Quantification of Physical Blockage Based on Digital Surface Model (DSM) Dataset

Rumadi
Biak Satellite Control Center, Space and Atmospheric Observation, and Remote Sensing Office
Indonesian National Institute of Aeronautics and Space (LAPAN)
Biak Numfor, Indonesia
rumadi91@lapan.go.id

Kamirul
Biak Satellite Control Center, Space and Atmospheric Observation, and Remote Sensing Office
Indonesian National Institute of Aeronautics and Space (LAPAN)
Biak Numfor, Indonesia
kamirul@lapan.go.id

Farid Armin
Biak Satellite Control Center, Space and Atmospheric Observation, and Remote Sensing Office
Indonesian National Institute of Aeronautics and Space (LAPAN)
Biak Numfor, Indonesia
farid.armin@lapan.go.id

Stevry Yushady CH Bissa
Biak Satellite Control Center, Space and Atmospheric Observation, and Remote Sensing Office
Indonesian National Institute of Aeronautics and Space (LAPAN)
Biak Numfor, Indonesia
stevry.yushady@lapan.go.id

Suisbiyanto Prasetya
Biak Satellite Control Center, Space and Atmospheric Observation, and Remote Sensing Office
Indonesian National Institute of Aeronautics and Space (LAPAN)
Biak Numfor, Indonesia
suisbiyanto.prasetya@lapan.go.id

***Abstract*—In this paper, we introduced a new approach for quantifying the amount of physical blockage surrounding a certain ground station. This type of blockage is important to be analyzed since it could reduce the duration of communication between ground stations and satellites. The amount of physical blockage has been calculated by employing a Digital Surface Model (DSM) dataset. The DSM enables the calculation of elevation offset between a ground station to its surrounding natural and man-made objects. Based on the simulation, the accuracy of the proposed approach is capable of resulting in 93.1% of accuracy. Apart from quantifying the amount of physical blockage for a certain point, the proposed approach has also been applied to map the distribution of physical blockage on the entire study area, Biak Island, Indonesia. It is found that the generated map can be used for determining a suitable location for building a ground station site.**

Keywords—elevation, blockage, DSM

I. Introduction

For the last decades, satellites have become indispensable for human life since they play an important role in many fields such as navigation [1-2], communications [3-4], defense [5], and remote sensing [6-7]. In order to perform satellite mission, a ground station is needed to communicate to the satellite. There are important factors in building a ground station such as location, link data rates, requirements for data handling, etc. One aspect that must be considered in choosing a ground station location is elevation blockage. Elevation blockage is caused by uneven elevation distribution, i.e., tall building, mountain, or hill surrounding the ground station. Elevation blockage will block incoming satellite signals and force Acquisition of Signal (AOS) time to be delayed. In the same case, if the blockage area is located on Loss of Signal (LOS) side, an established communication link will end sooner than expected. In essence, the existence of an elevation blockage will result in the communication duration being cut off. Of course, this condition will be detrimental to satellite operators requiring a longer duration of the communication. Hence, an approach in determining elevation blockage is urgently required.

Based on data released by the Union of Concerned Scientists on March 31, 2020, there are 2,666 of active satellites orbiting the Earth, which is dominated by LEO and MEO orbit by 77 %. LEO and MEO orbit satellites are identic to small size satellite and light in mass. Although limited in capabilities, small-size satellites are an attractive alternative to save on development and launch costs compared to larger satellites so that the launch opportunity increases [8]. Therefore, placing small-size satellites on LEO and MEO orbit is becoming popular. Another advantage of LEO satellites is that they are widely used for remote sensing purposes [9-11].

The ground station is the key for Telemetry, Tracking and Command (TT&C), and payload data transmission to ground purposes. Therefore, choosing an appropriate location for building the ground station is mandatory. This step must be taken to find a location having a minimum amount of obstacles so that communication with the satellite can be carried out as long as possible. Mohammadi *et al.,* in [12], has determined the best Receiving Coverage Area (RCA) to meet the requirements and construction costs of the ground station. In their research, they also described the effect of obstacle height and distance on the minimum elevation angle required to establish a satellite communication link. However, the effect of elevation blockage has not been comprehensively explained. Therefore, calculating the elevation angle is needed to map the elevation blockage profile around the location of the desired ground station site before the construction begins.

