OWL-NET: A GLOBAL NETWORK OF ROBOTIC TELESCOPES DEDICATED TO SSA OBSERVATION

Jang-Hyun Park(1), Hong-Suh Yim(1), Young-Jun Choi(1, 2), Jung Hyun Jo(1, 2), Hong-Kyu Moon(1), Young-Sik Park(1), Young-Ho Bae(1), Sun-Youp Park(1), Dong-Goo Roh(1), Sungki Cho(1), Eun-Jung Choi(1), Myung-Jin Kim(1), Jin Choi(1, 2)

(1) Korea Astronomy and Space Science Institute, 776, Daedeokdae-ro, Youseong-gu, Daejeon, Republic of Korea, Email:jhpark@kasi.re.kr
(2) University of Science and Technology, Daejeon, Republic of Korea

ABSTRACT

We present a global network of optical telescopes developed for satellite tracking and its early test results. The OWL-Net (Optical Wide-field patroL Network) is composed of 0.5m wide-field optical telescopes spread over the globe (Mongolia, Morocco, Israel, South Korea, and USA). All the observing stations are identical, operated in a fully robotic manner, and controlled by the headquarters located in Daejeon, Korea. The main objective of the OWL-Net is to get orbital information of Korean LEO and GEO satellites using purely optical means and to maintain their orbital elements.

1 INTRODUCTION

Tracking of LEO satellites using an optical system is clearly disadvantageous compared to a radar system, but it is within reasonable range of cost and technology for most users. Several types of optical surveillance systems have been developed since the Baker-Nunn camera, one of the earliest optical system to monitor satellites [1, 2]. Even though tracking of LEO satellites is mostly dependent on radar systems, the use of optical systems to determine orbits of GEO satellites is still increasing. In recent years, most of the technical components for optical surveillance such as optics, mechanics, electronic control, and detector have been remarkably improved compared to the Baker-Nunn camera era. If we are not interested in monitoring tens of thousands of space objects but dozens of space objects, optical tracking and monitoring can be a cost-effective alternative.

In particular, because an optical surveillance system can monitor all objects from LEO to GEO and astronomical observations are also possible, it can be used for multi purposes. As a representative example, International Scientific Optical Network produces many research results by utilizing astronomical telescopes to observe space objects on GEO [3]. However, a more sophisticated approach is needed to observe space objects on LEO and to determine their orbital elements. First of all, we need observational sites as many as possible to overcome the restriction of observable time and the weather condition which are two major disadvantages of the optical system. Secondly, unlike ordinary celestial objects, fast moving objects require fast-moving mounts and optics with wide field-of-view to be observed. Thirdly, one needs a detector system that can acquire many observation points at a time and measure the exact time for each point. Fourthly, capabilities for systematic operation and maintenance of observation networks are needed.

The OWL-Net is a system developed to track LEO satellites at relatively low cost using current technology for optical observation and to determine orbit by analysing optical data. It is designed as a multipurpose system capable of observing GEO satellites as well as LEO satellites and performing astronomical observations. It is currently operating in five countries around the world, including Korea. Chapter 2 describes the OWL-Net sites and network configuration. Chapter 3 describes observation system installed in each site. The detector system and data processing is discussed in Chapter 4 and the initial performance of the OWL-Net in Chapter 5.

2 OWL-NET SYSTEM CONFIGURATION

2.1 OWL-Net System Design and Configuration

The primary goals of the OWL-Net are to track domestic satellites and to acquire orbital information using optical means. To overcome the limitations of optical observations, we constructed a network for optical observation distributed in five locations around the world which is able to obtain at least 200 observational points per satellite within a week [4]. The OWL-Net consists of five identical observatories, based on a 0.5-meter wide-field telescope, and a head quarter which manages the whole network.

The optical system was designed so that the position of satellites obtained from the TLE information can be safely entered in the field of view of the telescope.
To observe satellites using the orbital information with 10 km accuracy initially, a telescope system with an

Proc. 7th European Conference on Space Debris, Darmstadt, Germany, 18–21 April 2017, published by the ESA Space Debris Office
Ed. T. Flohrer & F. Schmitz, (http://spacedebris2017.sdo.esoc.esa.int, June 2017)

optic of wide field view and a fast moving mount is required. The mount can not only follow the satellite directly, but also move fast enough to get multiple exposures in a single pass. The detector system was designed to obtain multiple observation points during a single exposure.

Each station is controlled by a single master computer called Site Operating System (SOS), which connects to the headquarters (HQ). The SOS maintains the schedule information transmitted from the HQ and issues orders for observation. After each observation is finished, the detector system immediately analyses the observation data, extracts the position and time information from the satellite trajectory, converts it into an ASCII code form, and finally transmits it to the HQ through the SOS.

