The light curves of a Geostationary Satellite and its model

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Abstract

We observed brightness variations of a geostationary satellite to determine the reflectance of artificial objects versus sun phase angle. For this observation, we used two small optical telescopes with R bandpass filters. Main targets are Korean satellites and nearby objects. The maximum brightness occurred at the minimum sun phase angle as one would expect. But some double peak light curves show different features according to satellite shape and attitude. In this study, we present the light curve of satellites and compare with a brightness model. We expect that this observation study will play a basic role in research on brightness changes of satellites and other unknown objects.

1. Introduction

For the space object identifications, there are many kinds observing techniques over a wide range of the EM spectrum. Light curve photometry consists of measuring the variation in brightness of an object over time for the purpose of plotting and analyzing the data [1]. It is one of the most common techniques in astronomical observation for obtaining the variability of an object. Prior study has shown that photometric data is able to provide satellite orbit and spacecraft shape information and a light curve is also good tool for satellite characterization [2]. This work describes our observational result in determining the reflectance of a satellite in relation to sun phase angle. We introduce our sun angle program for estimating the time of a maximum brightness in Sect.2. In Sec.3, we present our photometric results for four geostationary satellites.

2. Phase Angle Calculation

We developed a sun phase angle program to estimate the maximum brightness of geostationary satellite. To obtain the phase angle, we calculate the position of the Sun, the observatory and the satellite in the Geocentric Reference Coordinate System (GCRS). The phase angle (θ) is:

$$\cos(\theta) = \frac{|\mathbf{r}_{sat} - \mathbf{r}_{obs}|^2 + |\mathbf{r}_{sun} - \mathbf{r}_{sat}|^2 - |\mathbf{r}_{sun} - \mathbf{r}_{obs}|^2}{2|(\mathbf{r}_{sat} - \mathbf{r}_{obs})|\cdot|(\mathbf{r}_{sun} - \mathbf{r}_{sat})|} \quad (1)$$

where $\mathbf{r}_{sat}$ is the satellite position, $\mathbf{r}_{sun}$ is the Sun position and $\mathbf{r}_{obs}$ is the observatory position. For the Sun position in GCRS, we used a series expansion formula [3]. In case of calculating the observatory position, we used an observatory position determination method [4] which includes an ellipsoidal Earth model (Fig.1).

$$u = r_e \cos L + h \cos\phi = \left[\frac{r_e}{(1-e^2\sin^2\phi)^{1/2}} + h\right]\cos\phi$$

$$v = (1-e^2)^{1/2} r_e \sin L + h \sin\phi = \left[\frac{r_e(1-e^2)}{(1-e^2\sin^2\phi)^{1/2}} + h\right]\sin\phi \quad (2)$$

$$\mathbf{r}_{obs} = u\cos H\,\mathbf{i} + u\sin H\,\mathbf{j} + v\,\mathbf{k}$$

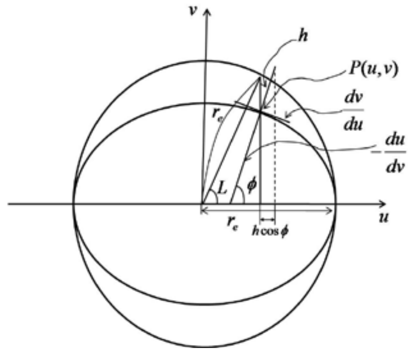

Fig 1. Earth Ellipsoidal Model

We can obtain the orbital elements of satellites in TLE but the three elements (Ω, ω, *M*) can be simply recalculated with J_2 perturbation only [5].

$$\Omega(t)=\Omega_0+\dot{\Omega}t,\qquad \dot{\Omega}=-\frac{3nJ_2 r_E^2}{2a^2(1-e^2)^2}\cos i$$
$$\omega(t)=\omega_0+\dot{\omega}t,\qquad \dot{\omega}=\frac{3nJ_2 r_E^2}{2a^2(1-e^2)^2}\left(\frac{5}{2}\sin^2 i-2\right) \tag{4}$$