The Digital Surface Models (DSMs) are the representations of the Earth's surface. This dataset has been utilized for various functions such as mapping forest biomass [14], building detection in intricate environment [15], building reconstructions [16], etc. The variables obtained from the DSM dataset can be used to calculate elevation blockages.

In this paper, we proposed a new approach that can be used to estimate the amount of blockage surrounding a ground station by using the DSM dataset. We have examined and found that the proposed approach is capable of resulting in 93.1% of accuracy. According to this result, the proposed approach can be used as a tool to calculate a representative blockage. The proposed approach can also be used to predict the potential of an area to be used as a ground station site. The result of this research is expected to be used as a reference for government and private companies in seeking an appropriate location for building a ground station in a given wide area.

II. Material and Method

A. Digital Surface Model (DSM) Dataset

The Digital Surface Model (DSM) is one of the elevation models that includes buildings, tree tops, ground, and everything [13]. In this work we used DSM data set provided by Earth Observation Research Center, Japan Aerospace Exploration Agency (JAXA). This data set has a horizontal resolution of 1 arcsecond (approximately 30 meters) generated from Panchromatic Remote sensing Instrument for Stereo Mapping (PRISM), which is an optical sensor on board the Advanced Land Observing Satellite (ALOS). The DSM sample dataset used for this study is the region of Biak Island in which is shown in Fig 1.

B. Calculation of Elevation Blockage

The proposed strategy for quantifying the amount of elevation blockage is based on a simple approach, as illustrated in Fig. 2. Fig. 2 illustrate the blocking phenomenon experienced by a particular ground station located at (α_0, β_0, h_0) caused by a taller blocking object at (α, β, h). The α, β, h, respectively represent the coordinate of latitude, longitude, and elevation, and the "0" subscript is used to designate the ground station's coordinate. Based on this illustration, the blockage angle (γ_{max}) representing the maximum height of elevation blockage can be simply obtained by using (1).

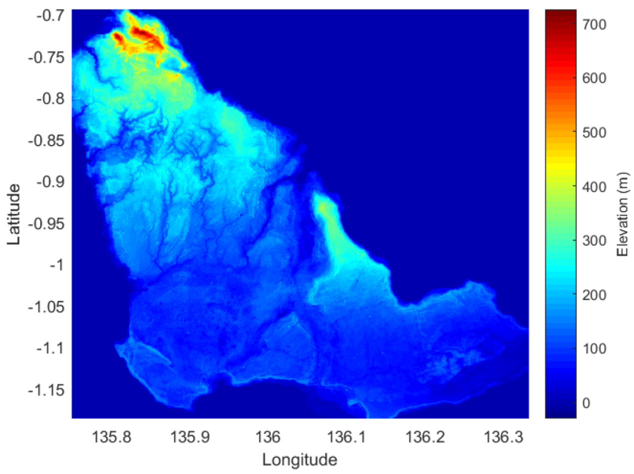

Fig. 1. Sample of DSM dataset used for testing purposes.

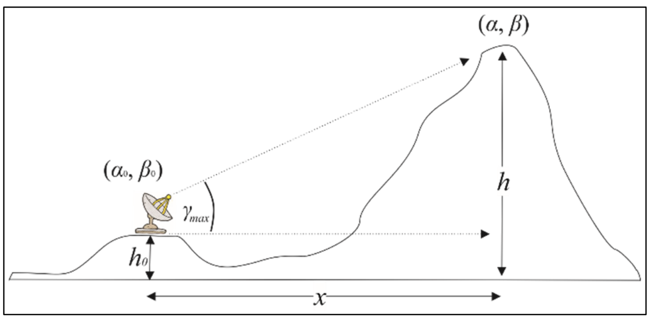

Fig. 2. Illustration of elevation blockage calculation.

$$\gamma_{\max} = \tan^{-1}\left(\frac{h-h_0}{x}\right) \quad (1)$$

x denotes the distance between the ground station and the blocking object in which can be calculated by using the information of given coordinates. The calculation of x has to be performed in a specific manner as the Earth is assumed as a great circle. Therefore, in this work, the Haversine equation for calculating a distance between two latitude-longitude pairs on the Earth is employed. The Haversine distance is formulated in (2).