The fully automated operation of the telescope system and the real-time monitoring of the site environment are required for the operation and maintenance of the global network. Environmental information is collected from the environment control system and transmitted to the HQ through the SOS. Images from CCTV installed inside and outside the dome are periodically transmitted to the HQ so that the surrounding environment can be directly monitored. In addition, the telescope control system was custom-made designed and manufactured for easy maintenance and part-replacement. Fig. 1 shows the overall system configuration of the OWL-Net.

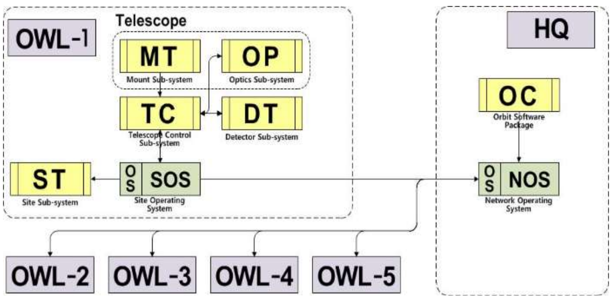

Figure 1. System configuration of the OWL-Net

2.2 OWL-Net sites

We analysed basic conditions (weather conditions, infrastructure, technology support, accessibility) of over 300 astronomical observatories around the world and selected 17 sites as early candidates for OWL-Net sites. Afterwards, the final 5 sites were selected through additional research and direct visits. Initially, both the northern and southern hemispheres were considered, but only the northern hemisphere sites were selected during the negotiation process. The final location and site images of the OWL-Net are shown in Fig. 2 and Fig. 3. Prior to the final decision on the site, we performed a visibility analysis of 17 primary sites for domestic satellites which are primary targets of the OWL-Net. Simulation results show that the higher the latitude, the more advantageous, but there is no problem to extract orbit information from optical observations at most sites [5]. Therefore, we put priority on operation efficiency of sites such as clear nights and infrastructure rather than location, and distributed them evenly on longitude.

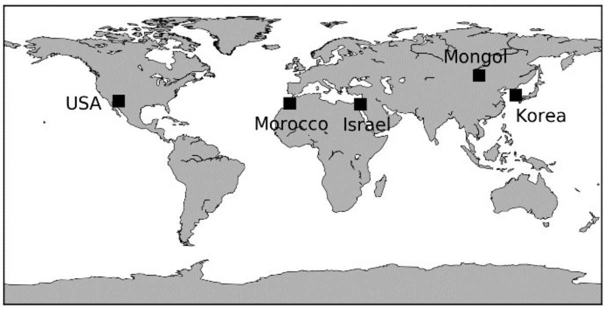

Figure 2. Site location map of the OWL-Net


Figure 3. Site photos of the OWL-Net (Testbed, Mongolia, Israel, Korea, USA, Morocco counter clockwise from upper left)

2.3 Scheduling and Operation

The entire OWL-Net is connected through the internet and controlled as one system. The software that operates the entire network controls each station and performs observations to maximize the efficiency and productivity of each station.

The allocation of observation time for each station is a key element of the preparation of the mission planning and is the main role of the Network Operating System (NOS). The Network Scheduling System (NSS) determines the priorities of observations based on past observation records, future observability, and user requirements. As a result, an Observation Command File (OCF) is created for each site at every day, and transmitted to each station. The SOS at each site analyses the OCF and performs observation allocated to each station. The environment and status information of each station is transmitted to the HQ in real time and displayed on the screen in the HQ. Various statistics such as weather conditions, instrument status, observation results and total operating hours for each site are displayed at the HQ. If any problem occurs, the HQ recognizes it and automatically reports to the person in charge of system operation.

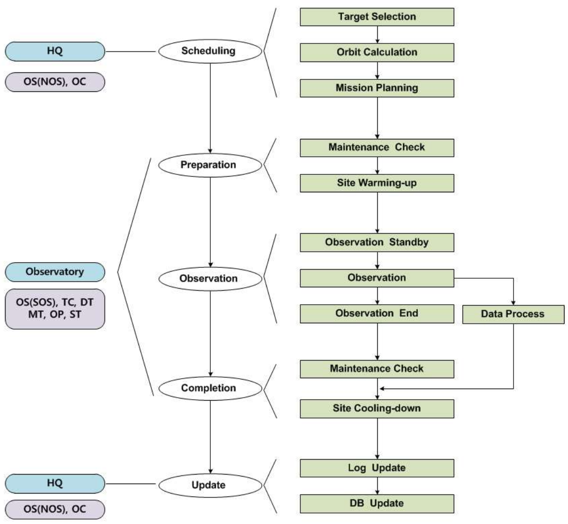

Figure 4. Observation process of the OWL-Net

Observation process of the OWL-Net consists of three stages. The first step is scheduling. The NSS computes the sunset/sunrise time and ephemeris for target satellites, creates an OCF based on priorities and possibilities of observation, and sends it to each station. An OCF file contains all the information necessary for the observation including observatories, objects, exposure time, filters, and moving speed of object. The second step is a real action for observation, which is divided into three detailed stages.

