
DEVELOPMENT OF SATELLITE CONSTELLATION PLANNING ALGORITHMS

AERO 402 Mid-Semester Report

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Satellite Pointing Algorithm

Background information

In satellite operations, two important concepts related to a satellite's observation capabilities are Field of View (FOV) and Field of Regard (FOR). The FOV refers to the specific area that the satellite's instruments can directly observe at any given moment, typically defined by a cone-shaped region extending from the satellite toward Earth. In contrast, the FOR represents the broader area that the satellite could potentially observe by adjusting its orientation or repositioning. While the FOV is limited to the area currently being observed, the FOR is constrained by the satellite's ability to physically slew or move to different targets.

Closely related to these concepts are the terms cross-track and along-track, which describe the satellite's positioning with respect to its orbital path. Along-track refers to the direction along the satellite's orbit, essentially following its trajectory. In contrast, cross-track is the direction perpendicular to the orbit, representing the lateral deviation from the ground track. Both cross-track and along-track angles are critical for understanding how the satellite maneuvers to cover its FOV and potentially expand its coverage within the FOR.

By combining the cross-track (γ_n) and along-track (ϕ_n) angles, we can calculate the overall angular displacement required for the satellite to align with a specific target. This relationship is essential when determining the satellite's pointing requirements and slewing rate, as these angles dictate how much the satellite needs to rotate to stay on target.

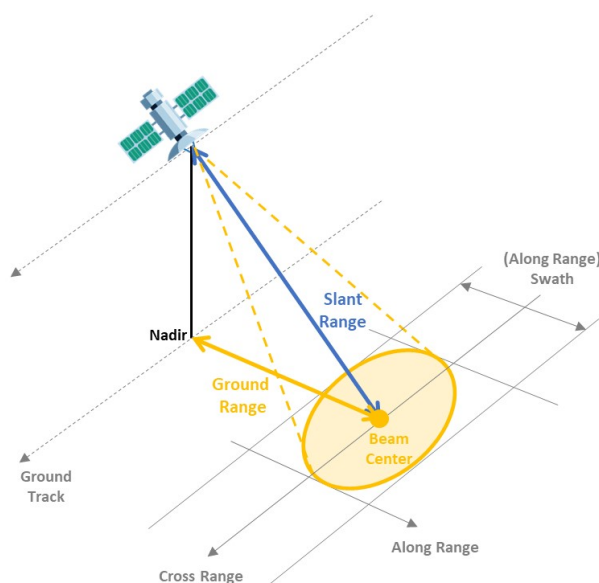


Figure 1. Satellite FOV Diagram

Solution

Building on this, my biggest contribution this semester was the development of a pointing algorithm that allows us to select precise access times between each satellite and its ground targets. Each ground target is divided into 324 unique angle bins, and the goal is to ensure that the satellite constellation can efficiently point at each bin for every target. To achieve this, the pointing algorithm prioritizes bin/target combinations based on the number of access points available for each combination. Those with fewer line-of-sight opportunities are addressed first. As the algorithm progresses, more frequent line-of-sight opportunities emerge, reducing the need for complex slewing maneuvers. This approach ensures efficient data collection from all bins while minimizing the time required for satellite repositioning.

As the algorithm iterates through various bin/target combinations, it processes data with multiple access times, satellite IDs, cross-range, and along-range values. From this data, the earliest available instance is selected and incorporated into each of the satellite ID specific plan. The availability of each access point is determined by the satellite's slewing rate constraints. To calculate the slewing rate between two access points, we define a new term, θ_n , which represents the magnitude of the angle defined by cross-range (γ_n) and along-range (ϕ_n):

$$\theta_n = \sqrt{\gamma_n^2 + \phi_n^2},$$

The slewing rate for each access point is then calculated by summing the angular distances between previously chosen access points and the FOV cone size (r) and between the current access point and the FOV cone size (r), using the following relationship:

$$\frac{\Delta\theta}{\Delta t} = \frac{|\theta_1 - r| + |\theta_2 - r|}{|t_1 - t_2|}$$

Where $\theta_n - r$ is adjusted to zero if the value is negative, meaning the point lies inside the FOV cone. An example can be seen in **Figure 2**.

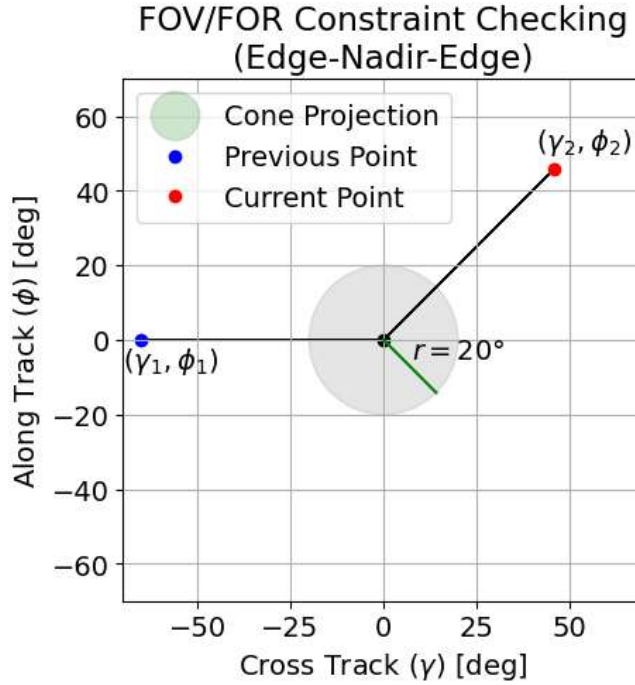


Figure 2. Cross Track vs Along Track Example

The slew rate calculation determines the speed at which the satellite must rotate to reorient its Field of View (FOV) between two access points. First, the satellite moves the edge of its FOV cone from the initial access point (Point 1) to align the center of the cone directly over nadir, the point on Earth's surface directly beneath the satellite. From there, the satellite slews again, moving the edge of the cone to the new access point (Point 2). This process gives the total slew rate required to transition between these points.

Results

The results of the pointing algorithm reveal its effectiveness in capturing bin/target combinations in the least amount of time possible. By prioritizing access times based on the scarcity of available line-of-sight opportunities, the algorithm enables the satellite constellation to systematically target each of the 324 angle bins across all ground targets.

To illustrate the impact of the algorithm, I conducted a comparison between the current approach and a scenario where the satellites operated with zero slewing capabilities. In this zero-slew case, each satellite was fixed in orientation and could only collect data from targets directly within its Field of View (FOV), leading to significant gaps in coverage and unobserved bins. This limitation particularly affected targets that required precise positioning to access. These results are seen in **Figure 3**.



Figure 3. Slewing Rate FOR Comparisons

I compared the algorithm I developed to three different planning schemes, as shown in Table 1. The results indicate that, over a sufficiently long observation window, the algorithm's performance percentage closely approaches that of an infinite FOV system. Additionally, both the maximum and average time to target are nearly identical to those of the infinite FOV, demonstrating the algorithm's effectiveness in minimizing time to target.

Table 1. Planning Scheme Performance

	Percentages (%)	avg Time to Target (days)	max Time to Target (days)
Infinite FOV	100.000000	7.719612	16.450642
Planning Algorithm	100.000000	8.622573	16.450642
No Slewing	33.333333	NaN	NaN
No FOV Cone	100.000000	13.131882	21.325839