$$x = \begin{cases} 4\tan^{-1}\left(\dfrac{\sqrt{c}}{1+\sqrt{1-c}}\right) & \text{if } \left(1-\sqrt{c}\right) > 0, \\ 4\tan^{-1}\left(\dfrac{\sqrt{c}}{1+\sqrt{1-c}}\right) & \text{if } \left(1-\sqrt{c}\right) \le 0. \end{cases} \quad (2)$$

c is the short form of trigonometry in which is given in (3).

$$c = \sin\left(\frac{\alpha-\alpha_0}{2}\right)^2 + \cos\alpha\cos\alpha_0\sin\left(\frac{\beta-\beta_0}{2}\right)^2 \quad (3)$$

By using (1), one can estimate the maximum height of blockage as a result of the existence of objects located at all azimuth range. Therefore, a profile of γ_{max} for all azimuth direction of a specific ground station can be generated. This profile could be used in predicting the true link establishment time in which is very useful for satellite commanding purposes. Since commanding a satellite located behind the blocking objects is unavailing, the availability of γ_{max} profile will assist the operator in sending a command at the right time.

Equations (1) to (3) enable only the calculation of blockage affected by a single object located in a specific direction of azimuth. To represent the amount of blockage caused by all objects surrounding the ground station, we averaged γ_{max} calculated from all azimuth direction as given per (4).

$$\bar{\gamma}(\alpha,\beta,h) = \frac{\sum_{i=1}^{N}\gamma_{\max(\alpha,\beta,h,\alpha_i,\beta_i,h_i)}}{N} \quad (4)$$

The N denotes the number of elevation point surrounding the ground station. The Eq. (4) allows the mapping of the average amount of blockage $\bar{\gamma}$ for all regions in DSM imagery becoming possible. This map is then can be used in assessing the quality of certain areas based on the amount of blockage. The assessment result can then be used as a reference in choosing a suitable location for building a ground station site.

C. Evaluation Strategy

In order to assess the proposed approach, we have also compared the calculated $\gamma_{\max}$ to those found in real case as experienced while commanding the LAPAN-A2 and LAPAN-A3 satellites. Both of these satellites are regularly commanded from Biak ground station located in the Southern region of Biak Island. Based on available TT&C log files, we have collected all the commands tried to send from the ground station to the satellites. Each of these commands is marked with a "success" or "failed" identifier, indicating whether the command successfully reaches the respective satellites. For the sake of simplicity, we denoted this identifier as "S", and rewrite the status as "1" and "0". Then, by using the timestamp of each command and employing the SGP4 orbit propagator, we can then know the status of a particular command sent to a specific azimuth and elevation (ε, γ). This information is useful in determining the accuracy R of the proposed approach.

$$R = \frac{\sum_{i=1}^{n} V_i}{n} \times 100\% \quad (5)$$

n is total number of commands tried to send while V_i is a binary state having value according to condition given in (6).

$$V_i = \begin{cases} 0, & \text{if } \langle (S=0)\,\&\,(\gamma > \gamma_{\max}) \rangle \text{ or } \langle (S=1)\,\&\,(\gamma \le \gamma_{\max}) \rangle \\ 1, & \text{if } \langle (S=0)\,\&\,(\gamma \le \gamma_{\max}) \rangle \text{ or } \langle (S=1)\,\&\,(\gamma > \gamma_{\max}) \rangle \end{cases} \quad (6)$$

γ denotes the current elevation angle of satellite seen from the ground station as the command being transmitted. By using Eq. (5), we can estimate the accuracy of the proposed approach in estimating the amount of blockage.

III. Results and Discussions

In this section, we reported the results of blockage calculation in which has been performed by using ALOS DSM dataset as the input. Furthermore, we also provided an analysis related to the accuracy of the proposed calculation. Along with the results, we also discussed the advantages and opportunities of using the generated elevation blockage map in the field of satellite communication.

