A Review of Space Situational Awareness Satellites:Silentbarker

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Abstract. Reviewed the development and status quo of space situational awareness satellites in the United States. According to the launch time of the satellites, four typical space situational awareness satellites, namely Midcourse Space Experiment, Space-Based Surveillance System, Geosynchronous Space Situational Awareness Program and Silentbarker are introduced. The basic information and mission requirements of these four typical space situational awareness satellites are described. This paper analyzes the development trend of space situational awareness satellites in the future, and provides reference for commercial space situational awareness satellites in the future.

Keywords: space situational awareness satellite; task requirements; space security; commercial aerospace

1. Introduction

Space Situational Awareness (SSA) is the current awareness and future prediction of all elements, actions and activities of the space environment and space objects. [1] As the "eyes" in space, space situational awareness satellites have the ability of target identification and target monitoring, which is one of the core capabilities to ensure the safety of space activities.

Most space situational awareness satellites are equipped with advanced imaging technology, carrying high-performance thrusters and a large amount of fuel, they can meet the needs of the corresponding task in a short time, and the observation ability and maneuvering ability are especially prominent during the task, which is of great help to the perception of space. [2]

This paper introduces the development and current situation of space situational awareness satellites, and looks forward to the future development of space situational awareness satellites, in order to provide reference for commercial space situational awareness satellites in the future.

2. Space Situational Awareness Satellites

2.1 Previous life: Midcourse Space Experiment

2.1.1 The Base

The past life of Silentbarker can be traced back to the 1990s, when the United States began to develop and launch space situational awareness satellites, intending to maintain its absolute supremacy in the space field.

In 1996, the United States launched the Midcourse Space Experiment (MSX), which carried the Space-Based Visible (SBV), officially operated since 1998, and officially retired in 2008. The valuable data experience gained over the past decade has been applied to the Space-Based Surveillance System (SBSS).

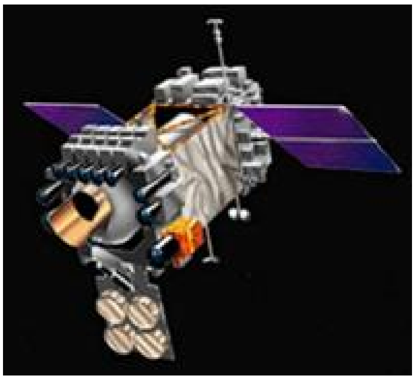

Fig. 1 Midcourse Space Experiment

Table 1. MSX Basic Data (Data as of June 20, 2024)

SATNAME	INTLEDS	LAUNCH	VEHICLE	SITE	PERIOD/day	INCL	ALTITUDE
MSX	1996-024A	1996-04-24	Minotaur-4	Va SLC-8	102.99	98.97°	893×906

2.1.2 Primary Mission

The MSX satellite is located in the sun-synchronous orbit, its body size is about 160cm×160cm×520cm, and the launch mass is about 2812kg. Designed to last five years, but it served for twelve. The MSX is an advanced concept technology demonstration (ACTD) of the SBV sensor. Regardless of weather, day and night limitations, the SBV, the only sensor on the MSX, always provides complete metric and Space object recognition coverage for the space surveillance network (SSN) in the geosynchronous belt.

The primary mission of MSX is to detect, acquire, and track targets and distinguish between lethal and non-lethal objects (detailed characterization and modeling of target objects and their associated ground, Earth edge, and celestial background phenomenology). The information collected by MSX will help fill significant space, spectral, and temporal gaps that exist in current models of the space environment, supporting the strategic defense initiative (SDI) by providing system functional demonstrations, target and background data, and technology demonstrations required for midcourse sensor platforms. It demonstrates the ability to acquire and track midcourse objects against a realistic background. The target is tested using the geometry, resolution and frame rate that are representative of the system, and infrared technology is used to operate the sensor. At the same time, MSX integrates a feature not found in other spacecraft: closed-loop tracking of targets other than stars. The tracking processor can obtain sensor information from multiple sensors to collect targets and track them in a closed loop. [3,4]

MSX's retirement marks the end of one of the most successful U.S. satellite programs ever. The MSX satellite not only accomplished an ambitious and important mission, but also provided a large amount of useful data well beyond its design life and explored the limits of mid-level sensor performance functions such as acquisition, cluster tracking, resolution, batch filtering, discrimination, and multi-sensor fusion.