For the satellite position vector, we calculated the true anomaly (ν) from the mean anomaly as shown below.

$$M(t)=M_0+n(t-t_0)-2\pi k$$
$$E-e\sin E=M(t)\qquad E:\text{eccentric anomaly}$$
$$\nu=2\tan^{-1}\left(\sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}\right) \tag{6}$$

And then we translated the satellite based coordinate system to GCRS in order to derive the sun phase angle [6].

$$\mathbf{r}_s=\begin{bmatrix}\cos\Omega\cos\omega-\sin\Omega\cos i\sin\omega & -\cos\Omega\sin\omega-\sin\Omega\cos i\cos\omega & \sin\Omega\sin i\\ \sin\Omega\cos\omega+\cos\Omega\cos i\sin\omega & -\sin\Omega\sin\omega+\cos\Omega\cos i\cos\omega & -\cos\Omega\sin i\\ \sin i\sin\omega & \sin i\cos\omega & \cos i\end{bmatrix}\begin{bmatrix}\dfrac{p}{1+e\cos\nu}\cos\nu\\ \dfrac{p}{1+e\cos\nu}\sin\nu\\ 0\end{bmatrix} \tag{7}$$

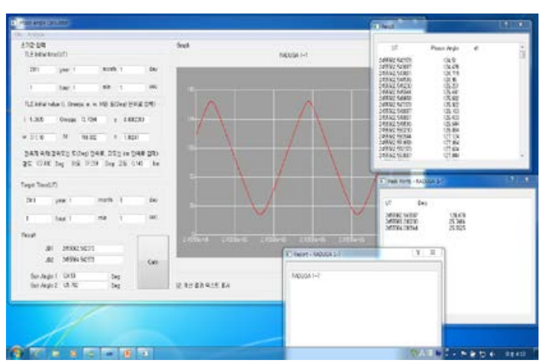

Fig 2. Phase Angle Program

Using these formulas, we made a phase angle program which is able to display time variation of the satellite's phase angle and sky position. The phase angle program is shown in Fig. 2. It is made in Visual C++ .Net 2010 with Qt GUI library. This program can be used on any computer independent of the OS.

3. Observation and Data Reduction

CCD photometry observations were carried out on 2 nights between February and March, 2011. We obtained a time series of CCD images through an R bandpass filter using two telescopes. One is the 61cm Ritchy-Chrétien telescope in Sobaeksan Optical Astronomical Observatory (SOAO). The other is 60cm prime focus telescope in Chungbuk national university Astronomical Observatory.

Using the IRAF CCDRED package, we processed the CCD images to subtract bias and dark frames and corrected pixel- to-pixel variations in quantum efficiency by flat-fielding. Instrumental magnitudes were obtained using the simple aperture photometry routine in the IRAF APPHOT package. The aperture radius was chosen to be 6″. We then calculated differential magnitudes for each satellite using a nearby comparison star with similar brightness and color. A detailed observation log is given in table 1. Figure 3 shows the finding chart. Figure 4 shows light curves for the COMS-1 and JCSAT-3A and Figure 5 present KOREASAT 6 and ABS-7. Because the observations were performed near the spring equinox, the Earth's shadow eclipsed the satellites. This results in a gap in the light curves shown in Figure 5.

Table 1. Observation log of selected satellites.

Object	Obs. Data (in 2011. KOREA)	Running (hours)	Data points	Telescope	note
COMS-1	23. Feb	8.3	303	61cm	Weather/Earth Science
JCSAT-3A	23. Feb	8.3	294	61cm	Communication
KOREASAT 6	22. March	9.5	635	60cm	Communication
ABS 7	22. March	9.5	639	60cm	Communication

