SMRS: TECHNOLOGY DEMONSTRATION FOR MARITIME SECURITY

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Abstract

In the field of navigation and remote sensing, maritime security is an important topic, which is supported by the high amount of attention it receives within the GMES programme [1]. It involves monitoring of shipping routes (both in open and coastal waters), anomalous navigation behaviours and illicit trafficking. In order to support the space-based maritime initiatives, the Space-based Maritime Reconnaissance and Surveillance (in short: SMRS) mission was initiated, which will be presented in this paper.

The SMRS mission is a low-cost in orbit demonstration (IOD) mission proposed by ESA for demonstration of new sensor technologies for ship detection and tracking as well as data fusion products for value added services to the maritime situation awareness community.

Currently the SMRS mission comprises selection and definition of payloads relevant to maritime applications and their consequent accommodation on a micro-satellite platform. The SMRS sensor suite consists of:

- AIS Payload (Kongsberg Seatex)
- Frequency Monitoring Package (QinetiQ)
- Navigation Radar Detector (LuxSpace)
- Maritime FMP (LuxSpace)

With the selected sensor suite, the SMRS mission is able to offer the following services:

- Ship tracking with AIS
- Ship positioning using X-band navigation radar emissions
- Ship detection and coarse positioning based on VHF and UHF emissions
- Mapping of frequency spectrum utilization in the maritime bands

In addition, the SMRS mission has the unique advantage of being able to operate sensors on the same platform, which gives the possibility to correlate the AIS reported positions with detection information from the other sensors. Furthermore, the SMRS data products can be fused with remote sensing data received from external sources, e.g. SAR images. These data fusion activities significantly increase the confidence in the reported traffic picture, and also enable the unveiling of ships with malicious intentions or ships in trouble.

As platform for SMRS, a modification of the small satellite platform TET is foreseen. This platform will be an improvement (lower mass/power ratio, higher payload power, higher downlink rate) of TET-1, which is planned for launch in 2011. In this way, the SMRS mission has access to a high-performance, low-cost platform solution with a short development time.

The SMRS spacecraft is planned to be launched into a 600 km sun-synchronous orbit with 18:00 AM LTAN. In this orbit, it is able to cover all global waters. As an additional bonus, it will have the similar ground track as Sentinel-1 thereby simplifying data fusion.

1. INTRODUCTION

The task of maritime surveillance is a known challenge due to the large areas that require coverage and the varying ship concentrations within these areas. Many systems and studies have been implemented in order to fully understand and address these issues. The core maritime surveillance systems that are currently operational are:

- Long Range Identification and Tracking (LRIT)
- VMS (Vessel Monitoring System)
- AIS (Automatic Identification System)
- Coastal Radar

In evaluating the capabilities of these current systems it is clear that the need for a space-based system that can offer worldwide coverage with an increase in the data update rate is required. To provide more reliable data sets the simultaneous acquisition of data is highly beneficial.

This paper intends to present the Phase-A results of the SMRS study performed by OHB-System under contract to ESA. The study encompassed in-depth investigation into the application potential and functioning of space-based maritime surveillance technologies, with the aim of selecting a payload suite applicable to maritime observation and demonstrating it. This payload suite will consequently be flown on the SMRS mission, which has been defined as a low-cost in orbit demonstration (IOD) mission for demonstration of new sensor technologies for ship detection and tracking as well as data fusion products for value added services to the maritime situation awareness community.

2. MISSION GOALS

The task of maritime reconnaissance and surveillance requires the use of a wide range of technologies, many of which have been developed and are currently flying or have already flown in space. Although many technologies that are applicable to maritime surveillance have been space qualified, some still have a relatively low TRL level and others have yet to be demonstrated in space. The technologies that the SMRS mission will demonstrate are:

- AIS Payload
- Frequency Monitoring Package
- Navigation Radar Detector
- Maritime FMP

The main goal of this mission is to develop and characterise new and developing technologies as well as to prove the feasibility of an operational mission that can provide services for maritime surveillance. In particular this mission will demonstrate the benefit of simultaneous data generation and data fusion with the payloads that are employed on SMRS and additional Earth Observation missions.

