# MULTI-SATELLITE IMAGING OPERATIONS WITH SATELLITE CONSTELLATION

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**ABSTRACT:** This paper studies the scheduling of multi-satellite imaging and the design of low-Earth orbit satellite constellations. Due to rapid technological advancements in recent years, the Low-Earth orbit (LEO) satellites are wildly used and deployed. Their major disadvantage, however, is that their coverage is much smaller compared to other medium and high-Earth orbit satellites. To solve this critical problem, many LEO satellites need to be combined into the form of constellations to improve the coverage of single LEO satellites. Although satellite constellation can cover larger region on the earth surface, this also increases the difficulty in the scheduling of satellite imaging. This paper first aims to design a satellite constellation using the well-known Walker Delta Pattern, and compares global coverage with limited target coverage. The genetic algorithm is then applied to optimize the orbit elements and other parameters of the constellation. Additionally, continuous coverage and other conditions will be added to the design objectives to meet different mission requirements. Then, with the specified constellation, we perform the scheduling design of multi-satellite imaging. STK software is employed to verify that the schedule and the constellation meets the imagine requirements.

## 1. INTRODUCTION

This research aims to investigate the design of a low earth orbit (LEO) satellite constellation that provides optimal coverage with application to remote sensing, especially in the aspect of multi-satellite imaging operations. Two tasks are involved in this issue. First of all, we aim to design a LEO constellation that covers the most area on the surface within a given time interval. Secondly, we aim to optimize the imaging operation with the designed constellation.

One of the challenges of using LEO satellites is that their low altitude limits the coverage area of a single satellite. Additionally, LEO satellites orbit the earth quickly, which means that the time a satellite spends above a particular region is short. To overcome these challenges, a satellite constellation can be used to expand the coverage area. Since 2019, the feasibility of using a low earth orbit (LEO) satellite constellation for 5G communication has been demonstrated by the Starlink program, which as of December 2022 consists of over 3,300 mass- produced small satellites in LEO.

Before designing a low Earth orbit satellite constellation, it is important to understand the most commonly used orbit type for such constellations: the Walker Delta Pattern [1]. A research team at Shandong University has provided a detailed explanation of the Walker Delta Pattern in which the team designs the orbit of the low Earth orbit satellite constellation in units of 100 kilometers between an altitude of 900 kilometers and 1500 kilometers. In 2001, an Italian team used a genetic algorithm to design a satellite constellation orbit within a specific target range [2]. Since the satellite constellation in [2] was at a higher altitude in the middle Earth orbit, each satellite had a much larger coverage than low Earth orbit satellites. As a result, there was only one satellite on each orbit plane. The results obtained in [2] cannot be applicable to our research project directly, because our project will focus on a LEO satellite constellation. Instead, we are going to reference the design method by the Italian team, which used the genetic algorithm for design optimization.

In [3], a method for calculating the continuous coverage rate within a spe- cific target coverage range is proposed, but it focuses more on the calculation aspect and does not design a low Earth orbit satellite constellation. The study in [4] focuses on optimizing the global continuous coverage of a low Earth orbit satellite constellation, but mainly from a cost perspective. This reference argues that the lowest cost does not necessarily mean the smallest number of satellites, and even takes into account the cost of launching the satellite constellation into orbit. It provides a different design perspective for this paper. Reference [5] uses the Streets-of-Coverage (SOC) method to design a global continuous coverage satellite constellation, but mainly uses polar orbits and does not impose any restrictions on the range.

A preliminary study was launched and presented in [6]. In the previous study, Teng and Hsiao analyzed the coverage capacity of the “Walker Delta Pattern” constellation orbit type, which determines the inclination, longitude of the ascending node, and true anomaly at epoch. To determine the coverage capacity, we calculated the projected range of each satellite on the surface of the Earth, centered at the projected position of the satellite. This range represents the area where communication is covered by the satellite. We then generated random particles globally and calculated the coverage capacity as the ratio of particles within the range to the total number of generated particles. If a particle was within the range of multiple satellites, it was only counted once. Using this information, the team was able to determine the coverage capacity of the constellation and applied a Genetic Algorithm to optimize the parameters.

This study seeks to address several important issues. Firstly, it aims to enhance communication coverage accuracy by incorporating the J2 effect into the Earth's gravity model. Secondly, it expands the optimization process by considering additional parameters and constraints beyond just the inclination and altitude of the constellation, avoiding overly simplistic solutions. Notably, this research distinguishes itself by validating its findings using existing constel- lations, unlike prior work that lacked such validation. Additionally, the study investigates the scheduling function within the STK orbit simulation software and aims to integrate it with constellation orbit design to evaluate the algo- rithm's effectiveness comprehensively.

## 2. METHODS

### 2.1 Walker Delta Pattern

The Walker Delta Pattern is a type of satellite constellation orbit that evenly distributes the satellites on the orbital plane to achieve better coverage. In this type of satellite constellation orbit, the satellites usually have similar eccentricities and inclinations, which expose each satellite to almost the same perturbation forces to enable control of the entire satellite constellation. The inclination is usually either a polar orbit or a near-polar orbit. Because a polar orbit may increase the likelihood of satellite collisions in polar regions, especially with a large number of satellites, a near-polar orbit is more often chosen.

In addition, the eccentricity of the Walker Delta Pattern is mostly zero, that is, a circular orbit. This is because a circular orbit can save more fuel and is also easier to maintain, which can significantly increase the lifespan of the satellite and save the cost of replacing it. At the same time, a circular orbit can also keep the signal strength of the satellite stable, without causing the signal strength received in different regions to vary due to changes in altitude.

