Proto-Type Development of Optical Wide-field Patrol Network and Test Observation

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ABSTRACT

We present a prototype system developed for optical satellite tracking and its preliminary test observation results. The main objective of the OWL (Optical Wide-field patroL) network is to get orbital information of Korean domestic satellites using pure optical means and to maintain their orbital elements. The network is composed of 5 small wide-field telescopes spread over the globe. Each observing station is operated in fully robotic manner and controlled by the headquarter located in Daejeon, Korea. We have developed a compact telescope system for robotic observation and easy maintenance. The aperture size is 0.5m with Ritchey-Chretien configuration and its field of view is 1.1 deg. It is equipped with 4K CCD with 9um pixel size, and its pixel scale is 0.98 arcsec/pixel. A chopper wheel with variable speed was adopted to get more points in a single shot. The CCD camera and all the rotating parts (chopper wheel, de-rotator and filter wheel) are integrated into one compact component called wheel station. Each station is equipped with a full automatic dome and heavy duty environment monitoring system. We could get an image every 20 seconds and up to ~100 trail points in a single exposure. Each point is time-tagged by ~1/1000 second precision. For one of best cases, we could estimate satellite position with RMS ~ 0.5km accuracy in the along-track with only 4 exposures (~100 points). The first system was moved to the Mongolian site after finishing the verification test in the test-bed site in Daejeon Korea. The second system will be installed in the end of this year.

1. INTRODUCTION

Since the Baker-Nunn camera which was the first dedicated optical satellite tracking network system, various kinds of optical system have been developed [1, 2]. Although tracking of LEO satellite is now mostly resorted to radar system, usage of optical systems still increases for GEO orbit determination. Optical systems have obvious disadvantages compared with radar systems for LEO object tracking, but the cost and technology for optical tracking system can be in the accessible ranges for most users. Now-a-days, most technologies for making optical tracking system such as optics, mechanical designs, control electronics, and detectors are in much higher level compared with the Bake-Nunn camera era. If we are interested in tracking only tens or a few hundreds of objects rather than tens of thousands, the optical tracking system can be cost-effective alternatives for satellite tracking. A brief design concept for the OWL-Net design is discussed in section 2, details about the proto-type system and preliminary test observation results are followed in section 4 and 5 respectively, and future plans are summarized in section 6.

2. OWL-NET DESIGN CONCEPT

The primary goal of the OWL-Net is to achieve and to maintain orbital information of LEO satellites by pure optical means. To overcome limits of optical observation, we need a global network of telescopes which run in a fully autonomous way. Optics should be designed to get a satellite safely into the field of view with TLE data and the mount system should be fast enough not only to get several shots in a single pass but also be able to follow the satellite. We have designed a detector system capable of taking many points in a single shot. For easy maintenance, we have designed a custom-made telescope control system and the whole system is designed as a unit base for easy replacement when needed.

Each observatory is controlled by one master computer; called the Site Operating Sever (SOS) connected to headquarter (HQ). SOS maintains scheduling information transferred from HQ and commands observation according to the schedule. After observation, the detector system reduces observation data into time and coordinates in an ASCII form and transfers them to HQ through SOS. All the environmental data are gathered into a single custom-made environment control board transferred to HQ through SOS. CCTVs, located in and out of a dome, continuously monitor the current status of the observatory, and selectively captured image are also transferred to HQ in a near real time. Fig. 1 shows overall connection among OWL-Net components.

