A PRELIMINARY STUDY ON A UAV-BASED METHOD TO ESTIMATE GNSS SIGNAL INTERRUPTION PROBABILITY

Shun Nagasaku[1] and Hiroto Shimazaki[2]
[1]National Institute of Technology (NIT), Kisarazu College, Kisarazu City, Chiba Prefecture, 292-0041 Japan,
Email: nagasaku.shun@gmail.com
[2] National Institute of Technology (NIT), Kisarazu College, Kisarazu City, Chiba Prefecture, 292-0041 Japan,
Email: shimazaki@c.kisarazu.ac.jp

KEY WORDS: GNSS, UAV, Canopy Openness, Morphometric Protection Index, Elevation Mask

ABSTRACT: This study examined a UAV-based method that uses the Digital Surface Model (DSM) derived from a set of high-spatial-resolution aerial images in order to evaluate the quality of the location data obtained by GNSS telemetry. The DSM was transformed into two indices: (1) the Morphometric Protection Index (MPI); and (2) the Elevation Mask (EM) to be used for predicting the values of Geometrical Dilution of Precision (GDOP) and number of satellites (NSAT). The degree of conformity of the MPI to Canopy Openness (CO), which has been widely used as the first-order approximation of the GNSS signal interruption probability (GNSS-SIP), was confirmed by a simple linear regression model, and the CO was successfully estimated from MPI over a broad spatial range. However, because the MPI was calculated based on solid DSM, the following problems remain unsolved: (1) the CO predicted from MPI represents only the CO at top of the terrain or off-terrain objects; and (2) it cannot consider the effect of GNSS signal transmission through an object or gaps among objects. Meanwhile, the GDOP and NSAT, which were predicted using the EM, were found to be useful for estimating the positioning accuracy and precision. Since both of them were predicted taking into account the GNSS satellites constellation, they could be more appropriate than MPI for the purpose of estimating the quality of location data. However, as same as the case of MPI, the GDOP and NSAT also have the problem regarding to the effect of GNSS signal transmission through an object or gaps among objects. To overcome this problem, future work will be focused on development of the new prediction method of GDOP and NSAT that can appropriately consider the effect of GNSS signal transmission through an object or gaps among objects.

1. INTRODUCTION

Incidents of agricultural crop damage by wild animals have been rapidly increasing and widely recognized as a serious problem in Japan (Chiba prefectural Agricultural Land and Rural Development Division, 2016). To cope with the situation, control measures for nuisance animals must employ multiple methods including: the direct removal method by trapping and hunting nuisance animals; and the barrier method by installing a wildlife fence that prevents nuisance animals from feeding on agricultural crops. An advanced method includes designing a land management plan effective for nuisance animal control. However, success of the advanced method relies on the information about behavioral ecology of nuisance animals such as movement patterns, home range size and habitat selection.

Location data obtained by GNSS telemetry has been widely used to estimate movement patterns, home range size and habitat selection of wild animals. However, reliability of the estimation highly depends on the quality of location data, which is often degraded due to GNSS signal interruption by rugged terrain and off-terrain objects such as buildings and tree canopies. To evaluate the quality of location data, GNSS signal interruption probability (GNSS-SIP) has been estimated by a ground-based method that uses a hemispherical image to calculate Canopy Openness (CO) as the first-order approximation of the GNSS-SIP (Bastos & Hasegawa, 2013). Although the ground-based method has been commonly used as a standard one, its applicability is limited in specific locations where hemispherical images were taken. To evaluate the quality of telemetry location data for free-ranging animals, an alternative method is needed to be developed.

This study examined a UAV-based method that uses the Digital Surface Model (DSM) derived from a set of high-spatial-resolution aerial images to evaluate the quality of telemetry location data. First the DSM was transformed to two indices: (1) the Morphometric Protection Index (MPI) (Yokoyama, T., 1999); and (2) the Elevation Mask (EM). Second the degree of conformity of the MPI to CO was evaluated based on a simple linear regression model, where the MPI was used as predictor variable and the CO as response variable. Once the statistical significance of the model is confirmed, the model can be applied to predict the CO over a broad spatial range. Finally, the EM was utilized in the GSILIB software library (Geospatial Information Authority of Japan) to estimate the values of Geometrical Dilution of Precision (GDOP) and number of visible GNSS satellites (NSAT) at a given time and location. Since the GDOP and NSAT are relevant to the positioning accuracy and precision, they could be helpful for estimating the quality of telemetry location data for free-ranging animals.