Generally, the design parameters of the Walker Delta Pattern are shown in Table 1. However, the final orbit that meets the service conditions is usually ob- tained through different optimization methods. In this study, the optimization method used is the genetic algorithm, which will be introduced in more detail in the following sections.

Table 1: Parameters to tune in Walker Delta Pattern and their influences. [1]

| Parameters | Influences on the Mission |
|---|---|
| Number of Satellites | It influences the coverage and total cost. |
| Number of Orbits | The cost of launching and transferring will vary depending on the coverage target. |
| Minimum Elevation | It constrains the coverage range of a single satellite. |
| Altitude | The increase of altitude increases not only the coverage, but also the cost to launch and deploy. |
| Inclination | It is designed according to the latitude to cover. |
| Eccentricity | In most cases, a circular orbit is selected because the satellite is easier to track. |

Walker Delta Pattern is usually represented in the following form: $i : t/p/f$, where $i$ is the inclination of the constellation, $t$ is the total number of the satellites in the constellation, $p$ is the total number of orbits in the constellation, and $f$ is an integer constant ranging from 0 to $p-1$ inclusive, representing the true anomaly difference $\Delta f$ in the neighboring orbit, where $\Delta f$ is given by

$$\Delta f = f \times \frac{360^0}{t} \qquad (1)$$

It is notable that satellites are distributed evenly in every orbit, and all the orbit planes are distributed evenly too.

Consider an example constellation where 12 satellites are placed at orbits with an altitude of 500 km. The Walker Delta Pattern for this constellation is 60◦ : 12/6/1, indicating that all the inclinations of the orbits are 60◦, and the constellation contains 6 orbit planes. As a result, every orbit contains 12/6 = 2 satellites. Additionally, $f$ = 1 means that

$$\Delta f = 1 \times \frac{360^0}{12} = 30^0 \qquad (2)$$

Therefore, the arrangement of the constellation is shown in Table 2. Another example is shown in Figs. 1 and 2 where the constellation is placed at the orbits with an altitude of 700 km and has the Walker Delta Pattern 78◦: 12/6/0.

Table 2: The example constellation with Walker Delta Pattern 60◦: 12/6/1. Inclinations of all orbits are 60◦. The longitudes of ascending nodes are selected as (0◦, 60◦, 120◦, 180◦, 240◦, 300◦)

| Orbit No. | True anomalies of satellites |
|---|---|
| #1 | 0°, 180° |
| #2 | 30°, 210° |
| #3 | 60°, 240° |
| #4 | 90°, 270° |
| #5 | 120°, 300° |
| #6 | 150°, 330° |

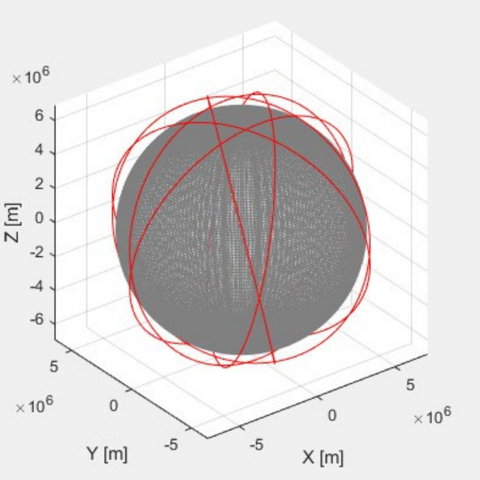


Figure 1: An example depicting the Walker Delta pattern. The constellation is placed at the altitude of 700 km and the parameters are chosen as 78◦ : 12/6/0

## 2.2 Coverage Capacity

In this study, the method for calculating coverage is to randomly place points on an ellipsoid and calculate the distance between the random points and the projected point of the satellite on the surface of the Earth. If this distance is less than the radius of the maximum coverage circle of the satellite, it means that this point can be covered by the satellite, otherwise it cannot be covered.

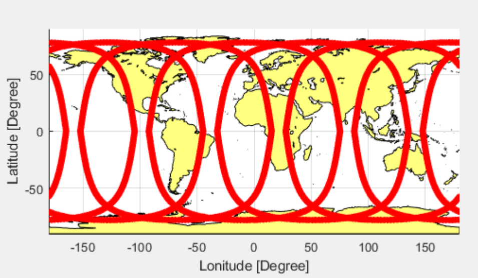


Figure 2: The ground track of the example in Fig. 1. The constellation is placed at the altitude of 700 km and the parameters are chosen as 78◦ : 12/6/0

### 2.2.1 Earth Ellipsoid

It is well known that the earth is not a perfect sphere, but rather the diameter of the equatorial section caused by the earth’s rotation is slightly longer than the diameter of the line connecting the north and south poles. In recent years, scientists have used many different methods, such as geodetic measurement and gravity measurement, to calculate many sets of different earth ellipsoid parameters. The ellipsoid parameters used in this study are WGS-84 [5] and provided in Table 3.