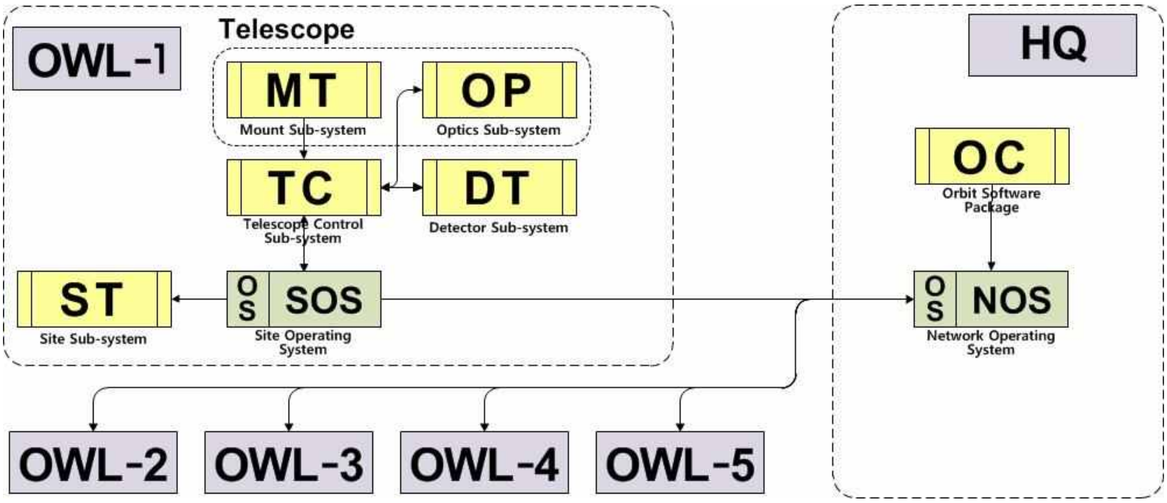


Fig. 1. Schematic diagrams of overall OWL-Net

3. DEVELOPMENT OF PROTO-TYPE SYSTEM

3.1 Telescope System

The telescope consists of a 0.5m primary mirror and a 0.2m secondary mirror with multiple corrections lenses. Conclusive f-number is 2.99 resulting in field of view 1.75 degree x 1.75 degree, which is wide enough to detect a target satellite in a single image. However, our first proto-type OTA failed to satisfy our requirements and was replaced by an OTA made by an Italian manufacturer, Officina Stellare. The replacement OTA has the same aperture size and final focus ratio of f/3.8. It is composed of two aspherical mirrors and three corrector lenses. Its field of view is 1.1 deg x 1.1 deg smaller than original design, but still being able to find satellites in the range of TLE error. Fig. 2 shows Officina OTA installed at the test-bed site and an image of M13 globular cluster taken by it.

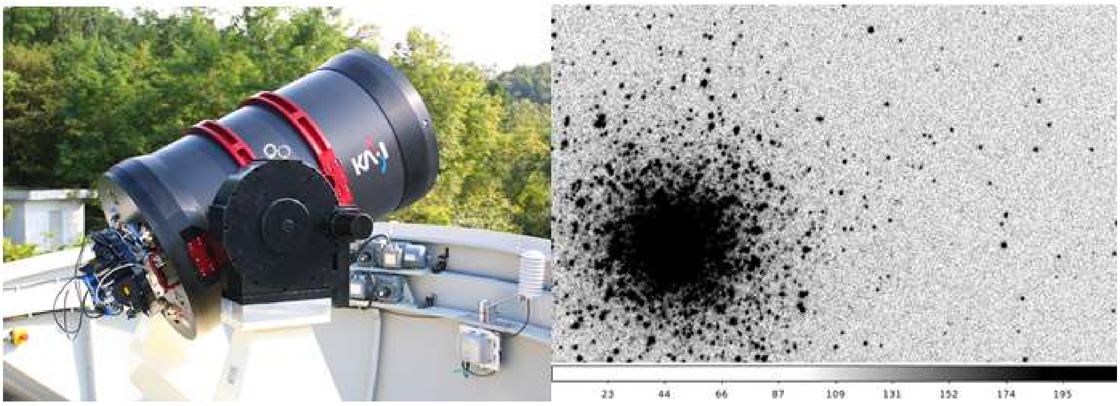


Fig. 2. Optical assembly tube installed at the test-bed site (left) and central part of M13 images (right), 2 second exposure time, average seeing ~ 2.5 arcsecond