2. MATERIAL AND METHODS

2.1 Study Site and Data

This study was conducted in the campus of the National Institute of Technology, Kisarazu College, located in Chiba Prefecture, Japan (Figure 1). The campus covers the area of a rectangle with the size of approximately 350 * 300 m, which has variation in terrain relief and surface features such as buildings, paved road, vegetation and bare ground. DSM was derived from a set of digital imagery, which was obtained using commercially-available inexpensive small UAV-based systems, and Structure-from-Motion (SfM) and Multi-View-Stereo (MVS) techniques.

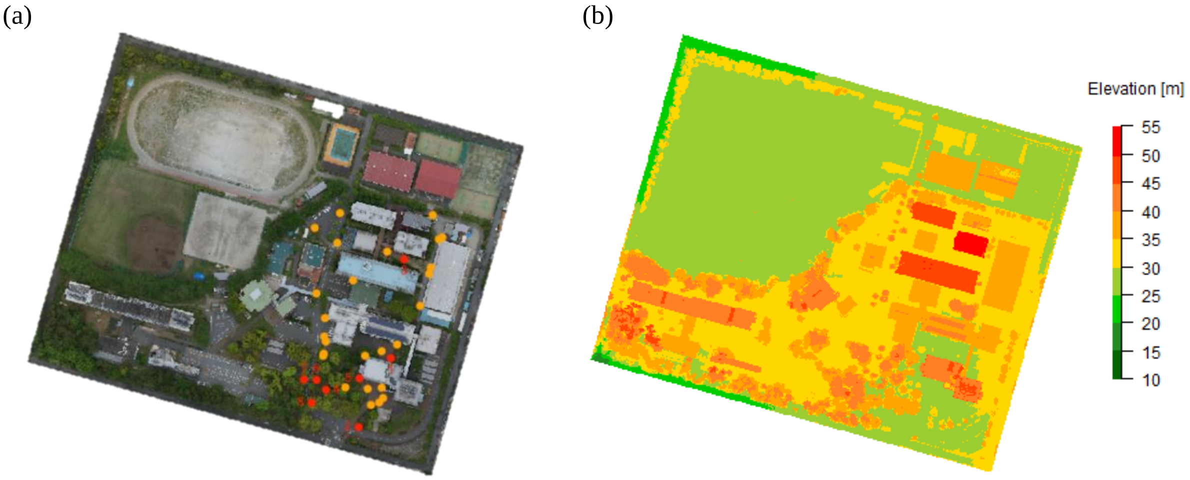

Figure 1. Orthomosaic image (a) and Digital Surface Model (b) of the study area. Dots on the orthomosaic image indicate the 32 location points where ground observations were made for statistical modeling of CO and MPI. Of the 32 dots, the red dots correspond to the location points selected for GDOP and NSAT analysis.

Considering the spatial configuration of off-terrain objects such as buildings and tree canopies, 32 typical points were selected for the place where ground observation should be made. Three dimensional coordinates of the 32 points were measured based on the JGD2011 / Japan Plane Rectangular coordinate system IX, using static GNSS surveying method with TOPCON HiPer II and Total Station radiation method with TOPCON Direct Aiming Station.