A. Simulation Result and Accuracy

In the first simulation, the maximum height of blockage (γ_{max}) for each particular azimuth near the Biak ground station has been estimated. The location properties of this ground station is given in Table 1 below.

The profile of γ_{max} near the Biak ground station is shown in Fig. 3. Based on Fig. 3, the physical blockage exists around the North of the test site. This blockage is currently ranging from 345° to 50° of azimuth with a maximum value of 7°. According to this result, it can be said that a communication link to a particular satellite located at 45° of azimuth can only be established after 7° of elevation achieved. Moreover, since there is no existing blockage at azimuth 130° to 270°, the satellite can be directly commanded as soon as it crosses the horizon of the ground station.

To analyze the accuracy of the estimated blockage, we compared this blockage to the elevation of commanded satellites extracted from the house-keeping file (HKF) of LAPAN-A2 and LAPAN-A3. The comparison result is shown in Fig. 4. The "CMD 0" and "CMD 1", respectively, refer to failed and successful commands. Based on Fig. 4, all of the successful commands are truly resulted after the elevation of the satellites exceeding the γ_{max} at given azimuth. Moreover, it is also shown that in general, the unsuccessful commands

TABLE I. Location Properties

Site Name	Parameter Details		
	Altitude	*Latitude*	*Longitude*
Biak Ground Station	50m above sea level	-1.1778829°	136.1017274°

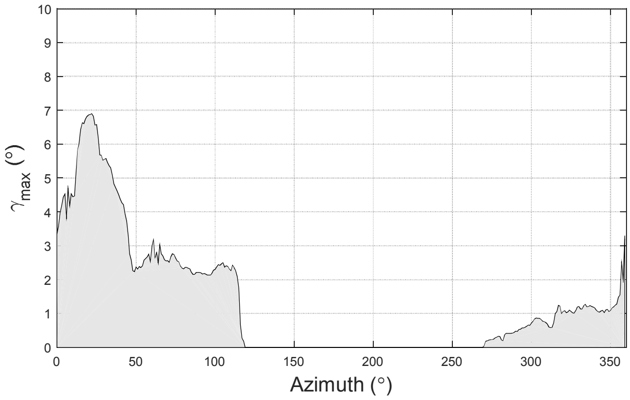

Fig. 3. Profile of maximum elevation blockage around the selected ground station.

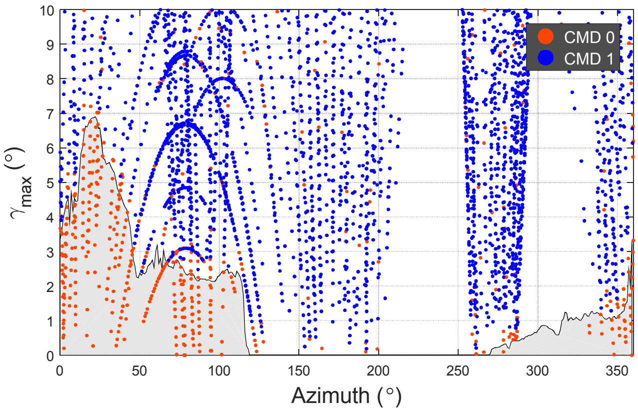

Fig. 4. Distribution of failed and succesful commands of LAPAN-A2 and LAPAN-A3 satellites.

are experienced as the commands are sent even the current elevation still below γ_{max}. This phenomenon indicates that the estimated blockage truly existing as it evidently influences the performance of Biak ground station in establishing successful communication links. To quantify the accuracy of the estimated blockage, we employed the Eq. (5) and found that the accuracy is 93.1% According to this result, the proposed calculation is capable of resulting in a representative blockage as the accuracy is satisfying. Then, the proposed calculation can be considered to be used in generating an elevation blockage map.