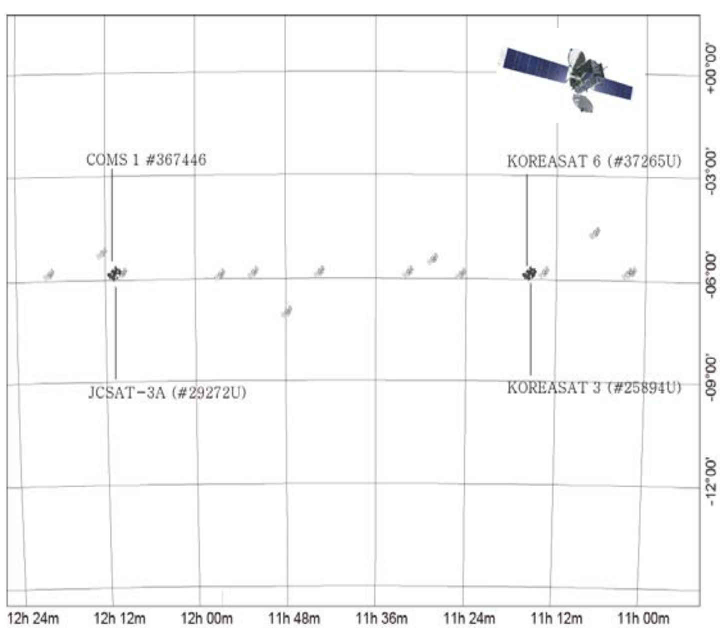

Fig. 3. Finding chart of Target satellites

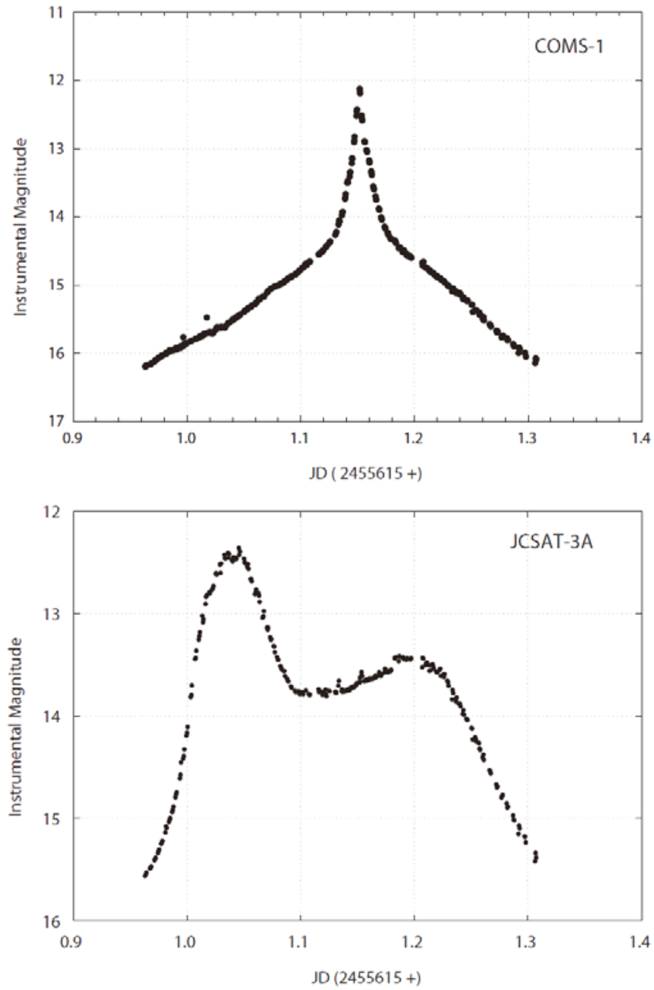

Fig. 4. The light curve of COMS-1 (Top) and JCSAT-3A (bottom)