The main user requirements that have been identified for this mission are:

- Launch in 2015
- Global coverage
- Timeliness < 2 hours

These user requirements have been used throughout the SMRS study in order to define a mission that resolves some of the current gaps in maritime surveillance and meets the user needs.

2.1. Services

The services that the SMRS mission can provide include; ship tracking of both cooperative and non-cooperative vessels, ship positioning based on the emissions from their X-band navigation radars, ship detection and coarse positioning based on VHF and UHF emissions, and mapping of the frequency spectrum utilization in the maritime bands as well as other selected frequency bands. Core services can be provided in several areas, among others:

- Fishery Monitoring
- Traffic Management
- Maritime Search and Rescue
- Border Control

In these areas, added-value services are evident in the safety of vessels, protection of the environment and logistics. Through improving route and port planning it is expected that fewer accidents will occur, which will increase maritime safety and reduce the carbon footprint via optimised vessel routes.

The main stakeholders with responsibilities in these domains are EMSA, FRONTEX, EDA and CFCA, as well as their equivalents at the national level. Through the use of missions like SMRS these stakeholders can extend the core services to:

- Marine pollution prevention
- Customs
- General law enforcement
- Defence

By providing SMRS data to the user community, its services and data products will be used together with other satellite products (e.g. SAR, LRIT) and coastal products (e.g. AIS, radar), as well as SafeSeaNet (SSN), CleanSeaNet (CSN) and other operational resources.

2.2. Data Fusion

The SMRS mission has the unique advantage of being able to operate multiple sensors on the same platform, which gives the possibility to correlate the AIS reported positions with detection information from the other sensors. The fusion of data products from SMRS payloads provides data products that are more reliable than data collected from a single sensor source. Furthermore, the SMRS data products can be fused with remote sensing data, e.g. SAR images. This data fusion significantly increases the confidence in the maritime traffic picture, and enables the unveiling ships with malicious intentions or ships in trouble [4]. To facilitate the data fusion process SMRS will operate in an orbit that is similar to those of Earth Observation SAR satellites. This collaboration of data is a great example and proof of value added service for the maritime situation awareness community.

Based on operational experience, the correlation of data from cooperative and non-cooperative sensors should have a minimal time difference in observations. The allowable time difference in observations varies depending on the vessel density in the area of interest and the reliability of the SAR imagery. The time correlation between SMRS and Sentinel-1 data will typically not exceed 50 minutes.

3. MISSION OVERVIEW

The SMRS mission will consist of two phases. The first phase will focus on **technology demonstration**, which will verify algorithms and optimize sensor settings for reliable ship detection during operations. The second phase is dedicated to the users by providing operational services and will perform **routine operations** such as data acquisition and fusion for maritime safety, security and environment services, and monitoring frequency band utilization.

The SMRS mission will use a single spacecraft on an orbit that has been selected to enable global coverage and to address the limitations innate to land-based maritime surveillance. The use of a polar orbit endorses the observation of all global waters, closing many of the gaps in current observation capabilities. Additionally, the orbit has been selected to align with current and future SAR satellites, specifically Sentinel-1, to simplify the data fusion with SAR imagery. The orbital parameters for the SMRS mission are:

- Altitude: 600 km
- Inclination: SSO
- LTAN: 18:00

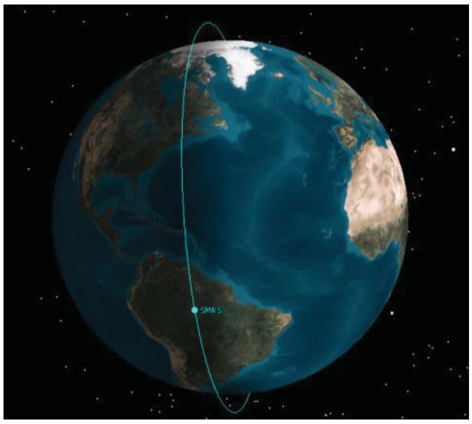

Figure 1: SMRS orbit

Moreover, this orbit is advantageous because of its homogeneous lighting conditions which lead to the optimization of the platform design, resulting in significant advantages for the electrical power and thermal subsystems.

As a low-cost in orbit demonstration the mission requires a high level of cost effectiveness. In order to maximize the cost effectiveness, the mass and size of the SMRS spacecraft will be optimized to enable a piggyback launch. The ground segment will also use the existing infrastructure of the DLR TET-1 mission [2] to increase cost savings.