B. Physical Blockage Map and Its Utilization

As the proposed calculation is evidently capable of producing representative physical blockage profile (γ_{max}), this calculation can be then implemented in numerous types of applications. One of them is for generating an elevation blockage map in which is used to represent the distribution of averaged physical blockage for each point of a given area. The averaged elevation blockage map of Biak Island is shown in Fig. 5. According to the generated map in Fig. 5, the Northwestern region of Biak Island, relatively has the highest level of blockage compared to other regions. On average, the minimum elevation of 4° to 8° between satellite and ground station is required to establish a communication link to the satellite. On the contrary, the Eastern part of this island seems to be a great place for performing a satellite communication with the blockage ranging only from 0° to 2°. Based on these results, it is recommended to place an antenna with the current configuration at the areas having a small amount of blockage such as the Western, Eastern, and some areas located at the mountains of the Biak Island.

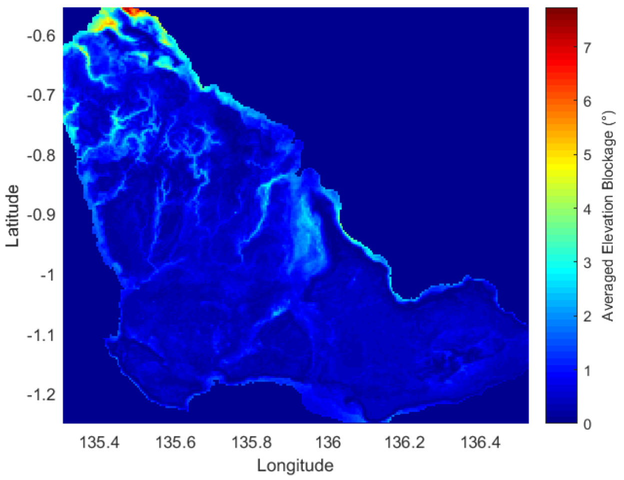

Fig. 5. Averaged elevation blockage map of Biak Island.

To specifically analyze the impact of the existence of elevation blockage on the link establishment performance for satellites orbiting at different orbit, we provided the elevation blockage map for equatorial and polar-orbiting satellites, respectively. In this step, we have assumed that an equatorial-orbiting satellite crosses the horizon at 45°-135° and 225°-315°of azimuth. At the same time, polar-orbiting satellites are assumed accessing the ground station at azimuth 315° - 45° and 135° - 225°. The illustration of these assumptions is summarized in Fig. 6.

According to the assumptions above, we only averaged the blockage for the given azimuth range and presented the result as two different maps. The maps of elevation blockage for equatorial and polar-orbiting satellites are respectively provided in Fig. 7 and Fig. 8. Based on the map in Fig. 7, it can be seen that the Nothern regions of Biak island in which is ranging from -0.5° to -1°, are found less suitable to be used as the location of ground station compared to the Southern regions. It is shown that the averaged blockage on the Southern regions ranges only from 0° to 2° in which is still acceptable for the satellite communication purposes. Likewise, in the Nothern regions, the higher blockage is found distributed with a value ranging from 2° to 6°. According to these results, the Southern regions of Biak island is the most recommended sites for communicating with equatorial-orbiting satellites. Furthermore, based on Fig. 8, all regions of Biak island is recommended for ground station development sites except the Northwestern region. It is found that the blockage in this region exceeding 10° while in the other regions, the blockage is found very less with a value distributed from 0° from 2°.

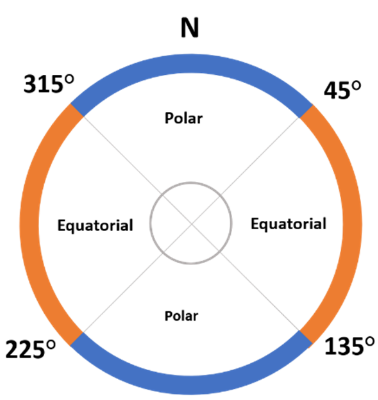

Fig. 6. Illustration of azimuth range for equatorial and polar-orbiting satellites.

