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ScienceDirect

Advances in Space Research xxx (2015) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Analysis of the angle-only orbit determination for optical tracking strategy of Korea GEO satellite, COMS

Jin Choi [a,b], Jung Hyun Jo [a,b,d,*], Kyoung-Min Roh [a], Ju-Young Son [a,b], Myung-Jin Kim [a], Young-Jun Choi [a,b], Hong-Suh Yim [a], Hong-Kyu Moon [a], Bang-Yeop Kim [c], Jang-Hyun Park [a], Erricos C. Pavlis [d]

[a] *Space Situational Awareness Center, Korea Astronomy and Space Science Institute, Daejeon 305-348, South Korea*

[b] *Korea University of Science and Technology, Daejeon 305-348, South Korea*

[c] *Geostationary Satellite Operation Team, Korea Aerospace Research Institute, Daejeon 305-600, South Korea*

[d] *Goddard Earth Science and Technology Center, University of Maryland – Baltimore County, MD 21250, USA*

Received 8 January 2015; received in revised form 3 June 2015; accepted 5 June 2015

Abstract

Increasing numbers of Geostationary Earth Orbit satellites have led to the requirement of accurate station keeping and precise orbit prediction to avoid collision between satellites. In the case of ground-based optical observation, angular resolution is better than other tracking systems, such as radar systems; however, the observation time of optical observation is limited by weather or lighting conditions. To develop an effective optical observation strategy, the optical observation campaign from January to February 2014 for Communication, Ocean and Meteorological Satellite (COMS) was conducted. Because COMS is a controlled satellite with station keeping manoeuvres performed twice a week, the observation results for 1- and 2-day observations were analysed. Sparse and sporadic cases for the sequential observation of multiple satellites and a dense case for the intensive observation of specific targets were assumed for the experiments. In the 1-day arc observation experiment, the estimated orbits for dense observation cases over 10% of the orbital period showed that the maximum difference was less than 40 km (station keeping area) for 7-day propagation compared to the estimation result using the whole 1-day measurement. For the 2-day arc observation, the orbit estimation difference could be maintained within 2 km using a more frequent observation than the 1-h interval for 13 h that was used in the sparse case. Additionally, the longitudinal and latitudinal positions via the estimation result using the optical observation were compared with the Two-Line Elements (TLEs) and operator's data. Through this study, an adequate optical tracking strategy was studied, and the possibility of cooperation with other systems was also validated.

Keywords: GEO; Optical tracking; Angle-only orbit determination; COMS; Sparse; Dense

1. Introduction

The first artificial satellite produced by mankind, Sputnik, was launched on October 4, 1957. Since then, 24 countries have launched satellites into the space. To date (April 2, 2015), 17,147 trackable artificial space objects out of the 40,556 catalogued ones are still in orbit.[1] After the first artificial space object was launched, satellite tracking, orbit determination, and identification of each satellite have been consistently pursued for the safe operation and

* Corresponding author at: Space Situational Awareness Center, Korea Astronomy and Space Science Institute, Daejeon 305-348, South Korea.

E-mail address: jhjo39@kasi.re.kr (J.H. Jo).

[1] www.celestrak.com/satcat/boxscore.asp

http://dx.doi.org/10.1016/j.asr.2015.06.005

0273-1177/

Please cite this article in press as: Choi, J., et al. Analysis of the angle-only orbit determination for optical tracking strategy of Korea GEO satellite, COMS. Adv. Space Res. (2015), http://dx.doi.org/10.1016/j.asr.2015.06.005

security of satellites (Veis, 1963). To determine or improve the satellites' orbits, signals from satellites or observation data using various equipment, including radar, lasers, and optical telescopes, are necessary. Among these equipment options, optical systems represent a relatively low cost and passive equipment for space monitoring. In particular, the Baker-Nunn camera was developed primarily for tracking space objects, such as satellites and launch vehicles. Baker-Nunn cameras were installed at 11 sites around the world and have been used in satellite observation for 12 years (Massevitch and Losinsky, 1970). After the development of the Baker-Nunn camera, dedicated satellite optical tracking systems, such as the US Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) and the Russian Okno observation networks, have been active. In addition, the European Space Agency Space Debris Telescope (ESASDT) was utilised for Space Surveillance Awareness (SSA) system operation and related research (Shoemaker and Shroyer, 2007).

