Concept of the Korean Optical Space Surveillance Telescope System NSOS_Beta for Monitoring the High-Altitude Orbit Region

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ABSTRACT

The NSOS-beta (Near Space Optical Survey-beta) is designed as an optical space surveillance system to monitor space objects in the Medium Earth Orbit and Geostationary Earth Orbit (GEO) region near the Korean Peninsula. The primary objective of NSOS-beta is not only to monitor satellites in GEO and inclined GEO owned by South Korea but also to independently track approaching space objects that could potentially collide with them. To achieve this, it will survey the high-orbit region containing South Korean GEO and inclined GEO satellites to detect space objects and acquire orbit information for specific target space objects. The survey of space object will primarily utilize a 0.8-meter diameter main telescope, with a 0.4-meter diameter auxiliary telescope equipped with CMOS to focus on monitoring South Korean GEO satellites. This effort will lead to the cataloging and management of detected space objects in the high-earth orbit region near South Korea, including obtaining orbit information for South Korean GEO satellites and potentially colliding space objects. The development of NSOS-beta is expected to span approximately four years, with two systems planned for installation in the Southern Hemisphere.

1. Introduction

The number of space objects has been continuously increasing. Notably, since 2012, the annual number of space object launches has risen from approximately 100 to over 2,000 by 2023 [1]. However, while the number of low Earth orbit (LEO) objects has increased dramatically, the number of geostationary orbit (GEO) objects has remained relatively stable. The exponential increase in LEO objects is not only attributed to the proliferation of space debris due to Anti-Satellite (ASAT) tests, but also to the economic launch of various satellites in the New Space era. The ongoing development of mega-constellations, such as Starlink, has significantly contributed to the rapid growth in the number of LEO objects, alongside the rise in the deployment of small satellites, such as CubeSats, which has further amplified the increase in LEO satellites.

The analysis of space hazards for GEO satellites necessitates a different perspective compared to that for LEO satellites. The number of GEO objects has not seen a significant increase relative to the number of LEO objects [2]. One contributing factor is the substantially higher launch costs associated with GEO objects compared to LEO objects. Additionally, the distance from the Earth's surface, which is tens of times greater for GEO objects, poses challenges in their utilization. However, GEO continues to offer distinct advantages over LEO. Unlike LEO, the distance from the Earth's surface to GEO is fixed, and the orbital inclination is limited. Consequently, the number of satellites that can be placed in GEO is inherently restricted. While the number of LEO satellite launches is not constrained, the placement of GEO satellites is subject to regulation. Therefore, nations or operators managing GEO satellites strive to adhere as closely as possible to their allocated orbital slots. As a result, the number of GEO objects tends to remain relatively constant.

The space hazards associated with GEO satellites differ significantly from those related to LEO satellites. Firstly, unlike LEO objects, GEO object doesn’t re-enter Earth's atmosphere. LEO objects typically re-enter within a few years or even weeks due to atmospheric drag, burning up as they descend. In contrast, GEO objects remain in orbit around the geostationary region without re-entry caused by atmospheric drag. Consequently, space hazards for GEO objects are primarily concerned with the risk of collisions. While GEO objects are generally considered to remain in fixed orbits, they are actually subject to perturbation forces that cause them to drift toward the Earth's gravitational stable points. The orbital inclination of these objects can oscillate, increasing up to 15 degrees before gradually decreasing. As a result, decommissioned satellites in GEO are not de-orbited through re-entry but are instead moved to a graveyard orbit, a region beyond the geostationary belt[3]. Moreover, because GEO satellites place specific regions, monitoring space hazards for these objects involves continuous ground-based observation of designated areas. Although a broader area must be monitored to detect approaching space objects, the ability to pinpoint the location of potential space hazards, unlike with LEO satellites, underscores the importance of sustained monitoring of specific regions. Additionally, the relative velocity of approaching objects is slower in GEO compared to LEO, and their positions are more predictable, allowing for pre-defined monitoring zones and more strategic surveillance efforts.

