Feasibility Analysis of Generating Simulated CAS500-4 Images

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1. Introduction

The growing incorporation of satellite images into various disciplines has led to a significant increase in interest of remote sensing research and the utilization of satellite images. This trend has prompted many countries and private enterprises to actively engage in satellite research and development, with numerous satellites currently operational across various sectors. Following this global movement, the Republic of Korea is advancing its space technology through the development of the Compact Advanced Satellite series. This initiative aims to enhance the country's industrial capabilities and expand the use of satellite data across multiple fields. (Kim, 2023)

Among these satellites, the Compact Advanced Satellite 500-4 (CAS500-4), scheduled for launch in 2025, is designed to play a crucial role in the monitoring and management of agricultural and forestry resources, with daily revisit coverage over the Korean Peninsula. CAS500-4 has a spatial resolution of 5 meters and a swath width of 120 kilometers, with spectral bands specifically tailored for agricultural and forestry applications. (Kim et al., 2016)

To prepare for the satellite's utilization, simulated images generated as specifications of the CAS500-4 are important. This simulation-based approach allows for early testing and validation of essential satellite operations, helping researchers identify potential issues and optimize solutions before actual data becomes available. Most previous studies have relied on data from satellites comparable to the CAS500-4 such as Sentinel-2 and RapidEye. However, differences in resolution, sensor characteristics, and orbital data can limit the accuracy of these data. These differences create environments that do not fully represent real satellite operations, restricting the ability to anticipate and resolve operational challenges.

To overcome these limitations, it is essential to generate simulated images that precisely match CAS500-4's specifications and operating conditions. This will improve operational efficiency and enable the early identification of potential issues before the satellite is deployed.

This study presents a simulation methodology for generating images that match CAS500-4's specifications and validates their accuracy. This approach will enable more accurate research in a tailored environment, facilitating the early identification and resolution of potential issues. Additionally, this research will significantly contribute to satellite image-based studies, particularly in the fields of agriculture and forestry.

2. Material and Methods

2.1 Materials

To generate simulated images for CAS500-4, ortho images, which had been corrected for terrain and geometric distortions to represent vertically captured images, from other satellite can be used. The ortho images are to reprojected into the spatial domain of the CAS500-4.

In this experiment, L1C (Level-1C) images from the Sentinel-2, which are radiometrically and geometrically corrected ortho images, were used. The Sentinel-2 has spectral bands of blue, green, red, and near-infrared bands with a ground sampling distance (GSD) of 10 meters, and a red-edge band with a GSD of 20 meters. The dataset comprised images captured in various locations to account for different environmental and geometric conditions. Additionally, the geometric properties of the simulated images were adjusted using RPCs from Korea's Multi-Purpose Satellite-3A (KOMPSAT-3A) L1R images, which were chosen to simulate CAS500-4 images over Korea.

For inverse orthorectification, a pre-established digital elevation model (DEM) that provides information on the Earth's surface altitude is required. A DEM with a GSD of 5 meters, produced by the National Geographic Information Institute (NGII), was used for this purpose. (Park et al., 2020)

2.2 RPCs Adjustment

Since KOMPSAT-3A's RPCs are tailored to its own imagery, they were adjusted to fit the simulated CAS500-4 images. First, the latitude/longitude offsets were adjusted to match the spatial extent of the Sentinel-2 images, and the height offsets were modified using the DEM. To ensure a GSD of 5 meters, the offsets and scales of the line/sample were iteratively adjusted.

2.3 Establishment of the RFM

To perform inverse orthorectification from ortho images back to raw CAS500-4 images, a sensor model between satellite image coordinates and ground coordinates is required. Using the adjusted RPCs, a rational function model (RFM) was constructed. Equation (1) represents the RFM, which describes the relationship between ground coordinates and image coordinates.

$$
\begin{aligned}
x_n &= \frac{P_1(X_n, Y_n, Z_n)}{P_2(X_n, Y_n, Z_n)} = \frac{\sum_{i=0}^{3}\sum_{j=0}^{3}\sum_{k=0}^{3} a_{ijk} X_n^i Y_n^j Z_n^k}{\sum_{i=0}^{3}\sum_{j=0}^{3}\sum_{k=0}^{3} b_{ijk} X_n^i Y_n^j Z_n^k} \\
y_n &= \frac{P_3(X_n, Y_n, Z_n)}{P_4(X_n, Y_n, Z_n)} = \frac{\sum_{i=0}^{3}\sum_{j=0}^{3}\sum_{k=0}^{3} c_{ijk} X_n^i Y_n^j Z_n^k}{\sum_{i=0}^{3}\sum_{j=0}^{3}\sum_{k=0}^{3} d_{ijk} X_n^i Y_n^j Z_n^k}
\end{aligned}
\tag{1}
$$

Where x_n and y_n represent the normalized image coordinates, and X_n, Y_n and Z_n represent the normalized ground coordinates. The coefficients $a_{ijk}, b_{ijk}, c_{ijk}$ and d_{ijk} are the rational polynomials P_1, P_2, P_3 and P_4.

These coefficients form the rational function expression that defines the relationship between image and ground coordinates. In constructing the RFM, we used only the coefficients of the third term and below from the ground coordinate terms.

2.4 Simulated Image Generation

Using the RFM, forward mapping was applied to project the ground coordinates to the corresponding image coordinates in the CAS500-4 image domain. The height values were calculated using the 3D terrain model. The height values were updated iteratively based on intersections with the DEM, ensuring accurate ground coordinate estimation.