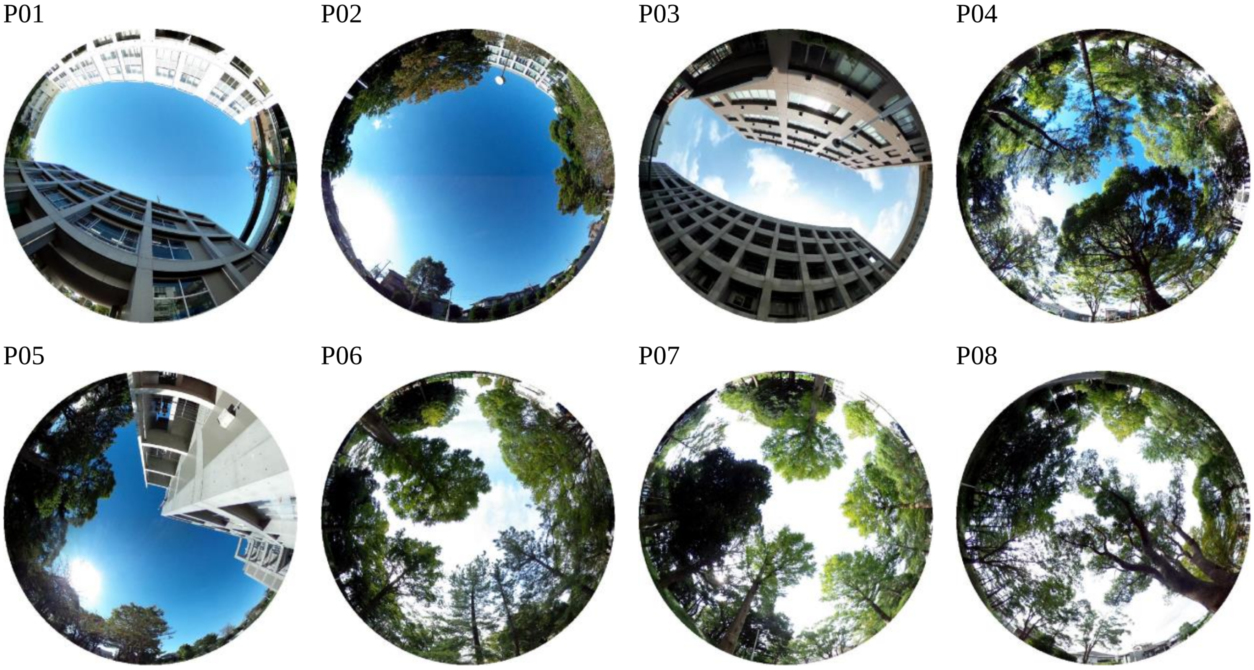

Figure 2. Example of hemispherical images for the selected 8 points. Locations of the points are indicated in Figure 1(a).

2.2 Calculation of Canopy Openness (CO) and Morphometric Protection Index (MPI)

Canopy Openness (CO) is an indicator representing the proportion of sky visible from ground level. For each of the 32 points (Figure 1(a)), the CO was calculated by analyzing a hemispherical image taken by Ricoh Theta 360 Degree Spherical Panorama Camera. The image analysis was executed using CanopOn 2 software (Takenaka, 2009). Examples of hemispherical images are shown in Figure 2.

Morphometric Protection Index (MPI) is a mean of zenith angles for the highest point found in each of the 8 directions around the point of interest (Figure 3). For each of the 32 points, the MPI was calculated from the DSM using SAGA software (Conrad et al, 2015).

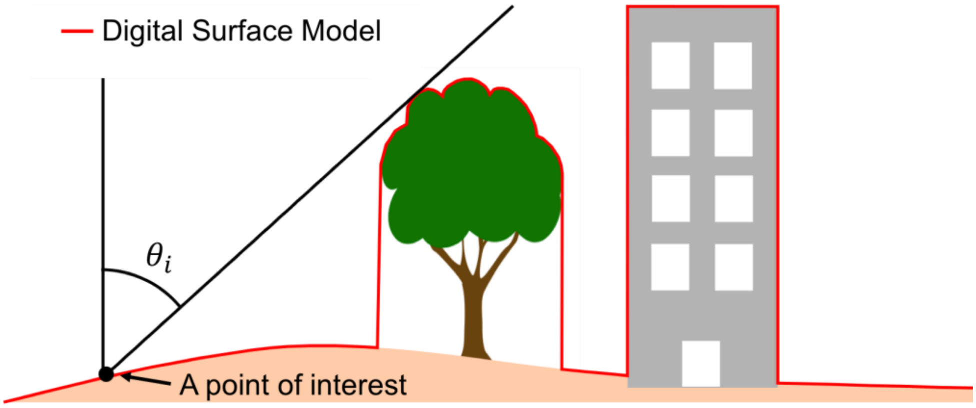

Figure 3. Zenith angle θ_i in the *i*-th direction. Morphometric Protection Index is defined as a mean of the zenith angle θ_i ($i = 1, 2, \ldots, 8$) measured in each of the 8 directions around the point of interest.