The tracking ability of the mount system is 2 arc seconds for 10 minutes and the pointing accuracy is less than 10 arc seconds, so that the telescope can be utilized for both sidereal mode and on-tracking mode. The maximum mount speed is 20 degree/sec and the acceleration is 2 degree/sec^2. The telescope system was designed to be operated in severe circumstances such as Mongolia. The mount system was designed for the OWL-Net by Korean vendor. Fig. 3 shows adjusting mount after installing at the test-bed site

Fig. 3. Custom made mount system installed at the test-bed site

Usually any control system at observatory based on commercial off-the-shelf PCs can have serious drawbacks. Due to frequent upgrades of operating system (OS) a number of OS-dependent software ought to be revised very often. Shortage of critical hardware due to launch of new products in the world PC market brought about a demand for a major re-design of the control PC. This is the reason why we intend to minimize PC-based controls. Instead, we adopt a software-imbedded custom-made circuit for controlling telescope, detector, dome and site utilities. We have designed dedicated control boards with a world renowned humanoid robot team on the development for devoted circuit boards and imbedded software for the OWL Project. They are compact in their shape and flexible in communication. The control board is equipped with USB, Serial, LAN, and CAN ports for flexible communication with external instrument. Fig. 4 shows custom made control board and motor controller.

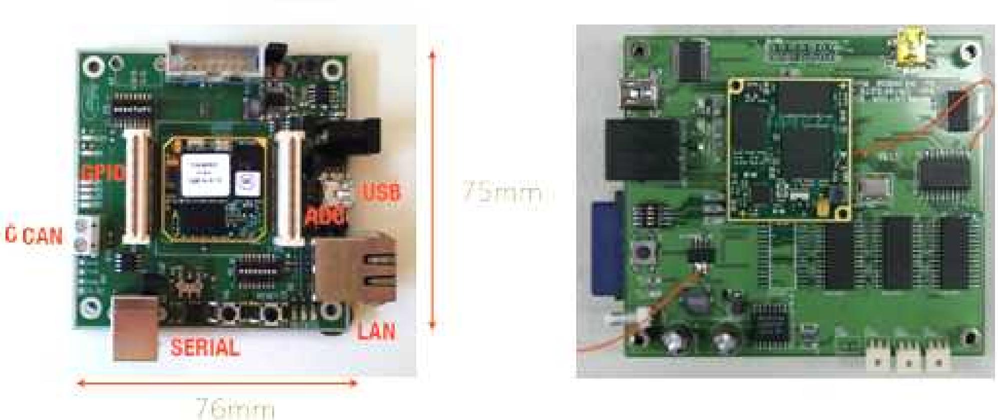


Fig. 4. Custom made control board and motor controller

A trade study is being conducted to achieve larger field of view and smaller plate scale. The selected detector is a FLI PL16803 CCD camera equipped with a Kodak 4096×4096 back-illuminated CCD. Its pixel size is 9um. The combination of the CCD and the telescope will yield effective field of view of 1.1 degrees and plate scale of 1.0 arcsec/pixel. The resultant limiting magnitude is estimated to be 18th mag. in Johnson R-band. A smart, custom-made camera controller will be capable of regulating chip temperature, controlling a series of imaging process and automated data reductions.

A chopper wheel is employed to maximize astrometric solutions in a single CCD frame, and a de-rotator is used to compensate field rotation of the alt-az type mount. We have designed a compact back-end unit, called Wheel Station, in which three rotating parts (chopper wheel, filter wheel and de-rotator) and a CCD camera are integrated.

Fig. 5. Filter wheel and chopper (left) and wheel station and CCD camera (right)

The rotation speed of the chopper is variable up to 50Hz. It starts in slow speed and then reaches to the expected speed after some acceleration. During acceleration period, we can get trails with variable length which can identify direction and starting point in a single shot. Each trail point also has time information with precision ~ 1 msec. For time-tagging we have developed a dedicated time-tagger and attached it to the wheel station.