The space hazards associated with GEO satellites are not limited to collisions alone. According to Conjunction Data Messages (CDM) analyses conducted on GEO satellites between 2014 and 2017, approximately 60% of collision risks in GEO were attributed to operational satellites, while nearly 40% of the risks were due to space debris floating in geostationary orbit. The threat posed by debris from geostationary transfer orbits (GTO) or high-eccentricity orbits was minimal in comparison[4]. This indicated that the critical importance of monitoring GEO to mitigate space hazards related to GEO objects. Continuous monitoring of both GEO and the movement of space debris within this region is essential to assess and mitigate the collision risks faced by operational satellites. As previously mentioned, since GEO satellites do not re-enter the atmosphere due to atmospheric drag, space debris generated by explosions or other incidents remains in orbit. These debris particles can drift toward gravitational stable points, posing significant collision risks to other GEO satellites. For instance, ExoAnalytic Solutions observed in 2017 that the anomalies involving Telkom-1 and AMC-9 in orbit generated substantial space debris[5]. The potential for explosions among geostationary satellites further emphasizes the necessity for ongoing monitoring of space objects in this orbit. This continuous monitoring is crucial to identify and mitigate the risks posed by space debris, ensuring the safety and operational integrity of satellites within GEO.

Since 2011, South Korea has been operating the OWL-Net(Optical Wide-field patrol-Network), a network developed for space object observation. OWL-Net is comprised of five observation sites located across the Northern Hemisphere and is tasked with tracking the country's LEO satellites and monitoring the GEO region. Additionally, OWL-Net is responsible for tracking re-entering space objects and those that might collide with South Korea's satellites. Among the five observation sites, the ones in Mongolia and South Korea are particularly utilized to monitor the domestic GEO regions. However, OWL-Net is also employed for various purposes, including LEO space objects trackings and monitoring natural space objects. Given that it dedicates over two hours during twilight and dawn to observe LEO objects, its ability to survey the GEO region is inherently limited. To effectively mitigate space hazards in the GEO, there is a need for a dedicated space surveillance facility that can allocate more observation time to this critical area. Considering the economic costs and efforts associated with GEO surveillance, the use of optical monitoring facilities is essential. In response to this need, South Korea has initiated the development of a new optical surveillance system, NSOS-B(Near Space Optical Survey-Beta), specifically designed for high-altitude space monitoring, particularly targeting the GEO region.

2. Operational purpose of NSOS-B system

The primary objective of the NSOS-B development is to achieve optical surveillance capabilities for monitoring space hazards in the high-altitude orbit region over the Korean Peninsula. To achieve this, NSOS-B is being developed as an independent infrastructure specifically designed for the detection, identification, tracking, and surveillance of space objects in higher-altitude orbits, beyond the LEO region. The final goals of this project are to autonomously generate orbital data for high-altitude space objects and to maintain continuous monitoring of the high-altitude orbit region over the Korean Peninsula.

As of 2024, South Korea operates eight GEO satellites. However, through the upcoming Korean Positioning System (KPS) project, an additional three GEO satellites and five inclined orbit satellites are planned for deployment, with further GEO satellites expected to be launched in the future. The necessity for continuous monitoring of the GEO orbit has been underscored by previous incidents, such as the collision risks faced by the Chollian satellites(COMS-1) in 2011 and 2012 with other satellites. These events have highlighted the ongoing need for robust GEO surveillance. Fig. 1 illustrates the orbits of currently operational geostationary satellites along with the planned orbits of the future KPS satellites.