2.3 Statistical Modeling between CO and MPI

The degree of conformity of the two indices, CO and MPI, was evaluated based on a simple linear regression model, where the MPI was used as predictor variable x and the CO as response variable y. The model examines whether a significant amount of the variation of CO can be explained by the variation in MPI. The model specification is as below:

$$\mathrm{logit}(y) = \beta_0 + \beta_1 \mathrm{logit}(x) + \varepsilon, \quad \varepsilon \sim N(0, \sigma^2) \tag{1}$$

Statistical significance of the model was confirmed based on the analysis of variance (ANOVA) for the null hypothesis that the regression coefficient is zero (H_0: $\beta_1=0$). Once the statistical significance of the model is confirmed, the model can be applied to predict the CO over a broad spatial range.

2.5 Prediction of Geometrical Dilution of Precision (GDOP) and number of satellites (NSAT)

Geometric Dilution of Precision (GDOP) is an indicator of the geometry of the visible GNSS satellite constellation. GDOP can be roughly interpreted as follows: the lower the value of GDOP, the better the positioning accuracy and precision; and the higher the value of GDOP, the worse the positioning accuracy and precision. It is also know that the greater the number of satellites (NSAT), the lower the value of GDOP. Hence we predict the GDOP and NSAT using the DSM, and attempted to evaluate whether the predicted GDOP and NSAT can actually explain the variation of the positioning accuracy and precision.

The values of GDOP and NSAT were predicted for the selected 8 points using the Elevation Mask (EM) derived from the DSM (Figure 4). The EM was generated using an in-house software developed with R environment (R Development Core Team, 2016.), and prediction of the GDOP and NSAT with the EM was executed using GSILIB software library (Geospatial Information Authority of Japan, 2016). The GSILIB can predict the constellation of GNSS satellites at a given time and location using the Two Line Element (TLE) data provided from CelesTrak (Kelso, 1985).

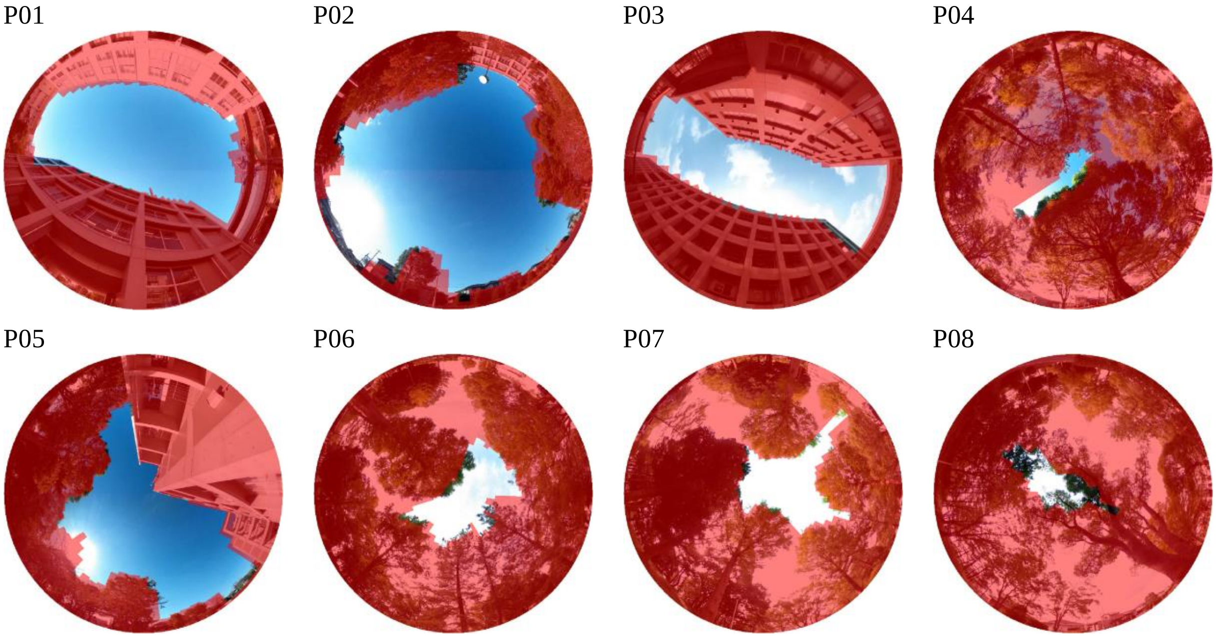

Figure 4 Elevation Mask (red) overlaid on hemispherical images.