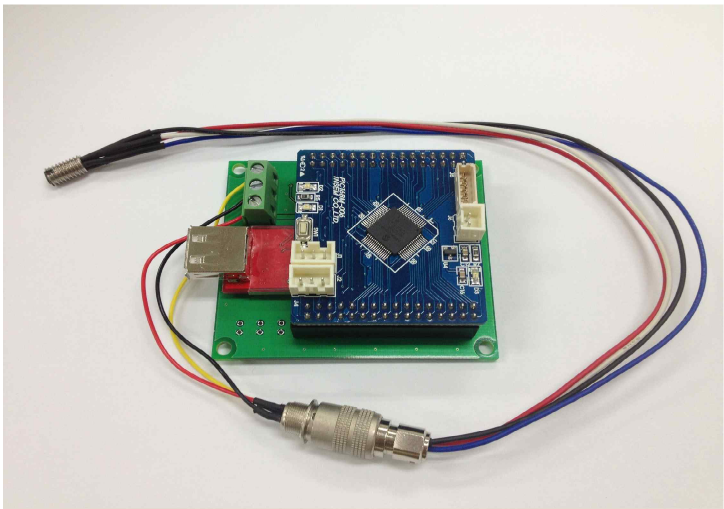


Fig. 6. Time-tagger board

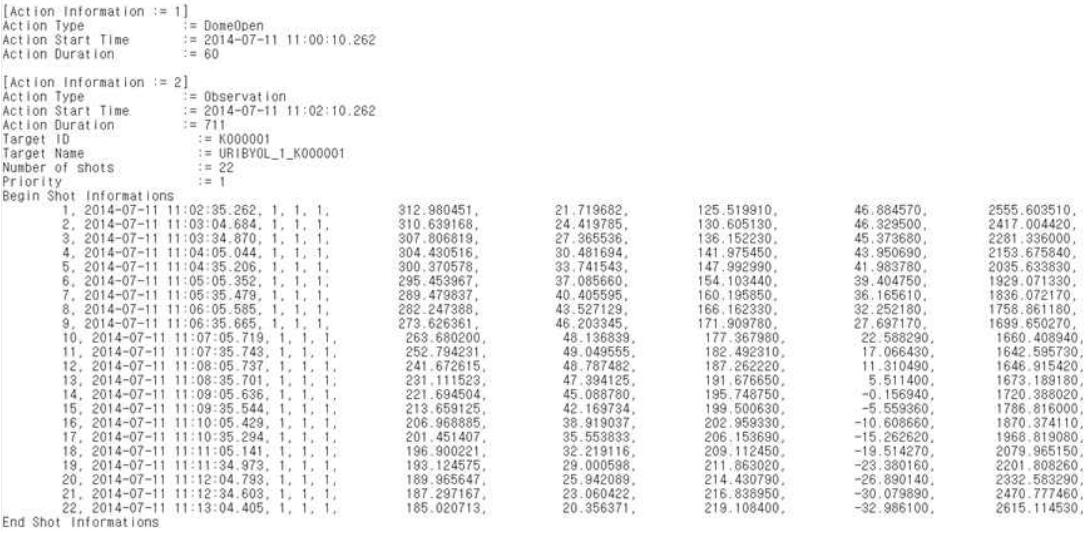
3.2 OWL-Net Operation

OWL facilities will be linked to the internet, and controlled as if they were a single living organism. This is the reason why we call them the *"OWL-Net."* The site operations processes will be linked, controlled and executed in such a manner that a suite of network operating software maximizes observation efficiency, and hence, the overall data productivity.

Mission planning is the main task of network operations; time allocation is the key figure of this task. Network operating system (NOS) will determine target's priorities taking into account of past observation records, feasibility of future observations and user’s inputs. As a result, the software will produce an OCF (Observation Command File) for each night and each site. Then, the operating system of each site will receive a new OCF before observation.

The system status information from all sites will be collected at HQ in near real time. When an incident occurs, the system operator at HQ will recognize and handle the immediate task properly and without delay. Likewise, the Network Operation display exhibits various statistics either from individual sites or the whole OWL-Net. The display includes the weather condition, observation results, the total operation time of each site, and etc.