2.2 This life: Space-Based Surveillance System

2.2.1 The Base

In 2002, building on the success of the MSX satellite, the U.S. military launched the Space-Based Surveillance System, a program that combines satellite constellations with supporting ground infrastructure to track Space objects in orbit. And enable space situational awareness for future space control operations. The project will eventually build a constellation of low-Earth orbit optical remote sensing satellites with all-weather orbital sensing.

The military plans to develop SBSS in two phases: The first phase will be the launch of a Block 10 satellite in September 2010 to replace the MSX satellite as the lead satellite for SBSS. In the second phase, the United States will launch four more satellites to form a constellation with the Block 10 satellite. After the completion of the SBSS, the United States will form an integrated space surveillance capability.

In order to fill the gap between SBSS and SBSS FO (SBSS Follow-up, also known as Silentbarker), the United States commissioned the MIT Lincoln Laboratory to develop Operationally Responsive Space5 (ORS-5). It was launched in August 2017.

Fig. 2 taken during the Block 10 integration

Fig. 3 ORS-5 was mounted on a rocket

Table 2. SBSS and ORS-5 Basic Data (Data as of June 20, 2024)

SATNAME	INTLEDS	LAUNCH	VEHICLE	SITE	PERIOD/day	INCL	ALTITUDE/km
SBSS（USA 216）	2010-028A	2010-09-26	Minotaur IV	Vandenberg Space Force Base SLC-8	97.08	97.87°	618×620
ORS-5 SENSORSAT	2017-050A	2017-08-26	Minotaur IV Orion-38	CC SLC-46	96.33	0.04°	573×588

2.2.2 Primary Mission

SBSS-1, a follow-up mission to the ACTD of the SBV sensor, is located in a sun-synchronous orbit, and the spacecraft has a launch mass of 1,031 kg and an average power generation of 840W. The mission design life is 7 years. But it has not retired. On February 23, 2011, the Space and Missile Systems Center (SMC, now the Space Systems Command (SSC)) transferred control of SBSS-1 to the 1st Space Operations Squadron (1 SOPS) at Schriever Air Force Base, marking the start of the satellite's mission. The SBV imager on the SBSS-1 has a 30 cm aperture telescope with a 2.4 megapixel detector, more than twice the sensitivity and ten times the capacity of the MSX. The SBSS-1 provides a clear view of objects orbiting the Earth throughout the day, making an average of more than 12,000 deep space observations per day. Based on data from SBSS pre-deployment available capabilities, SBSS-1 has resulted in a fivefold increase in observations and an estimated 66 percent reduction in satellite losses. Compared to ground-based space situational awareness equipment, the SBSS-1 increases SSA performance by three times. [5,6]

ORS-5, also known as Sensorsat, is a single satellite constellation. It is about 1.5m long and has a mass of about 140kg. Its most unique feature is the combined use of Time Delay Integration (TDI) technology in the sensor's camera system and flight geometry, which, when combined, allows continuous imaging and reading of the sensor, resulting in uninterrupted imaging of the GEO orbit. ORS-5 provides space situational awareness at a low cost and fills the gap in the Block 10 mission, delaying subsequent SBSS launches. [7]

2.3 The twin: Geosynchronous Space Situational Awareness Program

2.3.1 Base data

To further control strategic areas in Space and ensure its own space superiority, the United States Air Force proposed the Geosynchronous Space Situational Awareness Program (GSSAP). On August 2, 2023, the U.S. Space Operations Command announced that GSSAP-2 was no longer in service. At the same time, two more GSSAP satellites have been ordered, namely GSSAP-7 and GSSAP-8. [8]