To evaluate whether the GDOP and NSAT could explain the variation of the positioning accuracy and precision, GPS observations were made every 1 second for 10 minutes at the selected 8 points using the i-gotU GPS equipment manufactured by Mobile Action Technology Inc. The i-gotU GPS equipment was employed because it relies on similar hardware devices to those used for wildlife tracking. The degree of precision was evaluated by standard deviation of the i-gotU observations. On the other hand, the accuracy was evaluated by comparing the mean of i-gotU observations to the reference data obtained by conventional surveying method with GNSS and Total Station.

3. RESULT AND DISCUSSION

3.1 Compatibility of CO and MPI

The model parameters estimated are summarized in Table 1. The goodness-of- fit of the model to data, which was evaluated by coefficient of determination of R^2, was found to be relatively good (R^2=0.87). Adequacy of the assumption of Gaussian error in the model was visually confirmed by the Normal Q-Q plot (Figure 5). As the result of ANOVA F-test, the probability of getting a value for $F_{1,30}$ as big as 198.4 or lager ($Pr(F_{1,30}>198.4)$) was found to be significantly small (p-value = 9.24e-15) if the null hypothesis is true. This result indicates that the null hypothesis (H_0: $\beta_1=0$) could be rejected at the almost 100 percent level of confidence.

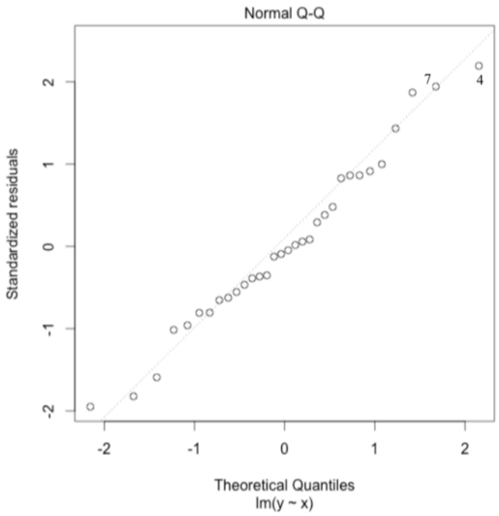

Figure 5. Normal Q-Q plot

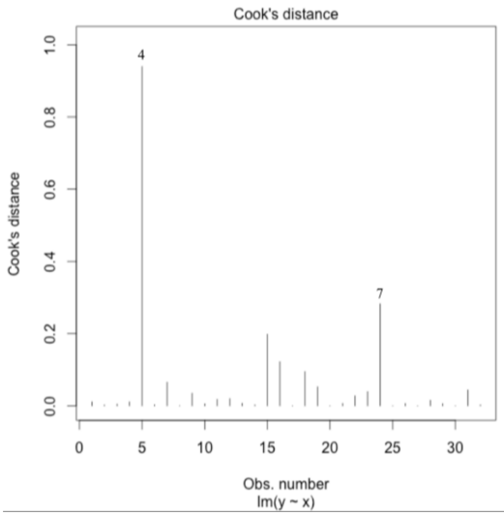

Figure 6. Cook’s distance

Cook's distance (Figure 6), which shows the influence of each observation on the fitted response values, suggested that some data points (P04 and P07) could be outliers. This might be attributed to the facts that: (1) the CO predicted from MPI represents only the CO at top of the terrain or off-terrain objects; and (2) it cannot consider the effect of GNSS signal transmission through an object or gaps among objects. Although these considerations are remained unsolved, the CO was successfully predicted from the MPI over a broad spatial range (Figure 7).

Table 1. The model parameters estimated.