OWL Operation is composed of three stages. The first stage is “Scheduling”. HQ calculates the sunset/sunrise time and ephemeris of the target satellites. Considering the feasibility, HQ completes the OCF and then sends it to the observatory via Internet. Second stage is “Observation”. SOS interprets the OCF and transfer it to TC(Telescope Control System) to proceed the observation. Also it is monitoring the environmental situation to maintain safety. After observation, SOS returns the observational results to HQ. Final stage is “Update”. HQ analyzes the observational results and keeps them in the OWL DB. HQ also uses it on the next “Scheduling”. The OCF contains all information about the observations, target name, start time to observation, finish time to observation, camera exposure time, filter, target speed, etc (See Fig. 7). All is scheduled, so it does not need any help by a human operator.



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Action Duration          := 60

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Action Duration          := 711
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End Shot Informations
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Fig. 7. A sample of OCF (Observation Command File)

3.3 OWL-Net test-bed site

In addition to a telescope and camera, each site has an enclosure, site control system, power manager, automatic weather station and indoor control utilities. The enclosure will be built to protect the telescope and related subsystems from severe weather conditions to function reliably and to demand low maintenance over the lifetime of the facility. We have designed dedicated site control boards for overall site control. Custom-built clamshell type all-sky domes are adopted.

A test-bed site was constructed for test of the proto-type system in the KASI campus. We have installed all components for robotic observation, performed test run for 6 months, and confirmed scheduled robotic observation in every detail. After finishing the test run, all the components are disintegrated, packed, and delivered to the designated site, and finally reinstalled at the site. Installation of the first site, the Mongolian site, was completed May 26, 2014. All other systems would be installed with the same procedure as the first site. Fig. 8 shows the test bed-site located at the KASI campus and the Mongolian site located near Ulaanbaatar.

Fig. 8. OWL-Net test-bed site (left) and Mongolian site (right)

4. PRELIMINARY TEST OBSERVATION RESULTS

During test runs, we have observed various kinds of satellites. The first targets were brightest ones and then moved on to Korean satellites. Figure 9 shows exposure of Adeos-II, one of brightest and STSAT-1 of Korean satellites. We have failed to detect satellites smaller than 1m in size because of too bright night-sky at the test-bed site in a large city, Daejeon. Our estimated detection limit is around 18th magnitude which is around 50cm in size.

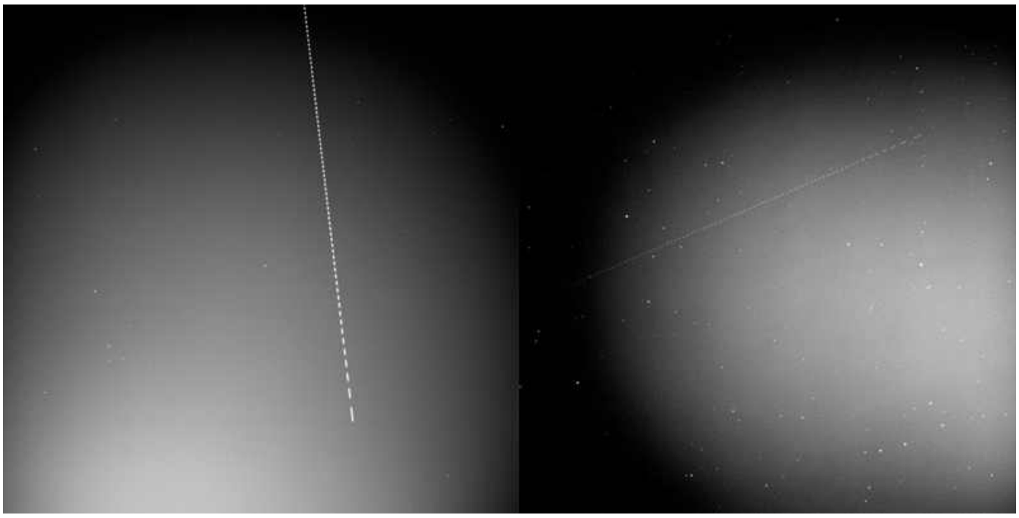

Fig. 9. Test observation of Adeos-II (right), Korean STSAT-1 (left**)**

One of the best example is for the case of the USA 234. We took 4 exposures with 4 minutes and obtained about 120 metric points at a single night, in total. We have propagated its orbit with optical solution and compared with AGI STK solutions. Resultant position uncertainty in 3sigma level is below 300m in the direction of along-track (See Fig. 10). Although it is one of best and specific case, it shows potential capability of optical method.

