Development of mission planning tool including optimization module

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***Abstract*— In order to achieve the next level services of earth observation satellite data, the web-based tool for mission planning is developed. The objectives are joint-usage spare resources of earth observation satellite amongst ASEAN, customer-self mission planning and optimization of mission plan. The tools are developed in three modules; web-based interface module for world-wide service, Orbital propagator/Earth projection module for the computation of feasible accessibility and optimization module for efficiency of mission planning. Three segments are carried out in parallel so as to get the tool ready-to-use as soon as possible. Each module will be initially tested in separation and finally as a whole once they are completed with current-used mission planning tool.**

Keywords- Mission Plan, Satellite position, Field of Regard, API Map, Accessibility

I. Introduction

The objective of this development is to create a centralized tool for co-managing the resource of satellites' data that Geo-Informatics and Space Development Agency (GISTDA) has acted as a distributor and it will soon become a centralized tool for co-planning of EOS in ASEAN such as THEOS, X-Sat and VNREDSAT.

Each satellite has its own mission planning system; therefore, the imaging plan has been developed separately and has not taken other satellites GISTDA is working on into consideration in aspect of accessibility and type of products. This constraint will be solved by integrating a number of EOS to optimize the time to complete the task and other user's requirements. Moreover, GISTDA also has a plan to encourage the establishment of collaboration amongst ASEAN nations on satellite constellation which allow resources sharing as well as increase versatility of product, coverage area and opportunity of success imaging.

Three modules that are developed in parallel in order to make the tool ready-to-use as soon as possible is illustrated in Figure 1

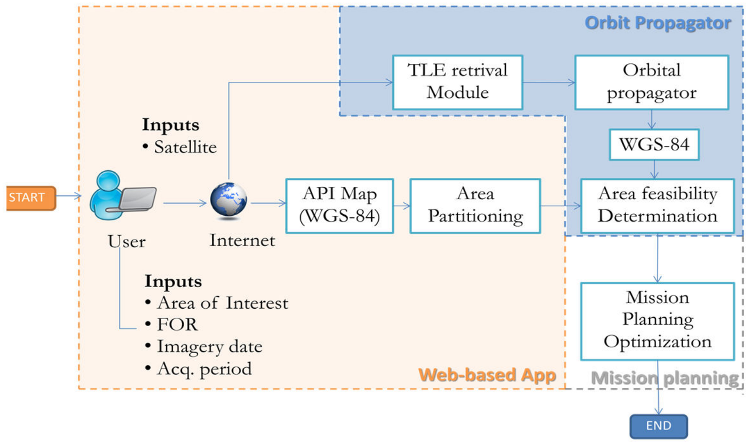

Figure 1. Working plan diagram

II. Earth Obsrvation Satellite

In this paper, EOS will be categorized in two categories as optical and SAR (Synthetic Aperture Radar) satellites. An area that earth observation satellite can access can be determined by access corridor resulting from attitude maneuver in across-track and along track directions which can be called Field of Regard (FOR) at satellite perspective as illustrated in Figure 2and 3;

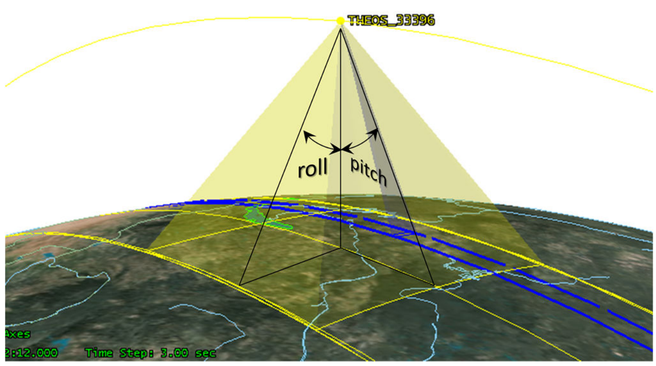

Figure 2. FOR projection resulting in access corridor for optical satellite

The yellows lines represents orbit trajectory and access corridor whereas blue lines represent swath width.