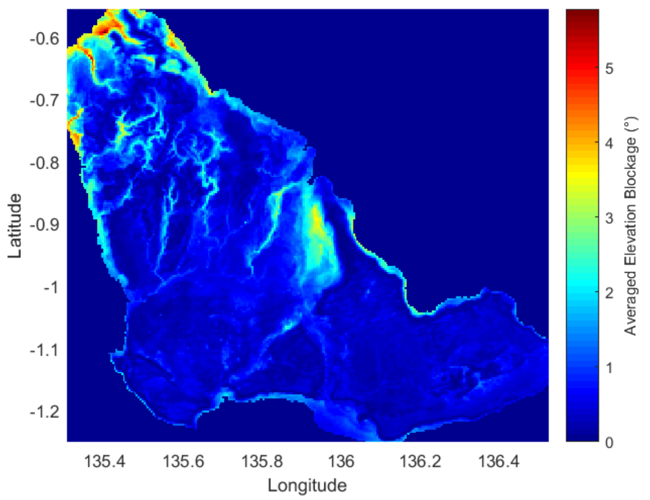

Fig. 7. Averaged elevation blockage map for an equatorial-orbiting satellite in Biak Island.

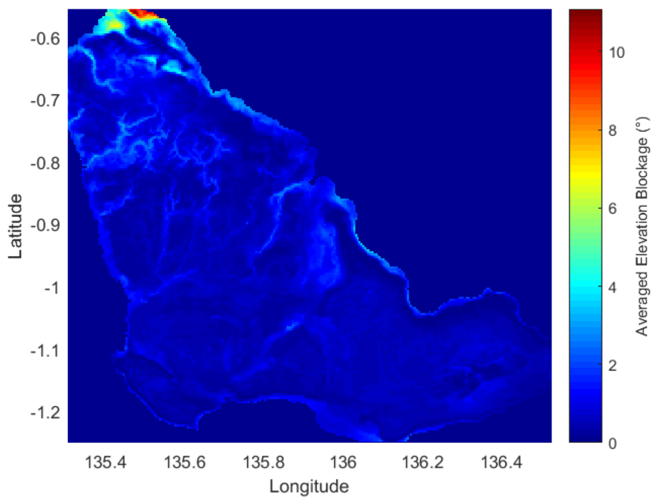

Fig. 8. Averaged elevation blockage map for a polar-orbiting satellite in Biak Island.

Based on the results and discussions above, it is clear that the proposed calculation can be used to quantify the amount of physical blockage surrounding an existing ground station. By knowing this information, a satellite operator will be capable of sending the desired command at an appropriate time. Moreover, the calculation can also be used to map the distribution of averaged blockage on a given area. This map is then can be used as a reference in choosing a suitable location for building a ground station site.

IV. Conclusion

In this paper, we have proposed a method for quantifying the amount of physical blockage surrounding a ground station. The calculation makes use of the *Digital Surface Model* (DSM) dataset provided by a Japanese satellite, ALOS. The existence of the physical blockage accounts for the delay of communication link establishment between the ground segment and satellites. Based on the simulation, the accuracy of the proposed method reaches up to 93.1% as implemented in quantifying the amount of blockage around a particular ground station in Biak Island, Indonesia. We have also found that all regions of Biak island, except the Northwestern region, are suitable to be used as a ground station site as the amount of averaged blockage in these regions are relatively small, around 0° to 2°.

The proposed method can be used to quantify the amount of physical blockage surrounding an existing ground station in which is very helpful for a satellite operator to send the desired command at an appropriate time. Furthermore, the calculation can also be employed to map the distribution of averaged blockage on a given area. This map is then can be used as a reference in choosing a suitable location for building a ground station site.

REFERENCES

[1] Y. Tang, Y. Wang and J. Chen, "High sensitive acquisition of signals for inter-satellite links of navigation constellation based on two-dimension partitioned FFTs," in *Proc. 2016 IEEE International Conference on Signal and Image Processing (ICSIP)*, Beijing, 2016, pp. 573-577, doi: 10.1109/SIPROCESS.2016.7888327.

[2] A. N. Khojasteh, M. Jamshidi, E. Vahedi, S. Telikani, "Introduction to Global Navigation Satellite Systems and Its Errors," *International Academic Institute for Science and Technology*, vol. 3, no. 3, pp. 53-61, 2016.

[3] E. Lagunas, C. G. Tsinos, S. K. Sharma and S. Chatzinotas, "5G Cellular and Fixed Satellite Service Spectrum Coexistence in C-Band," *IEEE Access*, vol. 8, pp. 72078-72094, 2020, doi: 10.1109/ACCESS.2020.2985012.