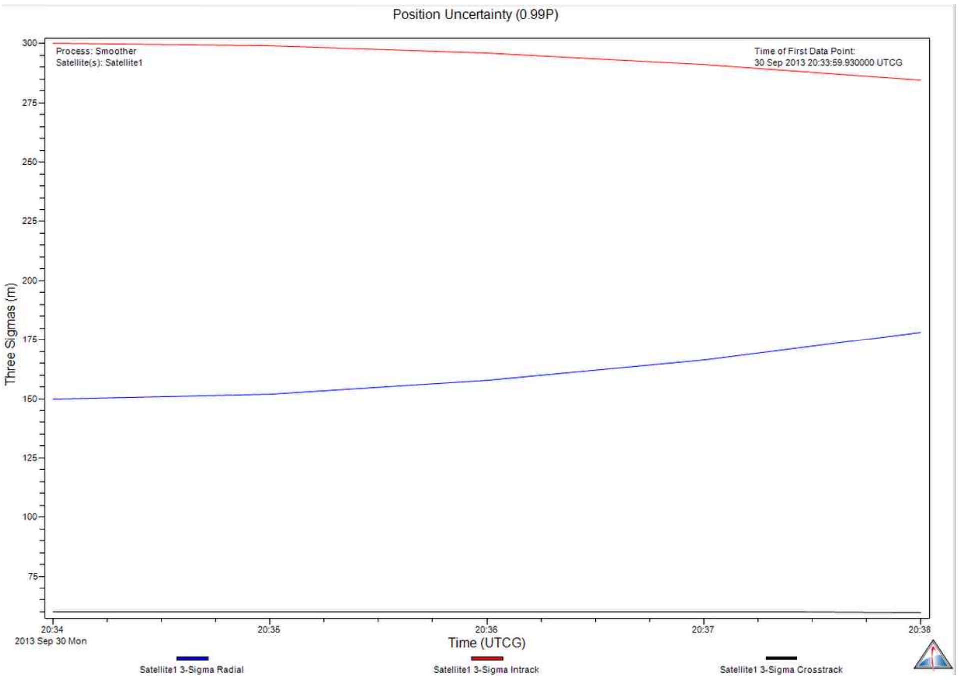

Fig. 10. USA 234 satellite (2013/9/30, 4 shots, total 4 minutes exposure, ~120 points)

As the five observatories of the OWL-Net was planned to be completed in sequence for three year time span from 2014, the quality and quantity of the optical observation data (i.e. angle only) from the OWL system cannot satisfy the requirement condition requested by the original system design until its completion. However, the OC subsystem must check the observation data from the each completed observatory and process it to verify the orbit determination results even it lacks major observation requirements before the full operation capability phase of the OWL system. Due to the requirement discrepancy between the normal operation mode and the long-term calibration/validation mode, we have decided the two track development plans for orbit estimation package in OWL system. First, we plan to use a commercial orbit determination tool with an in-house interfacing software to process the test observation data. Second, we plan to develop a batch type orbit determination filter for optical observation exclusively.