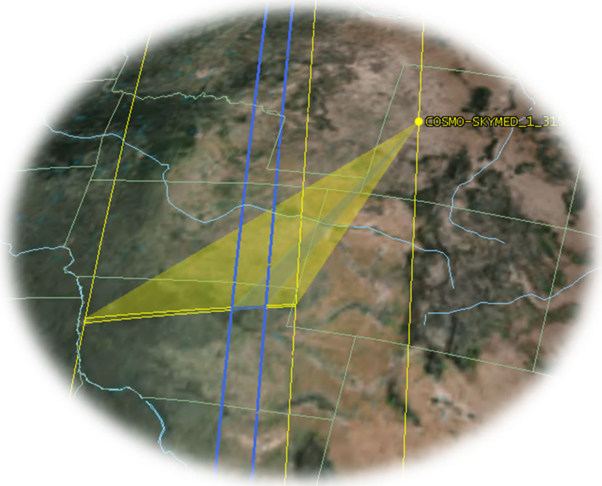

Figure 3. FOR projection resulting in access corridor for SAR satellite

The projection of FOR on Earth is an access corridor. Because satellite positions calculated by orbital propagator is usually in Earth-Centered, Earth-Fixed (ECEF) coordinate system, therefore the frame conversion from celestial to terrestrial is necessary; from ECEF to Local Geocentric Vertical (LGCV), in order to match with geographical location on Earth where a satellite can access.

The access corridor can be varied depending on imaging modes and the capability of each EOS. The imaging modes for an optical satellite are nadir, nominal and full angle modes which are slightly different from SAR that is capable of nominal and extended imaging modes as in Figure 4.

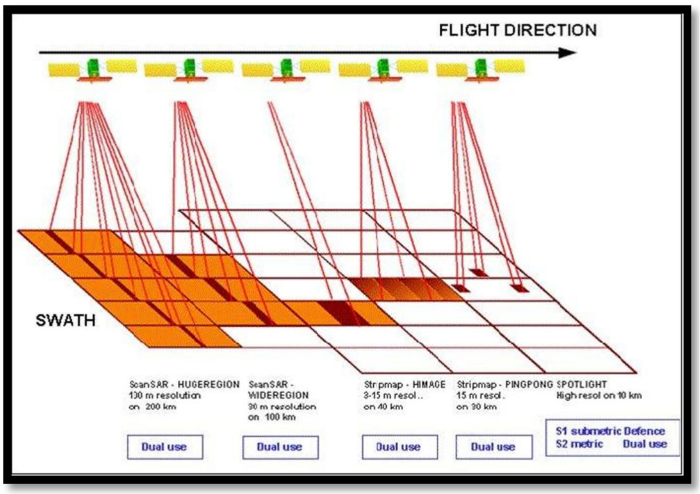

Figure 4. Cosmo-Skymed imaging modes

Another component for determining satellite revisit pattern is orbit cycle and orbital period which is a unique characteristic for each satellite. THEOS and Cosmo-Skymed satellites repeat their orbit cycle in 26 days and 16 days respectively. This tool has been developed based on each satellite orbit repetition, consequently, as long as positions in an orbit cycle is defined, the accessibility can be determined regardless of acquisition time.

III. ORBITAL PROPAGATION

In order to perform a mission planning, the satellite ephemeris with respect of time must be available. The necessary data for optimizing a mission plan are as follows; earliest/latest start time and duration of acquisition.

Simplified Perturbation Model is chosen based on the following reasons; first, Two-Line Element (TLE) data is the only source of public satellite data covering the majority of orbiting objects. Second, such an analytical approach has value for dealing with large number of satellite. Third, it has already proved that the accuracy of the propagator is generally in the kilometer-level range (Hartman,1993) of which is adequate for the acquisition assessment.