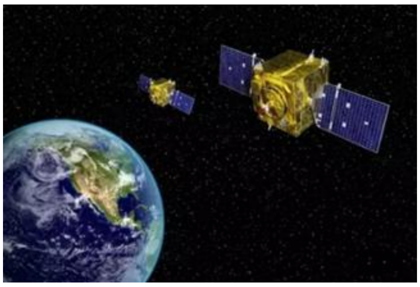

Fig. 4 Geosynchronous Space Situational Awareness Program

Table 3. GSSAP Basic Data (Data as of June 20, 2024)

SATNAME	INTLEDS	LAUNCH	VEHICLE	SITE	PERIOD/day	INCL	ALTITUDE/km
GSSAP-1	2014-043A	2014-07-28	Delta-4M+(4,2)	CC SLC-37B	1488.11	3.11	36788×36808
GSSAP-2	2014-043B	2014-07-28	Delta-4M+(4,2)	CC SLC-37B	1452.64	2.36	36104×36117
GSSAP-3	2016-052A	2016-08-19	Delta-4M+(4,2)(upg.)	CC SLC-37B	1434.59	1.66	35756×35758
GSSAP-4	2016-052B	2016-08-19	Delta-4M+(4,2)(upg.)	CC SLC-37B	1437.28	1.67	35796×35824
GSSAP-5	2022-006A	2022-01-21	Atlas-5（511）	CC SLC-41	1437.82	1.36	35807×35833
GSSAP-6	2022-006B	2022-01-21	Atlas-5（511）	CC SLC-41	1436.08	0.22	35775×35798

2.3.2 Primary Mission

The GSSAP as a dedicated SSN sensor for U.S. Strategic Command to monitor GEO collision threats and potential adversaries, its primary contractor is Orbital ATK. The GSSAP carries optoelectronic sensors that take up a clear, light-free vantage point to perform Rendezvous and Proximity Operations (RPO). RPO enables spacecraft to maneuver near resident space objects of interest by tracking radio emissions from resident space objects as an indicator of satellite identity and activity, while also maintaining flight safety through characterization of noamalic resolution and enhanced surveillance.

GSSAP 1 ~ GSSAP 4 were launched by the Delta4-Medium +(4, 2) rocket, GSSAP satellites were mounted side-by-side in the fairing, and the mass of a single GSSAP satellite is estimated to be about 650 to 700kg. It can carry large amounts of propellant and is most likely to use a single-component hydrazine propellant system for frequent orbit adjustments and to perform resident maneuvers while operating satellites drift or stay in new locations. The GSSAP satellite is able to approach and observe nearly 600 satellites on GEO, and it is speculated that during the mission of a pair of GSSAP satellites, the satellite drifts to a favorable position above or below the satellite of interest at a relatively low speed by pulse burning. [9]

Data from the International Scientific Optical Network (ISON), managed by the Russian Academy of Sciences, shows that since 2014 GSSAP satellites have carried out hundreds of maneuvers and carried out close-in or close-in operations on more than a dozen GEO satellites, which can not be tracked by ground-based optical telescopes and it is difficult to determine the true intentions of GSSAP satellites. In July 2021, GSSAP-4 deliberately approached and accompanied China's Shijian-20 satellite, with the nearest distance of 29km. The Shijian-20 satellite made a maneuver within 24h and successfully avoided GSSAP-4's reconnaissance through a maneuverable orbit change. [10]

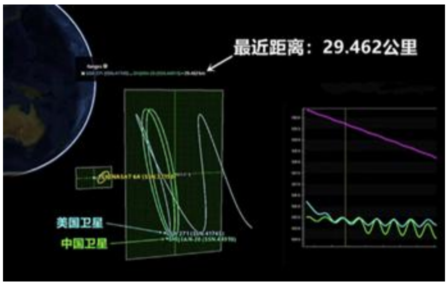

Fig. 5 GSSAP-4 close-in reconnaissance of China's Shijian-20

The GSSAP constellation characterizes objects in space to a very fine level, relaying information through the Space Force Satellite Control Network (SCN) ground stations and then to the Schriever Space Force Base in Colorado to help the United States and its Allies achieve safe use of space. The addition of the GSSAP constellation is critical to expanding the 1st Space Operations Squadron's space-based space situational awareness mission.