4. PAYLOADS

The SMRS mission will consist of four payloads, however the payloads will not have equal opportunities to operate. From the onset of the mission definition, the AIS payload was given top priority and therefore no other payload is allowed to interfere or degrade the AIS performance during their operation.

4.1. AIS

The AIS receiver is a sensor for the detection of AIS messages containing navigational and logistical information transmitted from ships. AIS enables vessel tracking and identification as well as determining the voyage status. Through space based AIS, the maritime picture and situational awareness of global waters is greatly improved as it is not limited to 30 nm like terrestrial AIS. The SMRS baseline for AIS detection is to detect Class A equipped vessels in all four AIS channels (AIS-1, -2, -3 and -4) and Class B equipped vessels in AIS-1 and AIS-2 (161.975 MHz and 162.025 MHz) [3].

Currently, space-based AIS receivers are being demonstrated, therefore giving this payload a relatively high technology readiness level (TRL) compared to the other technologies envisaged on SMRS. Despite the high TRL, there are significant developments required for space-based AIS. The requirements for the AIS receiver include the development and validation of new AIS receiver technology, including Faraday rotation techniques, Doppler and co-channel interference cancellation and ground based raw data processing.

The most common option for AIS antennae is the three orthogonal monopoles which yields excellent results, however an improvement was found when the three monopoles were aligned 45° to Nadir. With this new alignment the radiation pattern and footprint are more favourable as a higher gain is achieved and there is less footprint overlap.

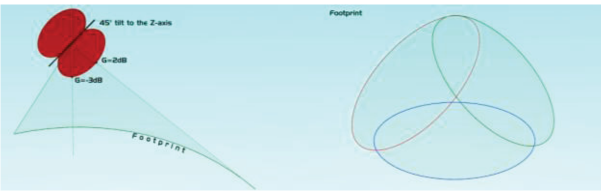

Figure 2: Antenna footprint for dipole tilted 45 degrees relative to z-axis

The AIS receiver will utilize a Software Defined Radio (SDR) architecture, which enables the receiver to sample and digitize the VHF frequencies directly. The use of SDR increases the effective sensitivity of the receiver by allowing for advanced algorithms and allows the firmware and software to be upgraded making the receiver more versatile. The versatility of the receiver is also seen in its ability to be adjusted such that alternate channels could be received once the primary mission objectives are complete.

As a result, the AIS payload will be used to demonstrate detection of both Class A equipped and Class B equipped vessels on AIS-1 and AIS-2, and only Class A equipped vessels on AIS-3 and AIS-4. The receiver is also capable of operating in several processing modes, including; on-board processing, digital sampling, and a hybrid of the two. Complementing the AIS receiver architecture is the use of 3 orthogonal monopole antennas that are aligned 45° to Nadir. This antenna configuration provides adequate detection while proving to be a low cost and robust solution.

4.2. NAVRAD

The Navigation Radar (NAVRAD) detector will localize ships by detecting and processing the signals emitted by ship-based navigation radars. The detection principle has been inspired by existing military applications. The NAVRAD detector will be operating in X-band and more precisely, it will cover a bandwidth of 60 MHz centred on 9410 MHz. The position of a specific NAVRAD is determined by a high end on-board processing principle. Link budget computations have shown that the link budget has sufficient margin to even allow for the detection of radars equipped on small sailing ships.

The probability of detection of a maritime vessel with the SMRS NAVRAD detector lies above 90%. For the ships that have been detected, the subsequent processing is able to yield a mean localization error of 5.3 km which is well below the targeted accuracy of 7.5 km.

4.3. FMP

The main function of the Frequency Monitoring Package (FMP) will be to map the in-orbit interference produced by either terrestrial or in-orbit emitters. The FMP will scan the frequency domain around the 10.6-13.75 GHz or 23.6-24 GHz frequency bands, with a bandwidth of 300 MHz. Although SMRS is a maritime surveillance mission, the FMP will only operate while the spacecraft is over land. The main objective of the FMP will be to perform detection, localisation and spectral analysis of signal sources to create an in-orbit and on-ground interference database. This database will then be used as input for future mission to help identify which frequencies will yield optimal results and which frequencies need to be filtered.