The pixel values from the ortho images corresponding to the estimated ground coordinates were used, and bicubic interpolation was applied. These pixel values were then assigned to the corresponding CAS500-4 image pixels. This process was repeated for each pixel, ultimately generating the final simulated image.

3. Results and Discussion

In this study, the generated simulated image is shown in Figure 1. The validity of the simulated image was verified by analyzing the imaging geometry through the RPCs and calculating the GSD. As a result, it was found that the simulated image followed the imaging geometry of the CAS500-4 image. Set A was configured with similar azimuth angles between Sentinel-2 and KOMPSAT-3A, while Set B was configured with similar incidence angles. Table 1 shows the viewing geometry and GSD of the simulated image based on the adjusted RPCs.

Furthermore, it was confirmed that for more accurate results, the incidence angle between Sentinel-2 and KOMPSAT-3A L1R images needed to be more similar than the azimuth angle, establishing a clear correlation with the imaging geometry. Additionally, pixel value comparisons between Sentinel-2 L1C and the simulated images showed similar values, confirming the successful reconstruction.

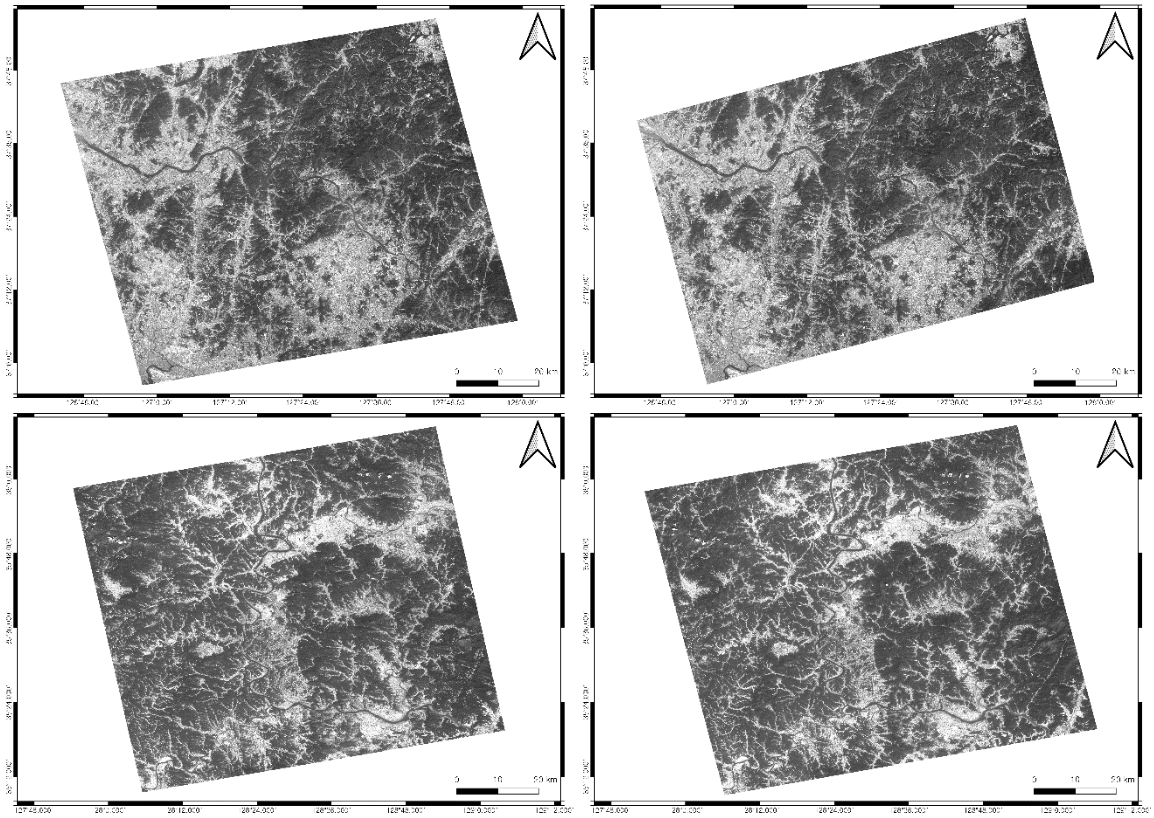

Figure 1: The result of Generating Simulated Images (Blue Band)

Table 1: Changes in Viewing Geometry and GSD due to RPCs Adjusting

Image	Set	Before		After	
		View Angle (Azimuth/ Incidence)	GSD	View Angle (Azimuth/ Incidence)	GSD
1	A	184.355º 3.012º	MS : 10 m, RE : 20 m	185.411º 16.414º	5.000 m
	B			264.979º 8.219º	5.000 m
2	A	101.830º 5.840º		102.893º 18.918º	5.000 m
	B			262.886º 11.849º	5.000 m

4. Conclusion and Recommendation

There are inherent challenges in perfectly matching the imaging geometry of ortho images with the RPCs from different satellites. To address these challenges, this study proposes a method for generating simulated images that meet CAS500-4's specifications. The simulated images produced in this study provided essential preliminary data before the satellite's launch, which would contribute to the advancement of satellite data research and analysis in the fields of agriculture and forestry. Further research is needed to generate simulated images using a physical sensor model of the CAS500-4 so that they can better represent orbital characteristics of the CAS500-4.

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