The model predicts the effect of perturbations caused by the Earth's shape, drag, radiation, and gravitation effects from other bodies such as the Sun and Moon. Simplified General Perturbations (SGP) models apply to near-Earth objects with an orbital period of less than 225 minutes. An EOS fall into this category. SGP-4 theory was primarily based on Brouwer (1959) and uses power density functions (Lane and Cranford, 1969; Lane and hoots, 1979) that require a term that encapsulates the ballistic coefficient, Bstar (See Vallado, 2007: 115). Simplified force modeling and the batch-least-squares processing of observational data often yield a Bstar that has "soaked up" force model errors.

The product of orbital propagation module is generally in ECEF coordinate; therefore, the sub-satellite location must be determined at this state for creating access corridor according to satellite sensor and agility. The transformation from ECEF to LGCV can be done with the Equation (1), (2) and (3);

$$R = \sqrt{x^2 + y^2 + z^2} \tag{1}$$

$$\lambda = \sin^{-1}\left(\frac{z}{R}\right) \tag{2}$$

$$\phi_c = \operatorname{atan2}(y, x) \tag{3}$$

IV. FIELD OF REGARD PROJECTION

In order to create an access corridor of the satellite, FOR resulting from satellite maneuver in roll and pitch direction is needed to be projected on Earth. The azimuthal equidistant map projection is proposed as a solution to the problem of mapping the potential swath coverage and subsequently, coverage area. Snyder (1987) provides the computation of x-y coordinate positions for the azimuthal equidistant projection. For mapping the sensor FOR coverage, it is a solution that would center the projection at the sub-satellite location. The azimuthal equidistant map projection has two properties that are particularly suited to the sensor coverage (access corridor) problem because they allow for a simple solution. These properties are; first, distances measured from the center are true and second, directions from the center are true.

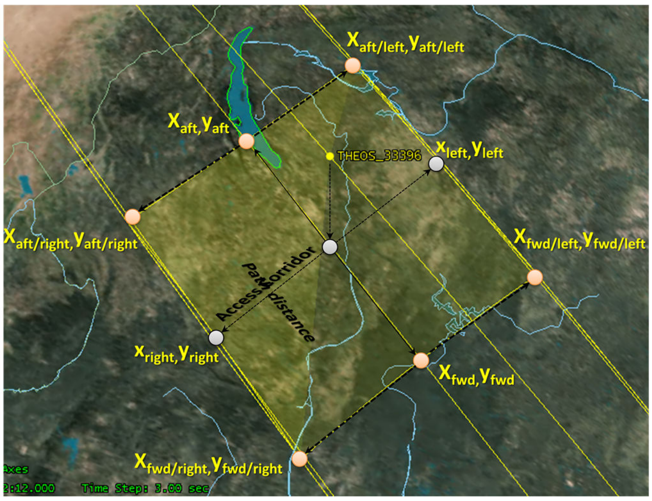

Figure 5. Azimuthal equidistant map projection

In Figure 5, given a sub-satellite location (ϕ_1, λ_0) and satellite heading are derived (direction satellite is moving to), the location (ϕ, λ) perpendicular to the satellite heading are derived.

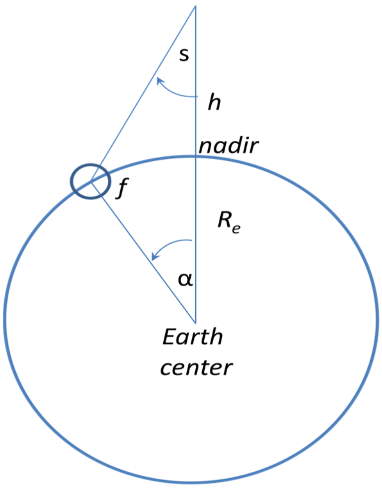

Figure 6. Spherical distance on Earth

In Figure 6, the satellite altitude (h), Earth radius (Re = 6,378.137 km) and boresight angle (s) are known. An α and access corridor can be determined by the following equation (4) and (5);

$$\alpha = \sin^{-1}\left[\frac{\sin(roll)(R_e+h)}{R_e}\right] - roll \qquad (4)$$