Table 3: Parameters of Earth ellipsoid [7]

| Reference ellipsoid name | Equatorial radius (m) | Polar radius (m) | Inverse flattening |
|---|---|---|---|
| Bessel(1841) | 6377397.155 | 6356078.963 | 299.1528128 |
| Clarke(1866) | 6378206.4 | 6356583.8 | 294.9786982 |
| International (1924) | 6378388 | 6356911.946 | 297 |
| Krassovsky(1940) | 6378245 | 6356863.019 | 298.3 |
| GRS-80(1979) | 6378137 | 6356752.314 | 298.2572221 |
| WGS-84 (1984) | 6378137 | 6356752.314 | 298.2572236 |

### 2.2.2 Random Points on An Ellipsoid

In order to obtain randomly distributed points on a sphere, this study employs Eqs. (3) to (5) to generate these points. The parameter $\theta$ in the equations ranges between 0 to 2π, and u ranges between -1 to +1. These two parameters are sampled with the command rand in Matlab.

$$x = \sqrt{1-u^2}\cos\theta \qquad (3)$$

$$y = \sqrt{1-u^2}\sin\theta \qquad (4)$$

$$z = u \qquad (5)$$

An example is of randomly distributed points on a sphere generated with Eqs. (3)to (5) is shown in Fig. 3.

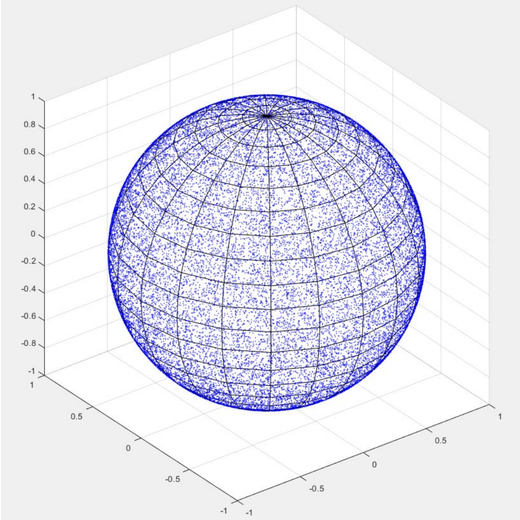


Figure 3: An example of randomly distributed points on a sphere

Having obtained randomly generated points on a sphere, we transform these points on an ellipsoid surface through a linear transformation given in Eq. (6), where (*x, y, z*) and (*ζ, η,* ξ)are the coordinates of the random points on the sphere and the ellipsoid, respectively, and (*a, b, c*) are the three major axes ofthe ellipsoid. Notably, here we assume $a \geq b \geq c > 0$

$$\begin{bmatrix} \zeta \\ \eta \\ \xi \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{b}{a} & 0 \\ 0 & 0 & \frac{c}{a} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad (6)$$

The originally uniform random distribution generally becomes non-uniform under the process of directly transforming random points on a sphere into random points on an ellipsoid surface. It is necessary to modify the transformed result. The method of modification can be found in [8].

## 2.3 Optimization of Coverage

### 2.3.1 Continuous Coverage

The calculation of this coverage is as follows:

1. Uniformly distributed random points are generated on the surface of the earth. Suppose there are N random points in total.
2. Let Nc denotes the points that are within the coverage of any of the neighboring satellites at a specific time t.
3. Define the coverage as $C_t$=$N_C$ /N × 100 %, which ranges from 0 % to 100 %.

Consider a time span $t_a \leq \mathrm{t} \leq t_b$. A region that is said to be under continuous coverage if the region is continuously covered by passing satellites in the time span of interest. An example is depicted in Fig. 4. In this example, a stripe of width d is continuously covered by passing satellites in the time span of interest. There are various types of continuous coverage, and we'll consider all the potential types in the research project. The parameters in Fig. 4 can be computed from the geometric relationship depicted in Fig. 5, where R is the length of arc *OP*. The equations to perform actual computations can be found in [6].

As a result, we define the continuous coverage as follows:

1. Uniformly distributed random points are generated on the surface of the earth. Suppose there are N random points in total.
2. Let Nc denotes the points that are within the region under continuous coverage in the time span$t_a \leq \mathrm{t} \leq t_b$.
3. Define the continuous coverage as$C_{tsp}$ =$N_C$ /N × 100 %, which ranges from 0 % to 100 %. With trials-and-errors we are able to find a candidate number of satellites along with candidate orbit plane number to fulfil the given minimum coverage capacity

### 2.3.2 Application of Genetic Algorithm to This Research

Among all algorithms for optimization, the GA is one of the most effective algorithms for finding global optimization. In computer science and operations research, a genetic algorithm (GA) is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA). Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection.

A typical genetic algorithm requires:

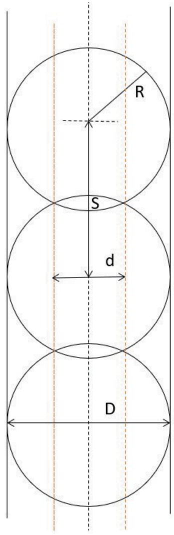


Figure 4: An example of continuous coverage

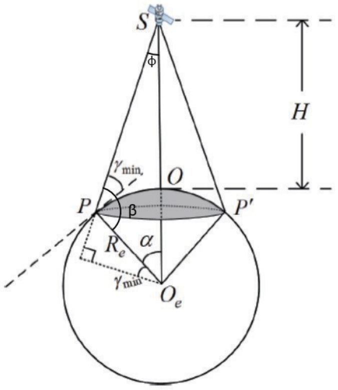


Figure 5: Parameters to compute coverage

1. genetic representation of the solution domain,
2. a fitness function F to evaluate the solution domain.

