in February 2015. The Radar transmit and receive building construction for sensor site #1 is nearing completion while the SOC continues to make steady progress toward readiness for equipment installation later in 2016. The Space Fence Program is on-track for IOC in 2018. The second sensor site FOC is planned for 2021.

6. SUMMARY

The Space Fence System is designed to address the Space Situational Awareness challenges presented by the growing number of objects in orbit. The system incorporates a high degree of automation to simplify the functions performed by operators and analysts. The large number of sensor observations generated by the system and the continuous monitoring of space events are automatically processed and distilled into a manageable set of displays and alerts for the operators. Its net-centric architecture allows authorized users access to both data and mission applications across disparate networks regardless of where they reside. The user interface was designed to allow efficient system control and monitoring with a minimal set of operators and maintainers.

Space Fence is a robust, flexible, advanced end-to-end system that will meet the warfighter's operational needs and revolutionize Space Situational Awareness, starting at IOC in 2018.

7. REFERENCES

1. Joseph A. Haimerl, Gregory P. Fonder, "Space Fence System Overview", Advanced Maui Optical and Space Surveillance Technologies Conference Proceedings, September 2015.