[4] A. Abdelsalam, M. Luglio, M. Quadrini, C. Roseti and F. Zampognaro, "QUIC-proxy based architecture for satellite communication to enhance a 5G scenario," in *Proc. 2019 International Symposium on Networks, Computers and Communications (ISNCC)*, Istanbul, Turkey, 2019, pp. 1-6, doi: 10.1109/ISNCC.2019.8909181.

[5] P. J. Nicholas, J. C. Tkacheff and C. M. Kuhns, "Measuring the operational impact of military SATCOM degradation," in *Proc. 2016 Winter Simulation Conference (WSC)*, 2016, pp. 3087-3097, doi: 10.1109/WSC.2016.7822342.

[6] S. Liu, J. Huang, W. Mao, Q. Ni, L. Wu and L. Fu, "Experimental study on possibility of earth surface stress detecting using satellite remote sensing," in *Proc. 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, 2017, pp. 1165-1168, doi: 10.1109/IGARSS.2017.8127164.

[7] Y. Ji-yang, H. Dan, W. Lu-yuan, G. Jian and W. Yan-hua, "A real-time on-board ship targets detection method for optical remote sensing satellite," in *Proc. 2016 IEEE 13th International Conference on Signal Processing (ICSP)*, Chengdu, 2016, pp. 204-208, doi: 10.1109/ICSP.2016.7877824.

[8] J. Alvarez and B. Walls, "Constellations, clusters, and communication technology: Expanding small satellite access to space," in *Proc. 2016 IEEE Aerospace Conference*, 2016, pp. 1-11, doi: 10.1109/AERO.2016.7500896.

[9] C.-R. Chen, F.-T. Hwang, C.-W. Hsueh, "Mission studies on constellation of LEO satellites with remote-sensing and communication payloads," in *Proc. SPIE 10402, Earth Observing Systems XXII*, p. 1040207, sept. 2017, doi: https://doi.org/10.1117/12.2273482.

[10] S. Ozafrain, P. A. Roncagliolo and C. H. Muravchik, "Remote sensing with GPS signals on low Earth orbit satellite," in *2015 XVI Workshop on Information Processing and Control (RPIC)*, Cordoba, 2015, pp. 1-6, doi: 10.1109/RPIC.2015.7497148.

[11] A. Ravanbakhsh and S. Franchini, "System engineering approach to initial design of LEO remote sensing missions," in *Proc. 2013 6th International Conference on Recent Advances in Space Technologies (RAST)*, Istanbul, 2013, pp. 659-664, doi: 10.1109/RAST.2013.6581292.

[12] L. mohammadi, N. molanian and A. heidari, "Determination of the Best Coverage Area for Receiver Stations of LEO Remote Sensing Satellites," in *Proc. 2008 3rd International Conference on Information and Communication Technologies: From Theory to Applications*, Damascus, 2008, pp. 1-4, doi: 10.1109/ICTTA.2008.4530157.

[13] Q. Zhou, "Digital Elevation Model and Digital Surface Model," *International Encyclopedia of Geography: People, the Earth, Environment and Technology*, 2017, pp. 1-17, doi: 10.1002/9781118786352.wbieg0768.

[14] T. Motohka, T. Yoshida, H. Shibata, T. Tadono and M. Shimada, "Mapping forest biomass using ALOS digital surface model and pan-sharpen image," in *Proc. 2013 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Melbourne, VIC, 2013, pp. 968-971, doi: 10.1109/IGARSS.2013.6721323.

[15] Y. Yan, H. Chen, F. Gao and Y. Zhang, "Building detection in intricate environment based on interference suppression with digital surface model and optical image," in *Proc. 2012 IEEE International Geoscience and Remote Sensing Symposium*, Munich, 2012, pp. 5717-5720, doi: 10.1109/IGARSS.2012.6352313.

[16] B. Ma, Y. Zhang and S. Tian, "Building Reconstrucion Using Three-Dimensional Zernike Moments in Digital Surface Model," in *Proc. 2018 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Valencia, 2018, pp. 1324-1327, doi: 10.1109/IGARSS.2018.8517724.