Once the genetic representation and the fitness function are defined, a GA proceeds to initialize a population of solutions and then to improve it through repetitive application of the *mutation, crossover, inversion* and *selection operators*. A flow chart of GA is provided in Fig. 6. In Matlab, one only needs

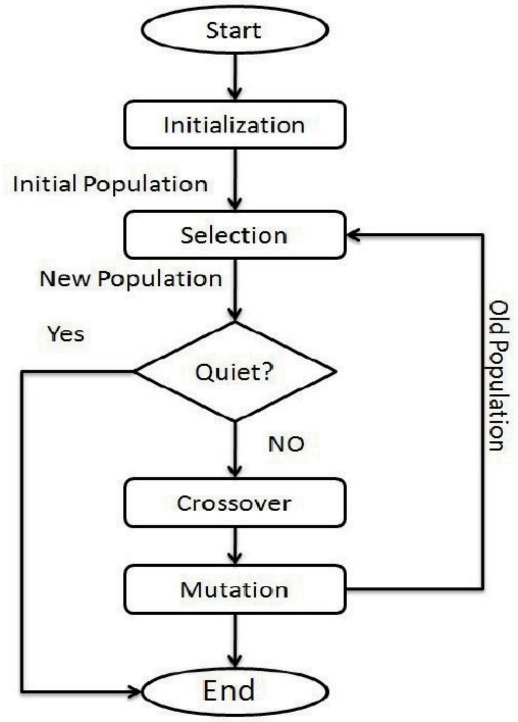


Figure 6: A flow chart depicting the process of the genetic algorithm. [4]

to define the fitness function, number of variables, and bounds and constraints on the states. Then, the function ga returns the solution that minimizes the fitness function. In this research, the fitness function is the continuous coverage, defined as F = $C_{tSp}$.

### 2.3.3 Potential Design Procedure

The potential design procedure to find constellation parameters are provided as follows:

1. Select initial parameters
    (a) The highest latitude to cover
    (b) The half cone angle of the communication
    (c) The time span of interest for continuous coverage
    (d) The altitude of the satellite constellation.
    (e) The minimum coverage capacity.

2. Determine the candidate parameters to optimize. For example, number of orbital planes, inclinations, number of satellites in each orbital plane, and so on.

3Generate random points

4. Confine the candidate range of inclination to the neighbourhood of the highest latitude. For example, let the range be the highest latitude plus or minus 10°.

5.Run GA to optimize the parameters. Check whether or not the coverage meets the criteria. If not, go back to Step 2.

# 3. VERIFICATION

## 3.1 Simulations of Non-continuous Coverage

This study first uses Taiwan's designed Formosat-7/COSMIC-2 satellite as an example for the verification of coverage. It serves as a follow-up project to Formosat-3 and consists of six satellites. In this study's coverage calculations, the target coverage area is limited between 24°N and 24°S, with each individual Formosat-7/COSMIC-2 satellite having a coverage area of a 285.7-kilometer radius due to its altitude of 720 kilometers. The time interval for calculation isfrom UTC September 28, 2023, 04:00:00 to UTC September 28, 2023, 06:00:00. Using MATLAB simulations, the coverage is determined to be 56.1 %, matching the results obtained through STK simulations. Figure 7 depict the orbit distribution, while Figure 8 illustrates the coverage rate calculated using STK simulations.

## 3.2 Simulations of Continuous Coverage

Next, we use the Starlink constellation as an example of continuous cover-age. Starlink is a low Earth orbit satellite constellation operated by SpaceX. SpaceX initiated the Starlink project's satellite launch program in 2019, and asof September 2022, they have launched over 3000 satellites into low Earth orbit.In this study, we will use the Phase 1 satellite constellation of Starlink as an example of continuous coverage.

the Phase 1 of the Starlink project is selected for simulation of the coveragerate analysis. The analysis was performed at five-second intervals, and star- point plotting was done every second. The calculated coverage rates for each interval ranged from 82.07 % to 83.14 %, with an average of 82.59 %.

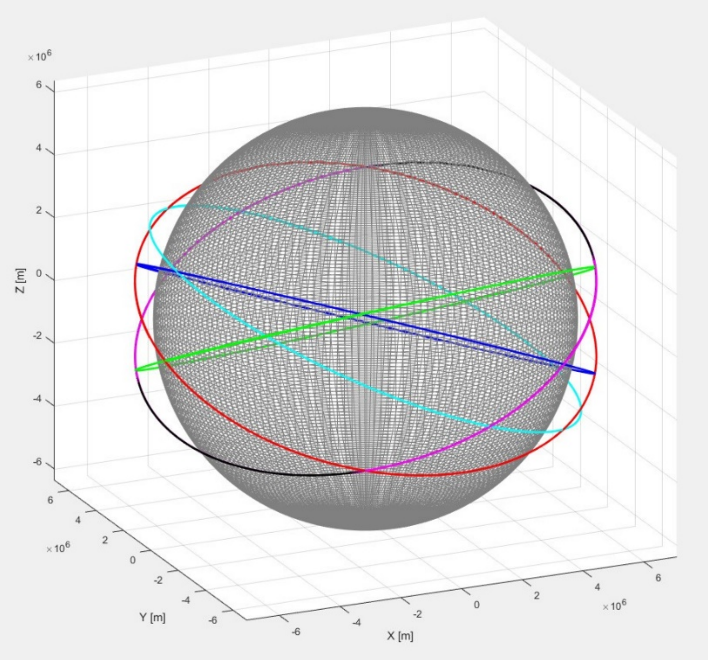


Figure 7: Orbits of FormoSat 7 constellation

This study selected the fifth set of satellite constellations from Starlink Phase1 as a verification example by comparing the results of our algorithm and STKsimulations. From Figure 5, it can be observed that the average coverage ratefor five-second intervals in the STK simulation is 11.18 %, while the average coverage rate calculated through MATLAB under the same conditions is 11.13 %.