	Esitimate	Std.Error	t value	Pr(>|t|)
β_0	0.3614	0.04482	8.063	5.33E-09
β_1	0.94739	0.06726	14.084	9.24E-15

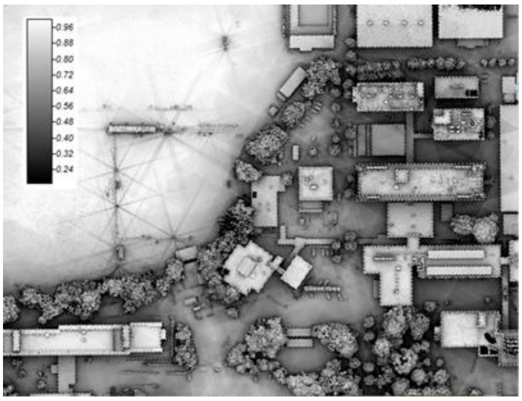

Figure 7. Canopy Openness predicted from Morphometric Protection Index.

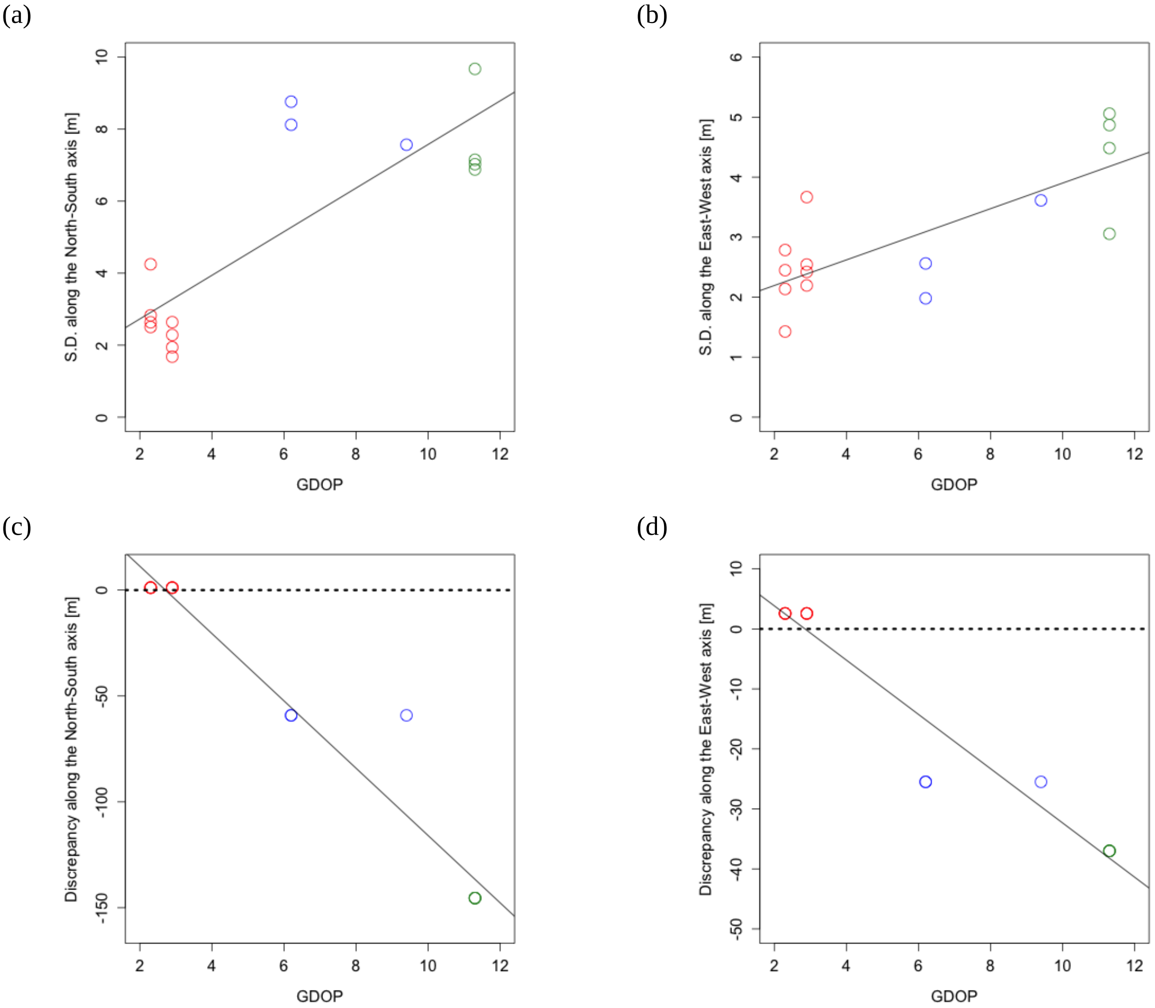

Figure 8. Positioning precision and accuracy in relation to the GDOP (Blue:P01, Red:P02, Green:P03).