The FMP is designed as a channelized digital receiver which allows a flexible (modular scalable) instrument architecture to be achieved. The number of digital receivers can be tailored depending on platform resources available. RF signals are received at the antenna and feed into the RF subsystem where they are sampled, filtered and converted to IF. The IF signals are digitised, after which the resulting data is analysed in real time before being transmitted to the on-board memory.

4.4. MFMP

The Maritime Frequency Monitoring Package (MFMP) is a sensor for detection and spectral analysis of signal sources and interference. The MFMP will simultaneously monitor one or several channels in the maritime frequency band. The MFMP will measure the power density for future applications and help detect voluntary or involuntary jamming on the given frequency. The MFMP will perform detection and spectral analysis of signal sources in the 108-180 MHz or 380-500 MHz frequency band.

The MFMP is based on the SDR technology used for the AIS receiver, which is space qualified and allows for the simultaneous reception of VHF and UHF signals as well as channel measurements and acquisition. The detection of the two frequency ranges is performed by two monopoles (one for VHF, one for UHF), each with sufficient bandwidth. The advantage of these simple monopoles is that the antennas can be stored in a stowed configuration easily and do not require complex mechanisms for their deployment.

5. PLATFORM

The SMRS platform is a modification of the small satellite platform TET-1, which is scheduled for launch in September 2011. In using the TET+ platform, the space heritage, lessons learned, and proven functionality of the platform can be applied to the SMRS mission. Additional benefits of the TET+ platform are a reduced development time and cost because it is based on the TET-1 platform.

The TET+ platform will have several improvements from the original TET-1 platform, such as increased power generation, however will retain its in-flight heritage. The increased power generation is a result of two additional solar panels, increasing the allowed average payload power consumption by approximately 20W. The key figures of the baseline TET+ platform, including the aforementioned modifications to the original TET-1 platform are detailed in Table 1 .

Parameter	Value
Spacecraft mass	150 kg
Payload mass	60 kg
Average spacecraft power	168 W
Average payload power	87 W
Downlink rate	2.2 Mbps
Pointing knowledge	10 arcsec (1σ)
Pointing accuracy	2 arcmin (1σ)

Table 1: Key characteristics of TET+ platform

Due to the constraints imposed by the payloads and the high operating duty cycle, the SMRS spacecraft will always remain in a Nadir pointing attitude. This fixed Nadir-pointing attitude is not the baseline attitude of TET-1, resulting in a rearrangement of the TET-1 platform's configuration. Both the high-gain S-band antenna and star sensors have to be moved. In addition, the payload segment was reinforced, two sun sensors were added and a second low-gain antenna was mounted.

With the new changes to the TET-1 platform, the new platform organization is depicted in its stowed and deployed configuration in Figure 3 and Figure 4, respectively.

Figure 3: Configuration of the SMRS spacecraft

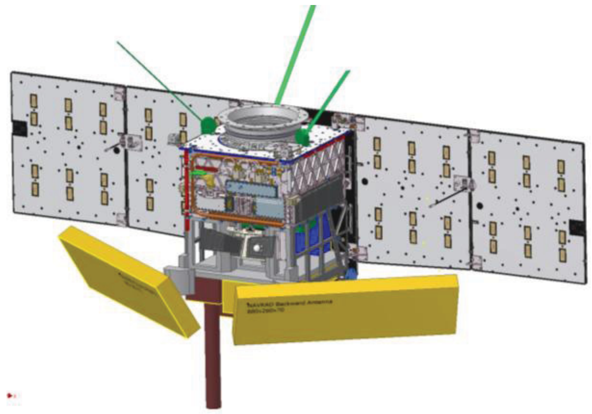

Figure 4: Deployed configuration of the SMRS spacecraft

6. GROUND SEGMENT

The ground segment of the SMRS mission will consist of a Payload Data Gateway, Neustrelitz, a Telemetry and Telecommand Gateway, Weilheim, a Mission Operations Centre (MOC), GSOC in Oberpfaffenhofen and a User Data Processing Centre for each payload. The two gateways and MOC are identical to the ones used in the TET-1 mission [2] to allow maximum reuse of ground segment equipment.