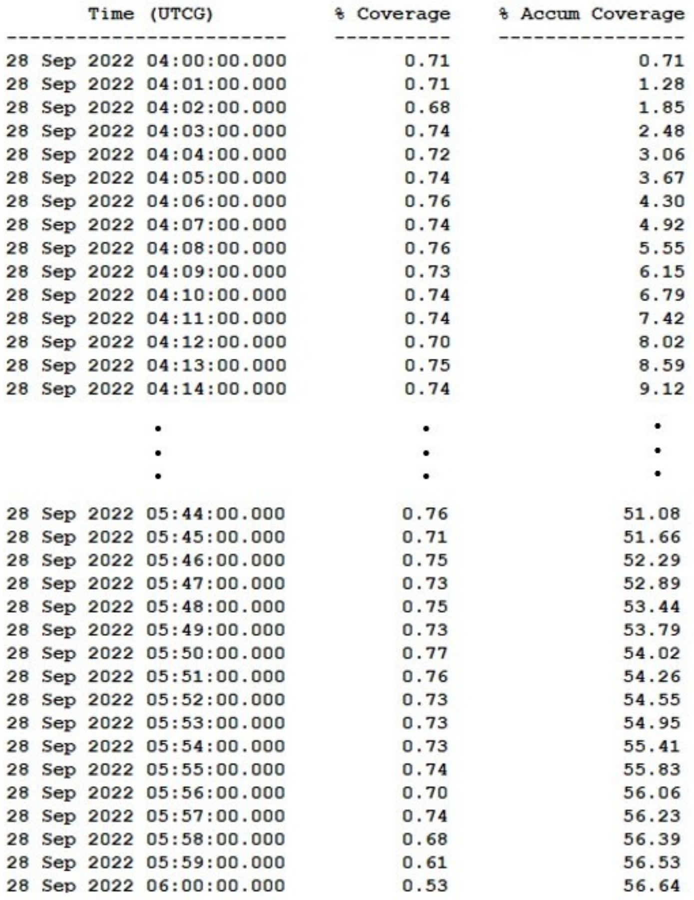
# 4. EXAMPLE MISSIONS

## 4.1 Targeting Region between $60^0$N and $60^0$S

### 4.1.1 Goal of Mission

The goals of the first example mission are listed as follows:

1. Targeting region: Region between 60◦N and 60◦S.
2. Half-cone angle of sensors: 30◦
3. Time interval to compute continuous coverage: 5 seconds
4. Altitude of orbit:900(km)
5. Required minimum coverage rate: 99.5 %

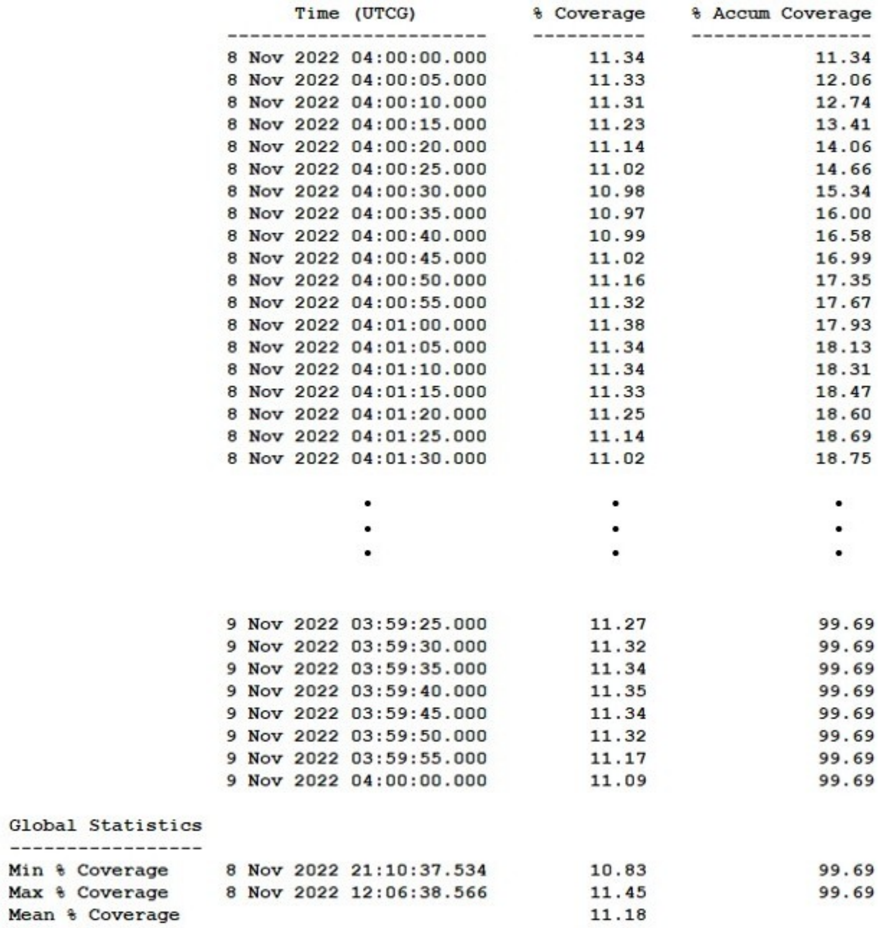


```
       Time (UTCG)          % Coverage    % Accum Coverage
------------------------    ----------    ----------------
28 Sep 2022 04:00:00.000          0.71                0.71
28 Sep 2022 04:01:00.000          0.71                1.28
28 Sep 2022 04:02:00.000          0.68                1.85
28 Sep 2022 04:03:00.000          0.74                2.48
28 Sep 2022 04:04:00.000          0.72                3.06
28 Sep 2022 04:05:00.000          0.74                3.67
28 Sep 2022 04:06:00.000          0.76                4.30
28 Sep 2022 04:07:00.000          0.74                4.92
28 Sep 2022 04:08:00.000          0.76                5.55
28 Sep 2022 04:09:00.000          0.73                6.15
28 Sep 2022 04:10:00.000          0.74                6.79
28 Sep 2022 04:11:00.000          0.74                7.42
28 Sep 2022 04:12:00.000          0.70                8.02
28 Sep 2022 04:13:00.000          0.75                8.59
28 Sep 2022 04:14:00.000          0.74                9.12
            .                       .                   .
            .                       .                   .
            .                       .                   .
28 Sep 2022 05:44:00.000          0.76               51.08
28 Sep 2022 05:45:00.000          0.71               51.66
28 Sep 2022 05:46:00.000          0.75               52.29
28 Sep 2022 05:47:00.000          0.73               52.89
28 Sep 2022 05:48:00.000          0.75               53.44
28 Sep 2022 05:49:00.000          0.73               53.79
28 Sep 2022 05:50:00.000          0.77               54.02
28 Sep 2022 05:51:00.000          0.76               54.26
28 Sep 2022 05:52:00.000          0.73               54.55
28 Sep 2022 05:53:00.000          0.73               54.95
28 Sep 2022 05:54:00.000          0.73               55.41
28 Sep 2022 05:55:00.000          0.74               55.83
28 Sep 2022 05:56:00.000          0.70               56.06
28 Sep 2022 05:57:00.000          0.74               56.23
28 Sep 2022 05:58:00.000          0.68               56.39
28 Sep 2022 05:59:00.000          0.61               56.53
28 Sep 2022 06:00:00.000          0.53               56.64
```