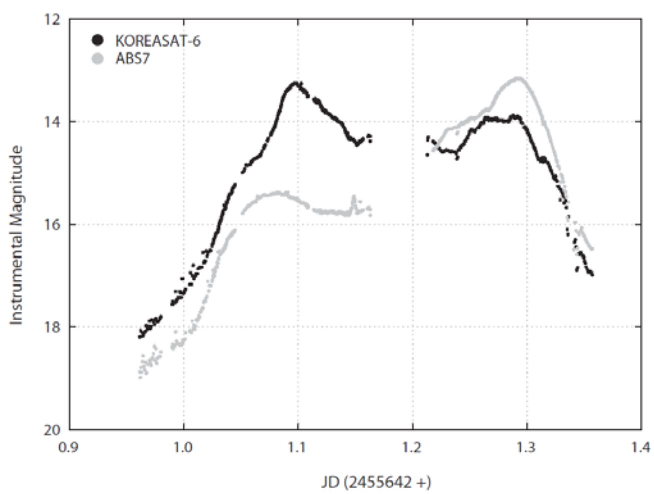

Fig. 5. The light curves of KOREASAT-6 and ABS7. Because the observation was conducted near the spring equinox, the Earth's shadow eclipsed the satellites, resulting in a gap in the light curves.

4. Photometric Results and its model

We examined the light curves of the four geostationary satellites. From the R band variations, we compared the time of maximum brightness for the calculated results and the observations. This comparison is shown in Table 2. The observed time of maximum brightness is derived from polynomial quadratic curve fitting with symmetrical minimum brightness datum in case of double peak light curve targets. The time difference is as much as 0.0152 day in our observed targets. The small time difference for the COMS-1 satellite is interpreted to be due to its simple geometrical shape when compared with the other satellites. Figure 6 shows a simple model of the observed satellites which can be used to approximate the relation between light curve and their satellite shapes. The light curves show different features according to the configuration of solar panel wings. Two-wing solar panel structures have the double peak, while the one wing structure has a one peak light curve. These light curves are similar to the model of Stanley & Wetterer [7].

Table 2. The maximum brightness time shows different form estimated peak time.

Satellite	Calculate (JD)	Observation (JD)	Time difference (JD)
COMS-1	2455616.1528	2455616.1518	0.0010
JCSAT-3A	2455616.1541	2455616.1389	0.0152
KOREASAT 6	2455643.1870	2455643.1834	0.0036
ABS7	2455643.1874	2455643.1952	0.0078

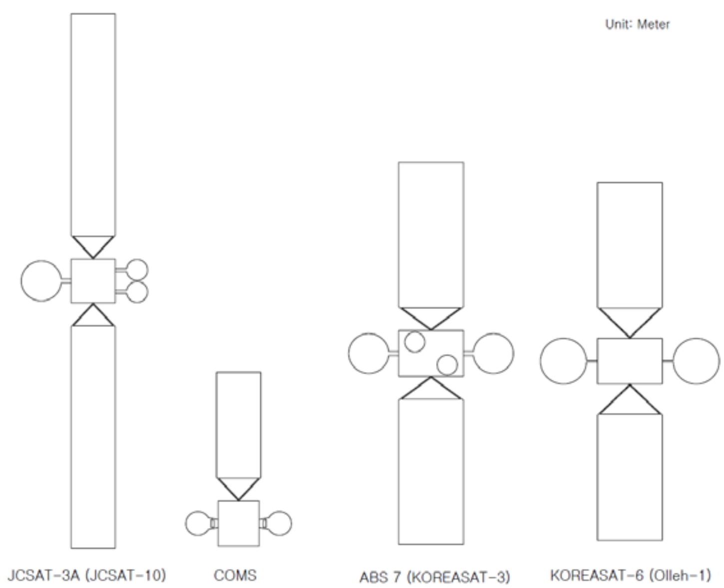

Fig. 6. The shape comparison of observed satellites.

5. Conclusion

We observed geostationary satellites to determine their light curve variations by photometry. Their light curves display the different patterns due to sun angle and satellite shapes as we expected. Maximum brightness occurred at near our estimated event time, but the light curve pattern is different for each satellite. The light curves show that two solar panel wing satellites have a double peak and one solar panel satellite feature a single peak. This light curve is similar to the Stanley simulation result. In the future we will calculate the absolute magnitude variance of each satellite and study the relationship between brightness and physical parameters. We expect that this work also will be used to investigate near earth small objects.

6. Acknowledgements

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7. REFERENCES

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