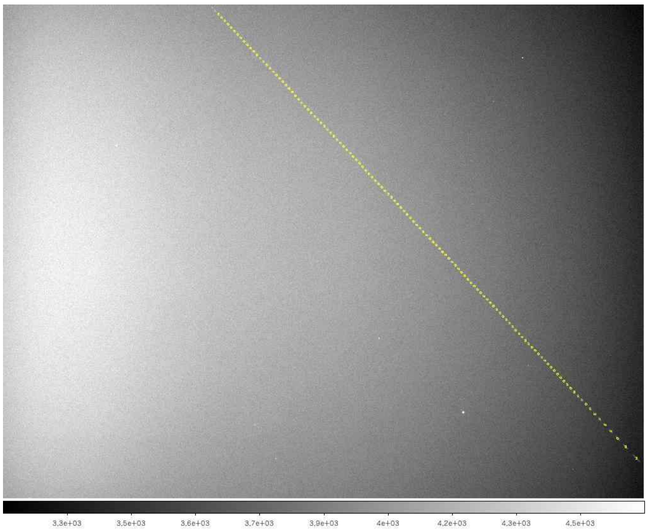

Fig. 11. A sample shot of Envsat taken at the Mongolian site in July, 2014. Yellow trails are selected as true ones by an extraction algorithm.

Currently, we have processed several sets of observation data from the OWL Mongolian observatory (See Fig. 11). The preliminary result shows that the designed operational capability in terms of orbit estimation precision is not farfetched. The quality and the amount of the observation data from the Mongolian observatory is very limited due to the tests of other subsystems and unusual local weather condition in summer, 2014. We can get an estimated orbit of the COSMOS 2428 satellite with 1,115 observation points for two passes within 108.3 minutes on July 8, 2014 UTC. The difference in ICRF xyz coordinate between an estimated orbit and 73 consecutively updated JSpOC TLE orbits for 23 days propagation is shown in Fig. 12.

Before the completion of the OWL system, the orbit calculation subsystem (OC) will continue to support the calibration/validation of the OWL system as well as the OC subsystem. During this period, the OC team will also finish the development of a batch type filter for normal operation phase.

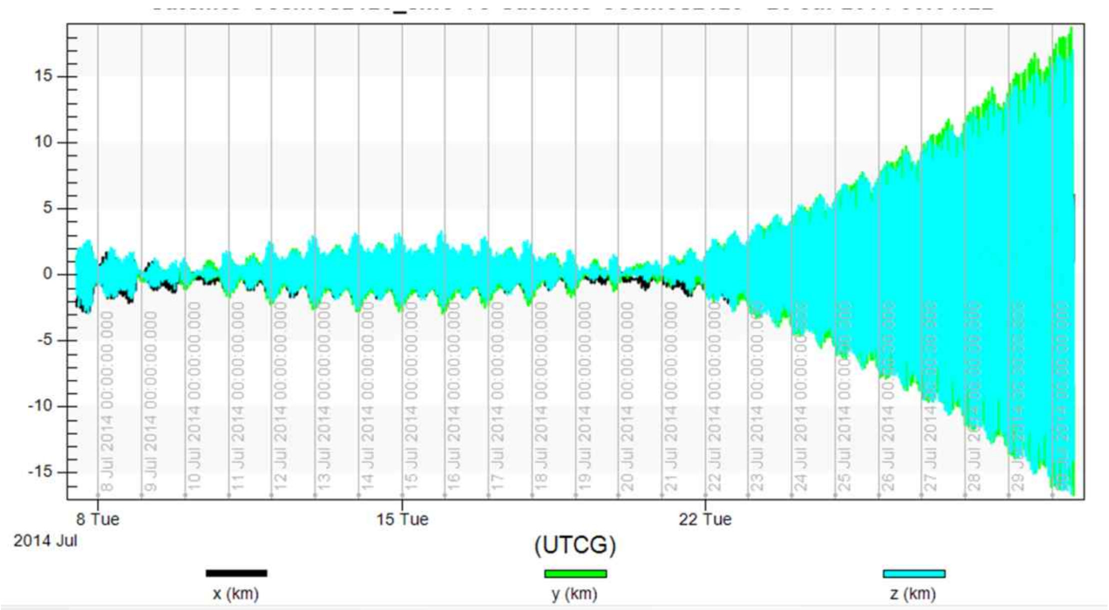

Fig. 12. The difference between propagated orbit of the estimated orbit from the optically observed data by OWL-Net Mongol station and the orbit from the 73 consecutively published JSpOC TLE during whole period.

5. ACKNOWLEDGEMENTS

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