Figure 8: Coverage rate of FormoSat 7 constellation

### 4.1.2 Result

The optimal orbital inclination angle, calculated using a genetic algorithm, is 55.79° when the target coverage area is set to be at latitude 60° North and South, with a total of 30 orbital planes. The average coverage rate is 99.79 %, with a maximum coverage rate of 99.81 % and a minimum of 99.78 %. The program checks the continuous coverage situation within 1° around the 55.79°inclination angle, with each 0.001° as one angle, and it is determined that the best orbital inclination angle for the mission's target coverage area at latitude 60° North and South with 30 orbital planes is 55.79°. The coverage rates in the vicinity of the optimal inclination angle obtained by the genetic algorithm are shown in Figure 10



```
                        Time (UTCG)             % Coverage    % Accum Coverage
                 ------------------------       ----------    ----------------
                 8 Nov 2022 04:00:00.000             11.34               11.34
                 8 Nov 2022 04:00:05.000             11.33               12.06
                 8 Nov 2022 04:00:10.000             11.31               12.74
                 8 Nov 2022 04:00:15.000             11.23               13.41
                 8 Nov 2022 04:00:20.000             11.14               14.06
                 8 Nov 2022 04:00:25.000             11.02               14.66
                 8 Nov 2022 04:00:30.000             10.98               15.34
                 8 Nov 2022 04:00:35.000             10.97               16.00
                 8 Nov 2022 04:00:40.000             10.99               16.58
                 8 Nov 2022 04:00:45.000             11.02               16.99
                 8 Nov 2022 04:00:50.000             11.16               17.35
                 8 Nov 2022 04:00:55.000             11.32               17.67
                 8 Nov 2022 04:01:00.000             11.38               17.93
                 8 Nov 2022 04:01:05.000             11.34               18.13
                 8 Nov 2022 04:01:10.000             11.34               18.31
                 8 Nov 2022 04:01:15.000             11.33               18.47
                 8 Nov 2022 04:01:20.000             11.25               18.60
                 8 Nov 2022 04:01:25.000             11.14               18.69
                 8 Nov 2022 04:01:30.000             11.02               18.75

                             .                       .                   .
                             .                       .                   .
                             .                       .                   .

                 9 Nov 2022 03:59:25.000             11.27               99.69
                 9 Nov 2022 03:59:30.000             11.32               99.69
                 9 Nov 2022 03:59:35.000             11.34               99.69
                 9 Nov 2022 03:59:40.000             11.35               99.69
                 9 Nov 2022 03:59:45.000             11.34               99.69
                 9 Nov 2022 03:59:50.000             11.32               99.69
                 9 Nov 2022 03:59:55.000             11.17               99.69
                 9 Nov 2022 04:00:00.000             11.09               99.69

Global Statistics
-----------------
Min % Coverage   8 Nov 2022 21:10:37.534             10.83               99.69
Max % Coverage   8 Nov 2022 12:06:38.566             11.45               99.69
Mean % Coverage                                      11.18
```

Figure 9: The coverage rate of the fifth set of satellite constellations from Star-link Phase 1 simulated by STK