3.2 Relevance of GDOP and NSAT to Positioning Error

The values of GDOP for P04 through P08 in Figure 4 were not predicted due to the poor number of visible satellite as estimated from the EM. Scatterplots in Figure 8(a) and (b) show us the positive correlation between the GDOP and GPS precision for both the North-South and East-West directions. Precision at several points seems to be worse than expected when comparing to a regression line. One reason might be the effect of multipath from the surface of buildings located at northern and southern sides of the point of interest. Figure 8(c) and (d) indicate the tendency that the increase of GDOP causes a decrease of accuracy.

The NSAT was predicted to be less than 4 at the location points for P04 through P08 in Figure 4. Nevertheless, GPS observations were practically obtained at these location points. This means that GPS devices received the signals from GPS satellites enough to fix the location, and the fact that NSAT was under estimated at these location points. This might be attributed that the EM cannot consider the effect of signal transmission through an object or gaps among objects.

4. CONCLUSION

To evaluate the quality of the location data obtained by GNSS telemetry, this study examined a UAV-based method that uses the Digital Surface Model (DSM) derived from a set of high-spatial-resolution aerial images. The DSM was transformed into two indices: (1) the Morphometric Protection Index (MPI); and (2) the Elevation Mask (EM) to be used for predicting the values of Geometrical Dilution of Precision (GDOP) and number of satellites (NSAT).

The degree of conformity of the MPI to CO was confirmed by a simple linear regression model, and the CO was successfully estimated from MPI over a broad spatial range. However, because the MPI was calculated based on solid DSM, the following problems remain unsolved: (1) the CO predicted from MPI represents only the CO at top of the terrain or off-terrain objects; and (2) it cannot consider the effect of GNSS signal transmission through an object or gaps among objects.

GDOP and NSAT, which were predicted using the EM, were found to be useful for estimating the positioning accuracy and precision. Since both of them were predicted taking into account the GNSS satellites constellation, they could be more appropriate than MPI for the purpose of estimating the quality of location data. However, as same as the case of MPI, the GDOP and NSAT also have the problem regarding to the effect of GNSS signal transmission through an object or gaps among objects. To overcome this problem, future work will be focused on development of the new prediction method of GDOP and NSAT that can appropriately consider the effect of GNSS signal transmission through an object or gaps among objects.

ACKNOWLEDGMENTS

This work was financially supported by the JSPS KAKENHI (Grant Number 26440253).

REFERENCES

Bastos, A, S., Hasegawa, H. Behavior of GPS Signal Interruption Probability under Tree Canopies in Different Forest Conditions. European Journal of Remote Sensing, 46, pp. 613-622.

Chiba prefectural Agricultural Land and Rural Development Division, Agriculture, Forestry and Fisheries Department,. 2016. Incidents of crop damage by nuisance animal (H23~H27). Retrieved September 9, 2016 from https://www.pref.chiba.lg.jp/noushin/choujuu/yuugai/documents/h27higaijoukyounosuii1.pdf.

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., and Böhner, J. 2015. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4, Geosci. Model Dev., 8, 1991-2007, doi:10.5194/gmd-8-1991-2015.

Geospatial Information Authority of Japan, 2016. GSILIB, URL http://datahouse1.gsi.go.jp/gsilib/gsilib.html.

Kelso, T, S., 1985. CelesTrak, URL https://www.celestrak.com.

R Development Core Team., 2016. R, URL https://www.r-project.org/.

Takenaka, A., 2009. CanopOn 2, URL http://takenaka-akio.org/etc/canopon2/

Yokoyama, T., 1999. Representation of topographical features by opennesses. Journal of Japan Society of Photogrammetry and Remote Sensing, 38(4), pp. 26-34.