$$Access\ Corridor = \left[\frac{\alpha}{2\pi}\right] R_e \qquad (5)$$

According to Figure 5, the left and right positions on the azimuthal equidistant map projection at right angles to the satellite heading are computed by Equations (6) – (9);

$$x_{right} = \cos(heading - 180) \times (-Access\ Corridor) \qquad (6)$$

$$y_{right} = -\sin(heading - 180) \times (-Access\ Corridor) \qquad (7)$$

$$x_{left} = \cos(heading - 180) \times (Access\ Corridor) \qquad (8)$$

$$y_{left} = -\sin(heading - 180) \times (Access\ Corridor) \qquad (9)$$

By convention, the point x_{left}, y_{left} or x_{right}, y_{right} is left/right of the satellite *heading*. Most of the remote sensing satellite has a descending heading in a southwesterly direction (e.g. 188 degrees) for daytime collections.

Then, the left and right position on azimuthal equidistant map projection can be transformed back to geocentric coordinate by the following Equation (10) – (13);

$$p = \sqrt{x^2 + y^2} \qquad (10)$$

$$c = \frac{p}{R_e} \qquad (11)$$

$$\phi = \sin^{-1}\left[\cos(c)\sin(\phi_1) + \left(y\sin(c)\frac{\cos(\phi_1)}{p}\right)\right] \qquad (12)$$

$$\lambda = \lambda_0 + \tan^{-1}\left[\frac{x\sin(c)}{p\cos(\phi_1)\cos(c) - y\sin(\phi_1)\sin(c)}\right] \qquad (13)$$

V. EARLIEST/LATEST START TIME AND DURATION

Three information that are required as the inputs for optimization algorithm for mission planning are earliest/latest start time and duration (Figure 7 and Figure 8). The earliest start time is the time that a satellite can start imaging the area of interest with the maximum forward pitch angle. While the latest start time is a result of maximum afterward pitch angle. The duration of acquisition is the period of time a satellite takes for imaging a strip.

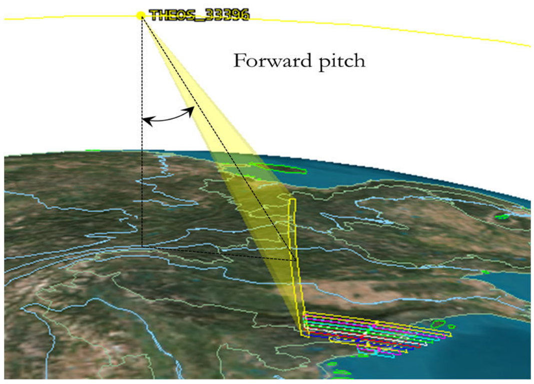

Figure 7. Earliest start time

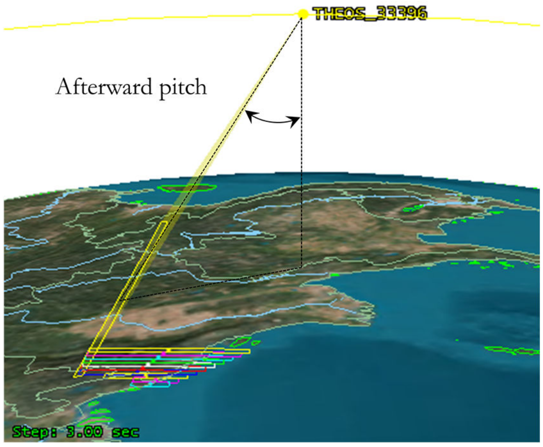

Figure 8. Latest start time

As Figure 5 illustrated, FOR projection with maximum pitch angle for determining earliest/latest start time of acquisition are as follows; an α, path distance, the forward (x_{fwd}, y_{fwd}) and afterward (x_{aft}, y_{aft}) position on azimuthal equidistant projection can be consequently determined according to the Equation; (14) - (19). The *x-y* is then converted back to geocentric with Equation (10) - (13).