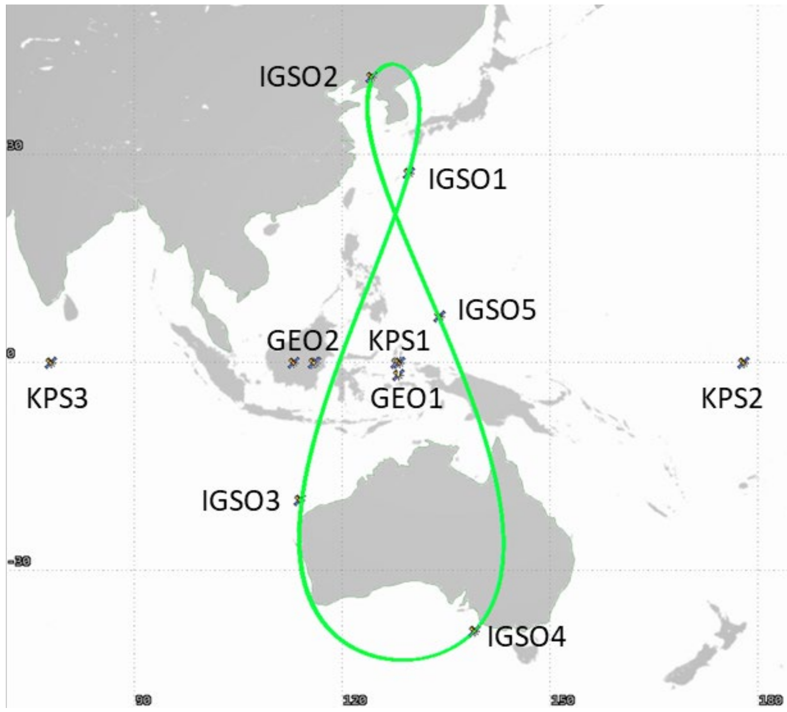

Fig. 1. Position of South Korean Geostationary Earth Orbit and Inclined orbit satellite

South Korea's GEO satellites are primarily stationed at longitudes 113°, 116°, and 128° East. The KPS constellation will include three GEO satellites, each positioned at equal longitudinal spans centered around 128° East. Additionally, four inclined orbit satellites will be placed in the same inclined orbital plane. These four inclined orbit satellites will follow a figure-eight trajectory, designed to maintain a consistent presence over the Korean Peninsula. The inclined orbit satellites will also pass over the southern region of the Australia, on the opposite side of the Korean Peninsula. The first launch of the KPS satellites is scheduled for 2027.

The expected outcomes from the development of NSOS-B are as follows: Firstly, it will enable the continuous production of orbital data for high-altitude space objects over the Korean Peninsula. This is anticipated to result in improved orbit determination accuracy compared to the current data generated by the OWL-Net. Additionally, it will allow South Korea to independently obtain orbital information for space objects that could potentially collide with its high-altitude space assets. The generated orbital data will be valuable for comprehensive space hazard analysis. Secondly, NSOS-B will facilitate the continuous monitoring of the high-altitude orbital region over the Korean Peninsula. This capability will enable the early detection of satellite station-keeping maneuvers and attitude changes, allowing for the prompt identification of potential space hazard events. Through this monitoring, unidentified or unconfirmed space objects in the high-altitude region surrounding the Korean Peninsula can be identified and cataloged, enhancing preparedness for space hazards. Moreover, the continuous surveillance of South Korea's GEO satellite region will allow for the early detection and response to collision or explosion events involving nearby satellites. The system will also play a crucial role in protecting national space assets by monitoring space objects and debris approaching South Korean satellites and conducting collision risk analyses.

The key outputs expected from the NSOS-B system are as follows:

NSOS-B is composed of a primary telescope, a wide-field monitoring telescope, and a GEO monitoring telescope. The primary telescope of NSOS-B will be used to generate mosaic images of the high-altitude orbital region. The wide-field monitoring telescope, attached to the primary telescope, will rapidly detect events occurring around the area being tracked by the primary telescope. The GEO monitoring telescope will be dedicated to the persistent observation of South Korea's geostationary satellite region. Through these observations, the system will collect astrometric and photometric data on space objects, which will be used for identifying space objects, calculating their orbital information, and assessing their status. These capabilities are essential for the identification and monitoring of space objects, allowing for the precise determination of their orbits and ensuring the protection and safety of South Korean space assets of high-orbit region.

3. Development Plan of NSOS-Beta system

The NSOS-Beta system is planned to be installed along the same longitudinal band to effectively monitor the high-altitude orbit region over South Korea. The areas around Korea, such as Australia in the Southern Hemisphere, have been identified as potential locations for installation. Additionally, in Mongolia and South Korea. the Northern Hemisphere OWL-Net were already installed. To maximize the synergy between NSOS-Beta and OWL-Net observations, it is more advantageous to install NSOS-Beta in the Southern Hemisphere. Furthermore, to prevent a reduction in observation coverage due to weather conditions and to efficiently monitor the widely dispersed KPS satellite region, it is necessary to install at least two NSOS-Beta systems. The wider the spacing between these two observatories, the more likely it is that observation efficiency will be enhanced through simultaneous observations.
The locations in Australia where telescopes can be installed are quite limited. Although NSOS-Beta is an unmanned observation facility, it still requires access to electricity and internet infrastructure. Additionally, personnel must be available to respond to any issues that arise at the observatory. Therefore, NSOS-Beta should be installed at an observatory where maintenance staff are stationed. Given that most of northern and central Australia consists of sparsely populated, harsh environments, these areas are unsuitable for installing NSOS-Beta. As a result, we are focusing on identifying suitable locations in Western Australia, south-central Australia, or near the eastern regions of the country. We are primarily looking for observatories operated by universities or private astronomical observatories as potential installation sites. Eastern Australia has long been known for its well-established astronomical observatories, with robust infrastructure supporting observations. Western Australia, on the other hand, has recently gained attention for its geographic advantages, leading to the installation of numerous facilities dedicated to space surveillance.