The SOS interprets the received OCFs and sends them to the Telescope Control system (TC). First, it performs the maintenance check and the site warming-up. At the end of this process, it performs the actual observations and save the results. After the observation is completed, the maintenance check and the site cooling-down process are performed, and then the log update process and the DB update process are performed. At this time, a set of processed data is transmitted to the HQ. The environmental monitoring information for the maintenance check is also transmitted to the HQ and displayed at the HQ from time to time. All of these are done completely automatically without human intervention. Fig. 4 briefly shows the observation process of the OWL-Net.

2.4 Observation Modes

OWL-Net's observation modes are largely divided into three categories for LEO, MEO/GEO satellites, and astronomical observations. Observation mode for LEO satellite is to observe a specific satellite and then to estimate orbital elements in which chopper operation applies. The mode for space object survey only extracts trail without chopper operation. In the case of MEO or GEO satellites, it is divided into a sub-mode for observing specific satellites and a sub-mode for surveying an area. In both cases, chopper operation is not applied. In the astronomical observation mode, it is divided into a sub-mode for observing general celestial objects and a sub-mode for observing fast-moving asteroids. The general mode simply acquires images at the specific coordinates during a given exposure time. In case of fast asteroids, only chopper operation is added to the general mode. All observation modes are based on sidereal tracking and use filters if necessary.

3 TELESCOPES AND INSTRUMENTS

3.1 Telescopes

There are two methods based on on-tracking and sidereal tracking method to obtain the positional information from optical observation of satellites. The on-tracking method can obtain a large number of positions in a short time, but it has to rely on mechanical precision and cannot obtain coordinates when tracking problems occur. The number of observational points obtained at one time is limited when using a sidereal tracking method, but we can obtain the precise positional information regardless of the mechanical state since the positional information is extracted only relying on the background stars. We adopted a coordinate extraction method based on sidereal tracking because we find astronomical observation can provide more reliable solutions.

We have developed a telescope system (optical tube assembly, mount, telescope controller) for robotic observation dedicated to satellite tracking. The aperture size of the mirror is 0.5m with Ritchey-Chretien configuration, and its field of view is 1.1 deg x 1.1 deg on the CCD sensor. The optical tube assembly was manufactured by Officina Stellare. The alt-az type telescope mount was developed for the OWL-Net exclusively. Its maximum slewing speed is 20 deg/sec, and its acceleration performance is 20 deg/sec. The pointing accuracy is 5 arcsec, and the tracking accuracy is 2 arcsec/10 minutes. Although on-tracking is also available, it is just for the experimental use.

Figure 5. Telescope system (optical tube assembly and mount) of the OWL-Net installed in Israel site

We have developed a dedicated control electronics and software for the telescope control. Because of the frequent upgrades or discontinuity, using commercial computers and control electronics makes maintenance difficult. The telescope control electronics is installed directly inside the mount and controlled from via the internet connection. Since the telescope is exposed to the outside during observation, a heater to control the temperature is installed inside the mount. In the case of the CCD camera, we need a separate computer for its control, so an industrial grade computer is installed also inside the mount.

Figure 6. Telescope control units of the OWL-Net imbedded in the mount

3.2 Instruments

OWL-Net is currently equipped with a 4k x 4k CCD camera. For easy replacement and maintenance of instruments, we designed a single unit back-end including the CCD camera, called “wheel station”. The wheel station includes all the moving parts like as filter wheel, chopper, and de-rotator. A chopper system is applied to obtain multiple streaks from a single exposure. The rotation speed of the chopper can be changed up to 50Hz. When the exposure starts, the acceleration starts at the same time and it reaches the desired number of revolutions within a few seconds. During the acceleration period, the length of streaks is changed, so that the traveling direction and the starting point of the satellite can be identified. The wheel station is also equipped with a time tagger to record the time when the chopper wing is changed to open or close position. This makes it possible to identify the time of each streak with accuracy of about 1/1000 second.

Figure 7. CCD camera and wheel station including filter, chopper, and de-rotator

4 DATA ANALYSIS AND ORBIT ESTIATION

4.1 Data Analysis

The image data obtained from the OWL-Net are the trajectories generated by the satellites and the stars that appear in the background (Fig. 8). The first step for data processing includes correction for bias, dark, and flat filed as in general astronomical image processing. However, if we need only the location information of target objects, this correction is not applied. The next step is to find background stars and satellite trajectories from the image, and to measure their position on the CCD.