To demonstrate timely delivery of data, TrollSat and SvalSat can be included as Payload Data Gateways. By using these two polar ground stations, the data latency of the SMRS payload data can be significantly reduced. Although not the baseline for the SMRS mission, the implementation of Svalbard and TrollSat can be temporary to increase the amount of data downlinked and to demonstrate a reduced timeliness. The benefit and need of more timely data can then be evaluated and traded against the additional involved costs.

Although Neustrelitz has a reduced data downlink capability compared to Svalbard or TrollSat, enough data is generated to provide adequate services. The payload data will be handled by the User Data Processing Centre (UDPC's), responsible for payload data processing, monitoring, archiving, reporting status and dissemination of data products to the users and service providers.

7. MISSION OPERATIONS

Through the SMRS study, various operational scenarios were investigated with the intention of validating the payload and sensor data. The operational concepts of the payloads were adjusted where appropriate for the different phases of the mission. The duration of each mission phase is not uniform for all payloads because of their different TRLs.

In the technology demonstration phase, the priority is placed on the experimentation and validation of the sensors and the optimization of settings. To properly evaluate the function and performance of the payloads they will be operated in areas of low, medium and high ship densities. The primary acquisition of this phase will be used to get a raw data product that can be investigated and processed on the ground with various algorithms to optimize the signal processing.

In the routine operations phase, the priority is placed on the delivery of data to the users and service providers. The payload operation will be maximised to the limits of the spacecraft power and data budgets. The main goal of the routine operations phase is to provide data in a timely manner, therefore the implementation of TrollSat and Svalbard might prove to be beneficial during this phase.

Different scenarios have been defined in the area of maritime surveillance to allow the analysis of the SMRS operational concept. One example scenario focuses on the monitoring of a cargo ship suspected by the fishing authorities for doing illegal transhipment of catches (so-called IUU). In Figure 5, the track of such a ship, which movements can be monitored by the SMRS spacecraft, is shown.

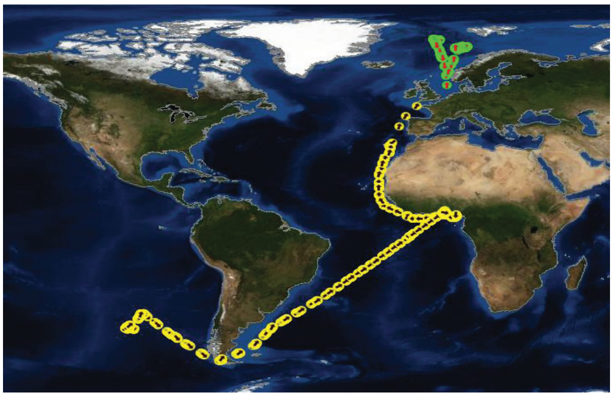

Figure 5: Illustration of the IUU fishing ship track (source: FFI)

8. CONCLUSION

The Space-based Maritime Reconnaissance and Surveillance (SMRS) mission will demonstrate multiple technologies related to maritime surveillance and demonstrate the benefit and ability to process and use the data for maritime applications. SMRS looks at all ends of the process, proving to be a well rounded mission, providing genuine developments for all parties involved in maritime surveillance.

The mission will demonstrate the technologies and services in two phases, each with a focus on different mission aspects. The technologies that will be demonstrated throughout the SMRS mission are an AIS receiver, NAVRAD detector, Maritime Frequency Monitoring Package, and a Frequency Monitoring Package. The two mission phases that will make-up the nominal operations are described:

- Technology demonstration: Verify algorithms and optimize sensor settings for reliable ship detection during operations.
- Routine operations: Data acquisition and data fusion for maritime safety, security and environmental services, as well as monitoring of frequency spectrum utilization.

The goal of SMRS is not only to prove these technologies that can be applied to maritime surveillance, but also to prove the ability and benefit of data fusion products. SMRS will be able to acquire data from multiple payloads simultaneously, dramatically increasing the confidence in the reported maritime picture and gathered information.

The strength of the SMRS system is that it provides simultaneous measurements using independent techniques. Such measurements enable data fusion that significantly increases the confidence of the data and gives more reliable detection of anomalies. Furthermore, through selecting an orbit that is similar to most Earth Observation SAR satellites, fused data products with SAR satellites can also easily be provided.

9. REFERENCES

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