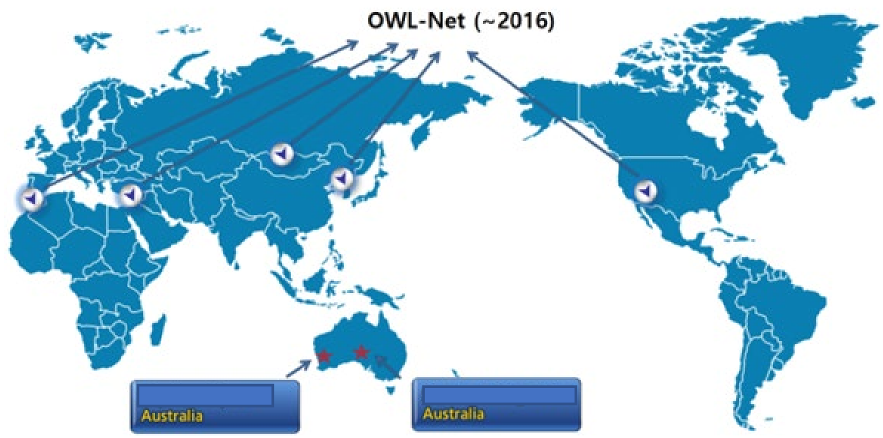

Fig. 2. Location of OWL-Net in northern hemisphere and candidate site of NSOS-Beta in the Australia

Fig. 2. indicates the locations of the OWL-Net in the Northern Hemisphere and the potential candidate sites for the installation of NSOS-Beta in Australia. As shown in Fig. 1., both Western and Eastern Australia are highly suitable locations for tracking South Korea's currently operational and future geostationary satellites. Additionally, the baseline distance between the OWL-Net observatories in Mongolia and South Korea and the candidate site of NSOS-Beta, nearly 6,000 kilometers, offers significant advantages for simultaneous observations. The installation of an observatory in Australia provides further benefits. The optical observation capabilities for LEO objects often vary with seasonal changes. An optical observatory in Australia could serve as a supporting facility for the Northern Hemisphere's OWL-Net, especially in urgent situations such as tracking re-entering space objects.
The analysis of observation results and schedule management will be handled by the headquarters, which will be established at the Korea Astronomy and Space Science Institute (KASI) in South Korea. However, the processing of observational data is intended to be carried out locally at each observatory. The analyzed results transmitted to the headquarters will be integrated with data from the OWL-Net and other space surveillance sources, enabling comprehensive space risk analysis.