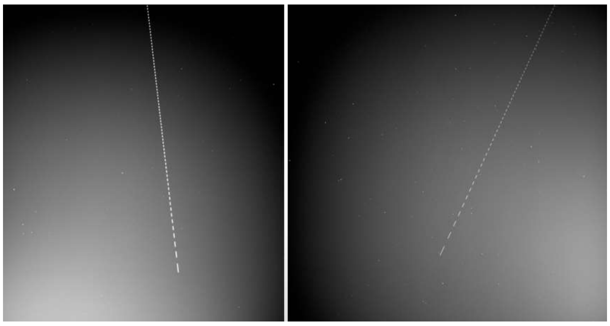

Figure 8. Trail images of satellites (left: Adeos-II, right: Okesan-4) taken from Mongolian site

SExtractor, which is a software for astronomical image processing, is used for that purpose. The coordinates of the midpoint of each trail are obtained, and then they are matched with the time information recorded by the time tagger. We compare the selected stars in the image with stars in an astronomical star chart to obtain the WCS

(World Coordinate System) solution using WCSTools. The final solution of real position and time for observed satellites are stored in an ASCII file and transmitted immediately to the HQ.

4.2 Orbit Estimations

ODTK, a commercial software developed by AGI, is used for orbital estimation from the position and time data extracted from the observed images. The initial orbit solution is determined by Gooding method, and then POD is applied. The GEOS-C data format is adopted to process OWL-Net optical data. We have developed a batch type orbit estimator based on least square method to link ODTK with OWL-Net, and also developed a software to automate orbit computation and trajectory maintenance from OWL-Net observations based on ODTK.

5 SYSTEM PERFORMANCE

5.1 Optical Observation Performance

Parking and pointing actions to a star at an appropriate altitude were repeatedly performed to measure the pointing accuracy of the telescope. Repeated photographs for specific stars showed that the pointing offset to the RA direction was within -0.9 to 1.5 arcsec, and the pointing offset to the DEC direction was within -0.6 to 0.5 arcsec. To measure the tracking accuracy, we have taken 15 consecutive images at intervals of 1 minute after first pointing was performed on the same star. As a result, it was confirmed that both RA and DEC directions are within 1 arcsec.

To measure the observational limits of the OWL-Net system, standardized observations for astronomical standard stars were performed at the Mongolian site and the testbed site. Using the Johnson B, V, R, and I filters installed in the OWL-Net system, star images were taken at various exposure times for standard stars in the Stetson catalogue. The general pre-processing procedures for astronomical observation were applied to the images such as bias, dark and flat fielding, and then air mass correction coefficients and standard correction coefficients were obtained.

As a result, the limited magnitude of the V filter was 15.8 and 14.7 for the Mongolian sites and the test bed sites, respectively. The sky of test bed is a bit brighter than Mongolian site because it is located in a big city. It is estimated that other sites are similar to the Mongolian site considering the surrounding environment. We are going to perform observation for the calibration on other sites to measure limited magnitude and optical performance.

5.2 Orbit Estimation Performance

To confirm the orbit determination capability of the OWL-Net, we used KOMPSAT-1 satellite data taken from the Mongolian site. KOMPSAT-1 is one of the Korean earth observation satellites orbiting low earth orbit at 700km x 740km. The data were taken in November, 2014. We got four passages over 5 days. 8-9 images were obtained for each pass. The estimated orbit were compared with 12 consecutive TLEs and the results are shown in Fig. 9. Although we are still in a test phase, our conclusion is that the OWL-Net is doing its job well as designed.

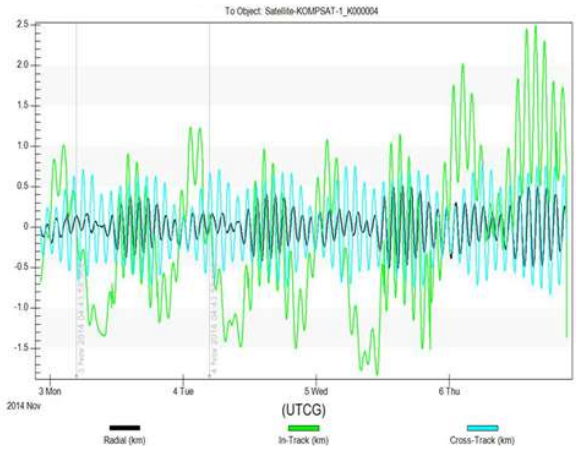

Figure 9. Orbit solution of KOMPSAT-1 calculated from optical data (Mongolian station)

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