### 4.2 Targeting Region at Asia

The goals of the second example mission are listed as follows:

1. Targeting region: Region between 78◦N and 78◦S.
2. Half-cone angle of sensors: 30◦
3. Time interval to compute continuous coverage: 5 seconds
4. Altitude of orbit: 900(km)
5. Required minimum coverage rate: 99.5 %

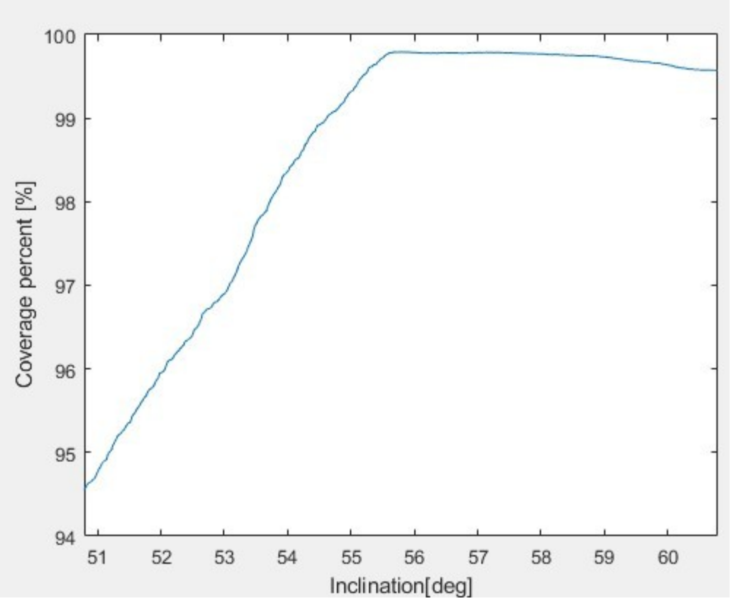


Figure 10: The relation between coverage rate and the inclination of constellation orbits for the example of targeting the region between 60°N and 60°S.

#### 4.2.1 Result

The optimal inclination angle of 73.31° was obtained through genetic algorithm calculations when setting Taiwan as the coverage target for a continuous low Earth orbit satellite constellation. The average coverage rate achieved was 99.51 %. The coverage rates in the vicinity of the optimal inclination angle obtained by the genetic algorithm are shown in Figure 11, indicating that 73.31°is the best inclination angle for achieving the highest average coverage rate.

## 5. SCHEDULING

One potential application of the algorithm described earlier is in the context of multi-satellite imaging processes. Imagine there are multiple targets that need to be imaged using a constellation of satellites. An effective approach is to en- hance the efficiency of the imaging schedule by utilizing a satellite constellation with the highest possible coverage rate. Detailed discussions about the coverage rate will be presented in the following sections, and the recommended approach for designing such a constellation involves the use of the proposed algorithm. When it comes to scheduling, the Scheduler kit available in STK is employed for this purpose.

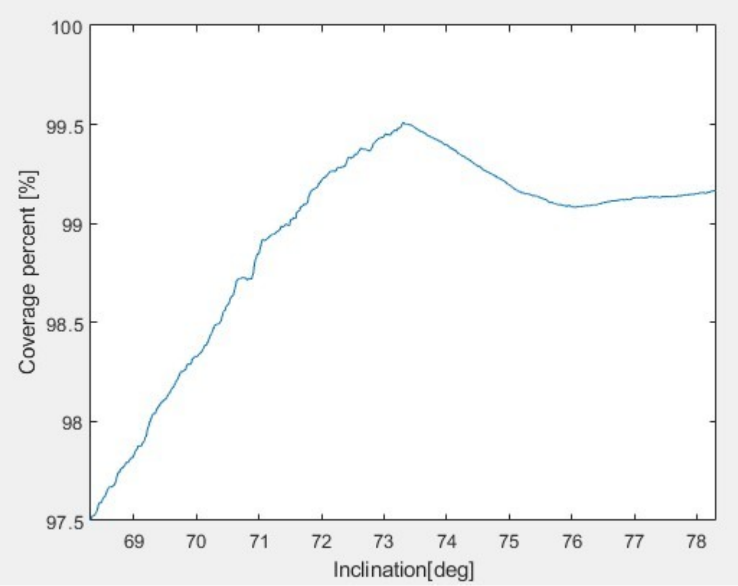


Figure 11: The relation between coverage rate and the inclination of constellation orbits for the Asia targeting example.

### 5.1 Brief on Schedule

The STK Scheduler, an integrated Systems Tool Kit (STK)® add-on module developed by Orbit Logic IncorporatedTM, offers a robust scheduling and planning solution for both mission designers and operations engineers. With this tool, users can define tasks and resources, request conflict-free schedule solutions, and assess outcomes through graphical or tabular GUI interfaces and ASCII reports. Moreover, it seamlessly imports STK objects, access calculations, and reports from a STK scenario to establish task scheduling windows and resource availability times. Powered by an advanced scheduling engine leveraging neural network technology, STK Scheduler excels in delivering superior solutions faster than traditional heuristic algorithms, even for larger and more intricate problems. This capability empowers system planners to optimize the utilization of limited resources effectively. Details of Scheduler can be found in [10].