The US operates a global space object observation network and provides unclassified space object information. The Joint Space Operations Centre (JSpOC) provides space object orbit information in Two Line Elements (TLEs) form. JSpOC TLEs are not in-situ osculating orbit data but rather the mean orbit data shared with the analytic propagator Simplified General Propagator 4 (SGP4). In addition, JSpOC distributes a Conjunction Data Message (CDM) for Owners and Operators. In 2009, a low Earth orbit (LEO) collision occurred between Iridium 33 and COSMOS 2251. The collision raised continuously increasing concerns regarding the dangers of collisions in Geostationary Earth Orbit (GEO) (Kelso, 2009; Lee et al., 2012). GEO is suitable for communications and broadcasting. However, due to limited spatial resources, satellite operation is regulated within limited allocated sections. The GEO protected region, Region B, was defined with a GEO altitude ± 200 km and latitude ± 15 degrees of arc (IADC, 2014). Any space debris in Region B will remain there almost forever. Kelso and Alfano (2005) introduced Satellite Orbital Conjunction Reports Assessing Threatening Encounters (SOCRATES) for GEO satellite collision avoidance. Additionally, optical tracking systems, such as the International Scientific Optical Network (ISON), continue to perform GEO ring surveillance for satellite and space debris collision avoidance research (Molotov et al., 2008).

The Republic of Korea is ranked 25th in world satellite operation and became the 11th country to enter the space club by launching the STSAT-2C satellite from the Korean territory in 2013. To date, a total of 10 LEO satellites and 7 GEO satellites have been launched for the purposes of scientific experimentation, resource observation, communications, and broadcasting. Korea plans to launch more than 11 satellites by 2020. Since 1987, a diverse range of studies have been conducted in Korea regarding satellite orbit determination. After 2000, research on the initial orbit determination, orbit estimation and observation strategies of geostationary orbit using optical observation have been pursued continuously (Kim et al., 1988; Lee et al., 2004). In addition, while 17 satellites have been placed into orbit, a number of ground stations for communication with satellites have also been constructed. However, no tracking of all of the Korean space objects, including obsolete Korean satellites, has been conducted for SSA in Korea. At the Korean Astronomy and Space Science Institute (KASI), the Near Earth Space Survey (NESS) system was used for high altitude observation. The NESS system was not dedicated to satellite tracking, but is a wide-field optical system that is able to track fast moving objects, such as asteroids. Wide Field Telescope 3 (WFT3) of the NESS system in Daejeon, Korea, has been used for satellite tracking research. KASI began development of the Optical Wide-field patrol (OWL) in 2011 for the tracking and monitoring of domestic satellites as a dedicated satellite tracking system. The WFT3 was used for back-up during the development period of the OWL system.

Using the WFT3, we performed an optical observation campaign for GEO satellite observation strategy analysis. The observation target was the Communication, Ocean and Meteorological Satellite (COMS). The COMS is an active Korean satellite that was launched in 2009 that performs the 3 tasks of Ka band communication, meteorological observation, and ocean observation. To keep COMS within a $\pm 0.05°$ control box, the station keeping manoeuvres are performed twice a week. In addition, momentum wheel control and Wheel Off-loading (WOL) manoeuvres are operated twice a day for attitude control (Hwang et al., 2008). As the optical field of view (FOV) of the WFT3 is 1 by 1°, which is relatively much larger than the COMS control box, $\pm 0.05°$ (equivalent to ± 40 km on GEO region), the COMS must be distinguished and identified from other GEO satellites in the same field.

To date, various orbit determination research studies for high altitude satellite have been conducted. Sabol (1998) and Sabol and Culp (2001) analysed the orbits of geosynchronous orbiting satellites using a few weeks of observation data. Vallado et al. (2009) used the Orbit Determination Tool Kit (ODTK) of analytical graphics, Inc., (AGI) to analyse the GEO satellite orbit estimation accuracy. The objective of the analysis was to predict the probability of collision between the satellite and geosynchronous space debris; the accuracy of TLE was improved using the optical observation data of ISON. In this experiment, global observation networks were used to obtain orbit estimation accuracy on the order of a few km with 10–15 observations per day for 3–4 days (Vallado et al., 2009). Kawase (2000) theoretically analysed the orbit estimation error for drifting geosynchronous satellites using sporadic simulated data and verified the error using observation data. Musci et al. (2004) analysed the orbit estimation accuracy using simulated sporadic GEO satellite observation data for 1 night. After the initial dense observation, 3 follow-up dense observations were simulated. The