$$\alpha = \sin^{-1}\left[\frac{\sin(pitch)(R_e+h)}{R_e}\right] - pitch \tag{14}$$

$$path\ distance = \left[\frac{\alpha}{2\pi}\right] R_e \tag{15}$$

$$x_{aft} = \sin(heading_i + 180) \times (path\ distance) \tag{16}$$

$$y_{aft} = \cos(heading_i + 180) \times (path\ distance) \tag{17}$$

$$x_{fwd} = -\sin(heading_i + 180) \times (path\ distance) \tag{18}$$

$$y_{fwd} = -\cos(heading_i + 180) \times (path\ distance) \tag{19}$$

The forward/afterward location in geocentric is now acted as the center of sub-satellite location. The left and right position of the forward $(x_{fwd/left}, y_{fwd/left})$, $(x_{fwd/right}, y_{fwd/right})$, and afterward $(x_{aft/left}, y_{aft/left})$, $(x_{aft/right}, y_{aft/right})$ location can be thereafter determined with Equation (10)-(13) to obtain the result in geocentric coordinate. The access corridor with respect of time is now created for forward/afterward pitch angle. Consequently the earliest/latest start time of acquisition can be determined.

As for the duration of acquisition which is the period of time a satellite take for imaging a strip. In reality, the duration of acquisition can be computed from camera reading speed in line per second but that would make the satellite pitch angle change during acquisition. Therefore, in order to simplify the problem, the duration of acquisition is computed based on the satellite ground velocity. The acquisition duration is determined by following (19);

$$DUR = START\ TIME - STOP\ TIME \tag{20}$$

The outputs from user input and orbit propagator module including earliest/latest start time and duration of acquisition is now available for mission planning optimization algorithm.

VI. Mission Planning Optimization

The area of interest will be defined as polygon by user covering a wide geographical area. The polygon will be partitioned into strips according to each satellite swath width of equal width but possibly unequal lengths. A satellite may take several strips of the same polygon by rotating itself between consecutive shots. Multiple strips associated with the same polygon must, however, be acquired consecutively both in space and time.

For this reason, there are quite a number of possible sequences for imaging task plan which is impossible to be all analyzed. The optimization algorithm is therefore necessary. Genetic algorithm is chosen because of the complexity of the problem, which is an NP-hard. In addition, genetic algorithm is popular and widely used in the area of combinatorial optimization.

By definition, the genetic algorithm is a search heuristic that mimic the process of natural selection. It is a population-based method which is developed from the natural survival concept and operates by several individuals in the population. The heuristic is routinely used to generate solution to optimization problem using techniques inspired by natural evolution such as inheritance, mutation, selection and crossover. The objective function set for this case is to determine the shortest time to complete the tasks that area related to roll angle.

Each satellite constraints that were taken into consideration are satellite agility and instrument delay before acquisition. As in Equation (21), the minimum transition time must be computed. The transition time is a necessary time to move the camera from the ending point of the previous acquisition to the beginning of the next acquisition. For each pair of possible acquisitions, an approximation of the rotation for moving the camera in radians can be computed as following (21)

$$Ro[k,k']2 = 2arctan\frac{Di[k,k']}{2Hs} \tag{21}$$

where *Hs* is a constant value, which represents the satellite altitude in meters. Then, the necessary transition time for each pair of possible acquisition is computed by (22)

$$Dt[k,k'] = Dmin + \frac{Ro[k,k']}{Vr} \tag{22}$$

Where *Dmin* is a fixed transition time in seconds which is instrument delay before acquisition and *Vr* is the average speed of rotation on itself of the satellite in radians per second. Both values are constant. In the recent years, several algorithms (e.g. simulated annealing, tabu search) were applied for solving the single objective Earth observation scheduling problem [2]-[3]. In [4], a tabu search was used for the multi-satellite, multi-orbit and multi-user management to select and schedule requests. For the multi-objective Earth observation scheduling problem, a genetic algorithm was tested by using instances of the French agile satellite [5]. In this work, we plan to use the genetic algorithm for solving the problem and apply to the real data from THEOS.