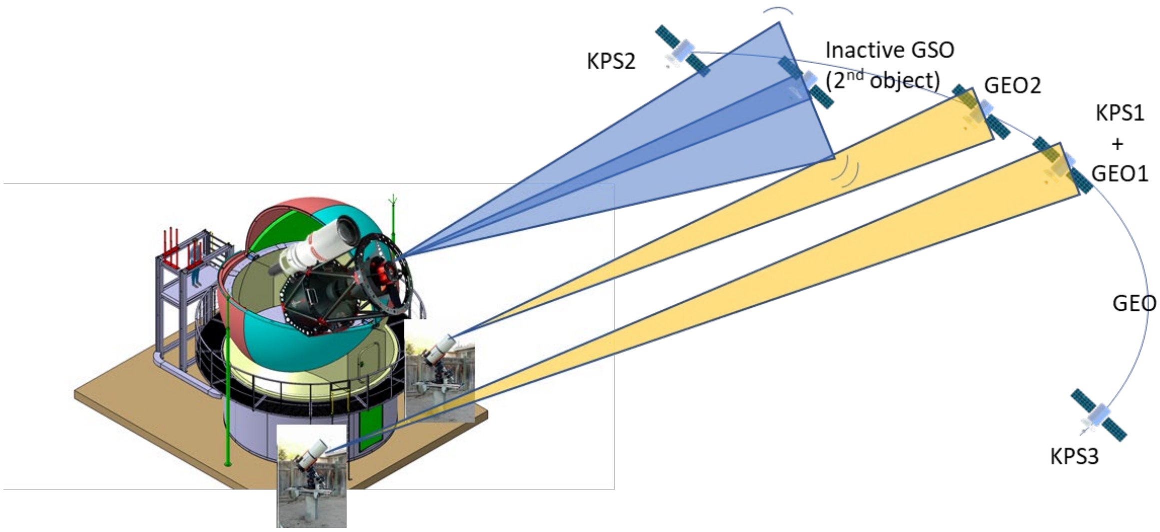

Fig. 3. Configuration of NSOS-Beta system and the observation targets of the system

As previously mentioned, NSOS-Beta is composed of a primary telescope, a wide-field monitoring telescope, and a dedicated GEO monitoring telescope. The primary telescope is an 0.8-meter-class telescope, which is expected to have approximately 2.5 times greater light-gathering capability compared to the OWL-Net telescopes. The wide-field monitoring telescope, similar in design to a guide scope, will be attached to the primary telescope. The purpose of this wide-field monitoring telescope is to quickly detect events occurring near the area being observed by the primary telescope in the GEO, allowing for rapid decision-making on whether additional observations are necessary. The GEO monitoring telescope will be mounted on a fixed mount. This telescope will be positioned to continuously track and observe the GEO satellites within the region where South Korea's GEO satellites are distributed. This allows not only for the calculation of the orbits and status check of GEO satellites but also for the focused detection of high-altitude space objects passing nearby. Since the KPS satellites are navigation satellites, they will be observed periodically as needed. Fig. 3. is shown proto-type configuration of NSOS-Beta and the observation targets of the system.

Table 1. Specification of NSOS-Beta

equipment	Optics aperture	FOV	Mount
Main telescope	0.8m class	> 1 square degree	Equatorial fork type
Wide-field monitoring telescope	0.2m class	> 20 square degree	attached
GEO monitoring telescope	0.4m class	> 4 square degree	Fixed type

Tab. 1. summarizes the specifications of the optical systems and mounts for NSOS-Beta. The field of view for the primary telescope is expected to be approximately 1 by 1 degree. The wide-field monitoring telescope is anticipated to have a field of view that is roughly five times larger than that of the primary telescope. The mount for the primary telescope will be designed as an equatorial type, which is advantageous for repeated monitoring of the high-orbit region. The GEO monitoring telescope will use a separate mount with the primary telescope, although it will be installed within the same dome as the primary telescope. Each telescope will utilize CMOS sensors to achieve rapid observation.

NSOS-Beta is an unmanned automated observation system, necessitating an automatic observation management system to determine when observations should be conducted. To support this, weather equipment for monitoring temperature, cloud cover, and humidity, along with an all-sky camera, will be installed. Additionally, an enclosure will be set up to protect the equipment, ensuring the accuracy of timing and the safekeeping of data. **Fig. 3** illustrates the basic design of the enclosure.

4. Summary

NSOS-Beta is a high-altitude monitoring optical surveillance system developed to protect South Korea's space assets from space risks. The system is designed to detect and identify space objects within the GEO region of South Korea and to track these objects to calculate their orbital information. Given that South Korea's GEO space assets are primarily located around 128° East longitude, NSOS-Beta is intended to be installed in Australia, where it can synergize with the Northern Hemisphere's OWL-Net to enhance observational effectiveness. NSOS-Beta consists of three main components: a primary telescope for high-altitude region monitoring and target tracking, a wide-field monitoring telescope for quickly detecting events around the observation area, and a GEO monitoring telescope focused on continuous observation of GEO satellites. Each telescope will operate according to its specific purpose, ensuring effective response to space hazards in the high-altitude region surrounding the Korean Peninsula. The development of the NSOS-Beta telescopes began in 2024, with the goal of completing the project by 2027.

5. REFERENCES

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