2.4 After life: Silentbarker

2.4.1 The Base

Before the United States Surveillance Force (USSF) partnered with the National Reconnaissance Office (NRO), Silentbarker is the successor to SBSS. Silentbarker/NROL-107 is a classified space situational awareness program that will improve satellite threat intelligence and space situational awareness capabilities. On September 10, 2023, three Silentbarker were lifted into space by a large Atlas-5 launch vehicle. The satellite's second launch is expected to take place in 2026. [11].

Fig. 6 Silentbarker launch scene

Table 4. Silentbarker Basic Data (Data as of June 20, 2024)

SATNAME	INTL EDS	LAUNCH	VEHICLE	SITE	PERIOD/day	INCL	ALTITUDE/km
Silentbarker 1	2023-140A	2023-09-10	Atlas-5(551)²	CC SLC-41	1457.63	12.07°	36188×36227
Silentbarker 2	2023-140B	2023-09-10	Atlas-5(551)²	CC SLC-41	1458.42	12.08°	36206×36239
Silentbarker 3	2023-140C	2023-09-10	Atlas-5(551)²	CC SLC-41	1436.11	12.08°	35785×35789

2.4.2 Primary Mission

An April 2023 Government Accountability Office (GAO) report titled " Space Situational Awareness – DoD Should Evaluate How it Can Use Commercial Data," estimated that the

Silentbarker program would cost $994 million. In September of the same year, Siltenbarker was launched from Cape Canaveral on an Atlas-5 (551) rocket with a powerful configuration and performance, which had a capacity of 9.8 to 18.85 tons on LEO and 4.75 to 8.9 tons on GTO. But this is the penultimate mission for the Silentbarker, and Vulcan is expected to take over the next Silentbarker mission. The maximum carrying capacity of the Vulcan LEO rocket is 25.8t, and the maximum carrying capacity of the GEO rocket is 6.5t, so it is speculated that the mass of a single star in the next mission may be as high as 1 to 2t. Silentbarker is an intelligence, surveillance and reconnaissance (ISR) satellite with the ability to search, detect and track objects from space-based sensors. It will collect real-time satellite data from GEO 24/7, will provide data back to The ground for timely monitoring and event detection, and the results will be communicated to The Combined Space Operations Center, the United States military. CSpOC, the National Space Defense Center (NSDC), and other classified users. This data is used for analysis and experimentation as well as integration into the broader space advantage architecture, ensuring that space-based space situational awareness capabilities are responsive to evolving threats. [12,13]

Although the United States has not yet announced the information on the official website, we can speculate that the three Silentbarker satellites will be deployed in orbits slightly lower or slightly higher than the geosynchronous orbit, through the relative drift of the geosynchronous orbit target to achieve geosynchronous orbit patrol detection.

The angular velocity of the target in geosynchronous orbit is assumed $\mathrm{n_T} = \frac{2\pi}{\mathrm{T_T}} = (\mathrm{u}/(\mathrm{R} + 35786)^2)^{1/2}$, The orbital altitude of the Silentbarker is hS, then its track cycle is:

$$T_S = 2\pi((R + h_S)^2/u)^{1/2}$$

The operating angular velocity is:

$$n_s = \frac{2\pi}{T_s} = (u/(R + h_S)^2)^{1/2}$$

Then the angular velocity difference between the Silentbarker and the GEO target is:

$$n_{T-S} = n_T - n_S = \frac{2\pi}{T_T} - \frac{2\pi}{T_S} = \left(\frac{u}{(R + 35786)^2}\right)^{\frac{1}{2}} - \left(\frac{u}{(R + h_S)^2}\right)^{\frac{1}{2}}$$

Then the time required for Silentbarker to complete GEO tape traversal is:

$$T_{T-s} = \frac{2\pi}{n_{T-S}} = 2\pi/(\left(\frac{u}{(R + 35786)^2}\right)^{\frac{1}{2}} - \left(\frac{u}{(R + h_S)^2}\right)^{\frac{1}{2}})$$