VII. TEST AND VALIDATION

The tests for program verification that has already been carried out so far are accessibility test for ensuring the accuracy of orbital propagation and mission planning test for practicality.

The test of accessibility has already been verified by Satellite Tool Kit (STK). The outputs that were checked are the number of access and acquisition date/time. Testing conditions were set in the aspect of type of sensors, imaging mode and area of interest.

In order to verify the results, an optical and SAR satellite. THEOS and Cosmo-Skymed-1 are chosen respectively. The nominal mode is set for both satellites. TABLE I presents THEOS imaging that was carried out over Cairo, Egypt for one month, Jan – Feb 2014.

TABLE I. COMPARING THE RESULT BY STK AND NEW DEVELOPED SOFTWARE FOR THEOS OVER CAIRO, EGYPT

STK		New developed Software	
No.	Acquisition date/time	No.	Acquisition date/time
1	29/1/2014 8:30:00.000	1	1/29/2014 8:29:30.000
2	30/1/2014 8:11:00.000	2	30/1/2014 8:10:00.000
3	3/2/2014 8:33:00.000	3	3/2/2014 8:33:30.000
4	4/2/2014 8:14:30.000	4	4/2/2014 8:14:00.000
5	8/2/2014 8:37:30.000	5	2/8/2014 8:37:00.000
6	9/2/2014 8:18:00.000	6	9/2/2014 8:17:30.000
7	10/2/2014 7:59:00.000	7	10/2/2014 7:58:30.000
8	14/2/2014 8:22:00.000	8	14/2/2014 8:21:30.000
9	15/2/2014 8:03:00.000	9	15/2/2014 8:02:30.000
10	19/2/2014 8:26:00.000	10	19/2/2014 8:25:00.000
11	20/2/2014 8:06:30.000	11	20/2/2014 8:06:00.000
12	24/2/2014 8:29:30.000	12	24/2/2014 8:29:00.000
13	25/2/2014 8:10:00.000	13	25/2/2014 8:10:00.000

TABLE II presents Cosmo-Skymed-1 (CSK-1) imaging over Stockholm, Sweden in nominal mode for the period of 13 – 29 Jun 2014 according to its orbit cycle, 16 days.

TABLE II. COMPARING THE RESULT BY STK AND NEW DEVELOPED SOFTWARE FOR CSK-1 OVER STOCKHOLM,SWEDEN

STK		New developed Software	
No.	Acquisition date/time	No.	Acquisition date/time
1	6/13/2014 4:05:43.000	1	6/13/2014 4:05:00.000
2	6/14/2014 4:23:49.000	2	6/14/2014 4:23:30.000
3	6/15/2014 4:41:57.000	3	6/15/2014 4:41:00.000
4	6/16/2014 16:37:34.000	4	6/16/2014 16:37:00.000
5	6/17/2014 16:55:41.000	5	6/17/2014 16:55:30.000
6	6/19/2014 4:17:43.000	6	6/19/2014 4:17:30.000
7	6/20/2014 4:35:50.000	7	6/20/2014 4:35:30.000
8	6/21/2014 16:31:26.000	8	6/21/2014 16:31:00.000
9	6/22/2014 16:49:35.000	9	6/22/2014 16:49:00.000
10	6/23/2014 17:07:43.000	10	6/23/2014 17:07:00.000
11	6/24/2014 4:11:39.000	11	6/24/2014 4:11:00.000
12	6/25/2014 4:29:46.000	12	6/25/2014 4:29:30.000
13	6/27/2014 16:43:33.000	13	6/27/2014 16:42:30.000
14	6/28/2014 17:01:40.000	14	6/28/2014 17:01:00.000

According to the result, the numbers of accesses are equal. However, there are slightly differences in acquisition date/time due to the frequency of data sampling which is maintained at 60 seconds/sampling for the computation load. However, it is still sufficient for determining earliest/latest start time of acquisition and duration for the mission planning optimization module.