### 5.2 Example Mission

The forthcoming sections will provide a succinct overview and practical demonstrations of key features. In Figure 12, we showcase the configuration options within the Scheduler module, highlighting users' ability to define multiple targets. Furthermore, as exemplified in Figure 13, users have the flexibility to define both multiple targets and multiple satellites. In the context of our illustrative mission, we've established 25 imaging targets and designated 3 satellites for mission execution, specifically opting for FormoSat2 and its variant versions as the chosen satellites. We present two illustrative scenarios: the first scenario involves three satellites with identical orbit elements, differing only in true anomaly, spaced at intervals of 120◦ apart. In the second scenario, three satellites share identical orbit elements except for the longitude of the ascending node, similarly spaced 120◦ apart. Their respective trajectories are visualized in Figure 14. The result imagine schedule is then provided in Figure 15.

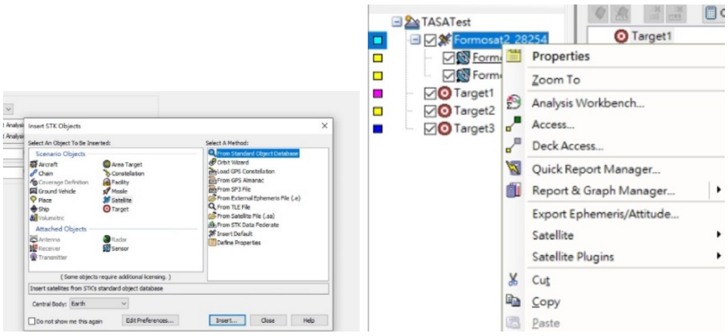
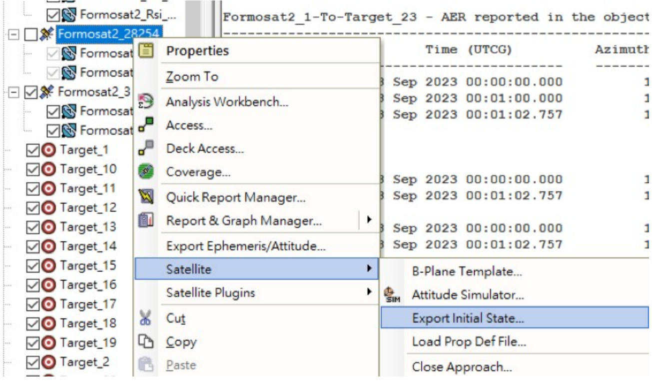


Figure 12: The snapshots of the Scheduler setting screen.

Figure 13: The snapshot of the Scheduler setting screen for multiple satellitesand multiple target.



```
Formosat2_1-To-Target_23 - AER reported in the object

        Time (UTCG)              Azimuth
-----------------------          -------
 Sep 2023 00:00:00.000                 1
 Sep 2023 00:01:00.000                 1
 Sep 2023 00:01:02.757                 1

 Sep 2023 00:00:00.000                 1
 Sep 2023 00:01:02.757                 1

 Sep 2023 00:00:00.000                 1
 Sep 2023 00:01:02.757                 1
```

## 6. CONCLUSION

this research delved into the intricate realm of multi-satellite imaging scheduling and the intricacies involved in crafting low-Earth orbit (LEO) satellite constellations. Given the rapid evolution of technology in recent years, the ubiquity

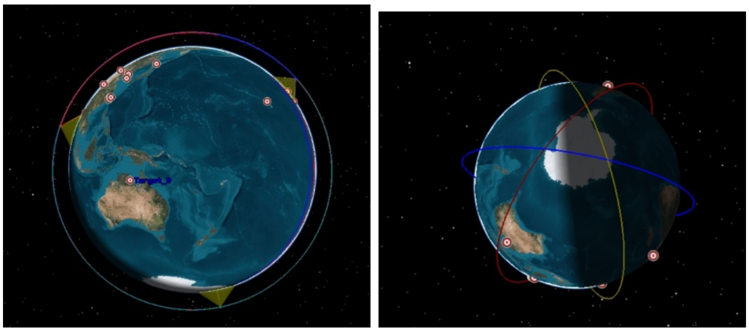


Figure 14: Two example constellation for imaging scheduling. In the left, the orbit elements are different only in true anomaly, whereas the orbit elements are different only in longitude ascending node in the right.

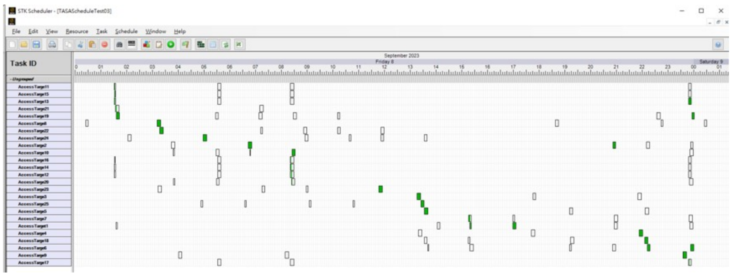


Figure 15: The result image schedule provided by Scheduler.

of LEO satellites has grown exponentially, necessitating innovative solutions to address critical challenges. One of the primary solutions explored in this study was the conceptualization of satellite constellations utilizing the well-established Walker Delta Pattern. These constellations were meticulously designed and eval-uated, emphasizing global coverage as well as specific target coverage. Leveraging genetic algorithms, we fine-tuned orbit elements and other crucial parameters to optimize constellation performance. Moreover, our research extended beyond coverage optimization by incorporating additional criteria, such as continuous coverage and mission-specific requirements, into the constellation designobjectives. The resulting constellations were tailored to accommodate a range of mission profiles and objectives.

## 7. ACKNOWLEDGMENT

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