From Formula, it can be seen that the traversal period and the target and observation satellite. The greater the orbital altitude difference, the smaller the traversal period. Case if the orbital altitude difference is 1000km, the left and right can traverse the Earth-earth synchronous belt in 25 days, and the orbital altitude difference is 100km, which needs to be about 280 days the geosynchronous belt is traversed. However, when the distance is far away, the imaging effect is worse and can not meet the requirements of target imaging. Therefore, in order to realize the imaging of the target. The altitude difference between the Silentbarker satellite's orbit altitude and GEO is generally within 100km, and the traversal time of GEO target is shortened by multi-satellite network. [14]

The instructions and warnings provided by Silentbarker will be used to protect America's high-value assets in space, enable the United States to determine if and when space assets need to be moved, and will significantly improve the United States' ability to determine future courses of action. The launch of Silentbarker shows that the US has moved the Space Force to the sky, which initially has surveillance and reconnaissance functions, and will work with GSSAP in the future, but whether it has strike capability is unknown.

3. Comprehensive analysis

3.1 The space situational awareness satellites‘ trend of future development

With the successful launch of Silentbarker, space situational awareness satellites show a development trend towards high mobility, high sensitivity and constellation. In the future, these satellites may be deployed to orbits higher or lower than geosynchronous orbit to achieve a wider range of monitoring, thereby realizing the vision of "feeling" 80,000 miles on a sitting day. Highly mobile, highly sensitive, and constellations of space situational awareness satellites will greatly enhance the ability to identify and monitor space targets, adapt more flexibly to space situational changes, and provide stronger support for maintaining space security and protecting space assets.

3.2 Expand space situational awareness applications

The impact of space situational awareness satellites extends far beyond the protection of space assets to a wide range of other applications.

At the government level, the full use of space situational awareness technology can help monitor and maintain national space security, thereby promoting national defense security and foreign policy implementation. Through the deployment of space situational awareness satellites, the government can monitor activities in space in real time, and this real-time monitoring capability provides the nation with timely intelligence to help early warning and prevent potential space conflicts and threats. In addition, space situational awareness technology can also be used to support international cooperation and diplomatic initiatives to promote international consensus on space security and maintain peace and stability in the space environment by sharing space intelligence and coordinating space activities.

For commercial companies, they can use this data to optimize the location and orbit of their satellites, ensuring the widest service coverage, the strongest signal, and the lowest latency. This optimization not only improves the quality of service, but also enhances the market competitiveness. With accurate space situational awareness, companies can better plan the layout of their satellite fleets, avoid potential conflicts with other space objects, and maximize the effectiveness of their satellite networks. This is particularly important for industries that rely on satellites, such as communications, earth observation and navigation. Space situational awareness data can also help commercial companies explore new market opportunities. The growing problem of space debris as space activity increases provides a new business model for commercial companies involved in space debris cleanup projects. By analyzing space situational data, these companies can prioritize and strategize cleanup efforts, contributing to the governance of the global space environment. Space traffic management services are also a new market where commercial enterprises can leverage space situation data. With the increase in commercial and civilian spaceflight, space traffic management has become complex and necessary. Commercial companies can provide space traffic control solutions based on space situation data to help all types of spacecraft share the space environment safely and efficiently.

In the university sector, the integrated use of space situational awareness data has great potential to promote research collaboration, academic exchange, and innovation. Through interdisciplinary cooperation and exchanges, universities can explore new frontiers in the space field, stimulate innovative thinking, and cultivate more talents interested in space science and technology. Such cooperation not only helps to promote the progress of academic research, but also promotes the in-depth interaction between industry, universities and research institutes, promotes the transformation of scientific and technological achievements to society, and brings more possibilities for space exploration and utilization.

Summary

In the field of space situational awareness, the United States is currently leading the way, and its deployed satellites and mature technology provide many learning opportunities for other countries. To promote the development of this field, we can make full use of our own advantages, adopt advanced space technology, and actively explore and develop space situational awareness capabilities to support the expansion of commercial aerospace.

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