As for the test for optimization algorithm, the testing area was set as presented in Figure 9 and TABLE III as well as earliest/latest start time also duration of acquisition. The test area can be partitioned into 10 strips as presented in TABLE III.

TABLE III. AREA OF INTEREST IN STRIPS

Area	Start Lat	Start Long	End Lat	End long
1A201	21.65295	92.17165	20.81965	91.9653
1A202	21.61355	92.34965	20.61375	92.1022
1A203	22.24845	92.69605	20.4079	92.2394
1A204	22.8214	93.0277	20.202	92.3767
1A205	22.79165	93.208	19.9961	92.5141
1A206	22.75935	93.3877	19.79025	92.6514
1A207	22.727	93.5673	19.58435	92.78875
1A208	22.6947	93.74695	19.37845	92.9265
1A209	22.66235	93.9266	19.17255	93.06425
1A210	22.63005	94.1062	18.9667	93.20205

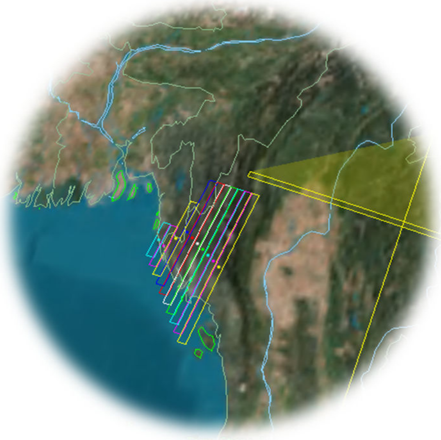

Figure 9. 10 strips to image

The satellite we chose for testing the mission plan is THEOS because we can verify the result with MISEO, THEOS mission planning tool whether the plan suggested by optimization algorithm for mission planning is practical or not. THEOS testing condition were set as follows;

- Maximum pitch angle = ±30 degrees
- Maximum roll angle = ±30 degrees
- Payload delay before acquisition = 120 seconds
- Average angular velocity = 0.023895 rad/s
- Altitude = 822 km
- Swath width = 22 km
- Maximum strip length = 1,000 km

The optimized sequence of acquiring the testing area can be summarized as in TABLE IV;

TABLE IV. SUGGESTED MISSION PLAN BY GENETIC ALGORITHM

Strip	Start acquisition (date/time)
1A210	6/16/2014 4:13:03.570
1A201	6/17/2014 3:54:00.000
1A202	6/17/2014 3:56:21.498
1A204	6/21/2014 4:16:38.150
1A209	6/22/2014 3:57:24.610
1A208	6/23/2014 3:38:06.040
1A205	6/23/2014 3:41:32.709
1A206	6/26/2014 4:20:25.670
1A203	6/26/2014 4:23:32.379
1A207	6/26/2014 4:26:20.811

The mission plan suggested by optimization algorithm takes approximately 10 days to complete the testing area which is quite fast acquisition based on the fact that THEOS normally takes 5 days to re-visit the area with maximum roll angle ±30 degrees. Therefore, the maximum time required to complete the area of interest is 50 days. The mission plan in TABLE IV has already been cross-checked its practicality with MISEO.

Even though the results of computation is satisfactory, more verification tests are necessary in aspects of the number of strips, different areas of interest, long-term estimation and mission planning for a SAR satellite.

VIII. SUMMARY

The tool is now available on http://geft.homeip.net that the user can determine which satellite can access the area of interest at specified date and time. A user can filter the result by an acquisition period, type of product and imaging mode.

Although it is now only possible to input an area of interest as a point, a user will be able to define a polygon over his requested area soon for more accurate result, strip partitioning and optimizing a mission plan.

Besides, the web-based service will be more self-sufficient after the integration of orbital propagator and earth model that are mentioned in this paper. TLE will be retrieved automatically from NORAD website on a daily basis resulting in near real-time computation. Orbital propagator and earth projection model also have their task to supply data as follows to the optimization algorithm; earliest/latest start time and duration.

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