Feasible Area Determination tool for Earth Observation Satellite

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***Abstract*— In order to achieve the next level services of earth observation satellite data, the web-based tool for satellite mission planning is developed. The objectives are joint-usage spare resources of earth observation satellite amongst ASEAN, customer-self mission planning and multi-objective optimization for mission plan. The tools is developed in three segments; web-based application for world-wide service, space mechanics and Earth model for the computation of feasible accessibility and multi-objective optimization for effective mission planning. The project started with the web-based development in order to make the tool available as soon as possible. The projection of satellite resulting from the computation in the later phase is now temporarily compensated by the database of satellite position created by STK (Satellite Tool Kit). At the moment, the tool is functional without neither orbit propagator nor earth model. For further enhancement, space mechanics and earth models as well as algorithm for mission plan optimization will be taken into account very soon in order to relieve the interaction between human and tool, make it self-sufficient for operation and increase mission planning efficiency.**

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

I. INTRODUCTION

As the space development and GIS agency of Thailand, GISTDA has distributed services of Earth observation satellite data, optical and Synthetic Aperture Radar (SAR) images for domestic and international uses. The Earth observation products GISTDA has distributed so far are optical and SAR images. The optical satellites include THEOS, Landsat and SPOT series whereas the SAR satellite is Cosmo-Skymed and Radarsat. The satellite data can serve several areas such as disaster management, agriculture, mapping, forestry and wildfire monitoring.

There are two main objectives of this development. First, it is to create a centralized tool for mission planning of the constellation of earth observation satellite amongst ASEAN countries consisting of THEOS, VNREDSAT-1A and X-SAT according to ASEAN constellation plan. Second, this will become a centralized tool that allows an operator to be able to make a right decision of which types of product, acquisition period and imaging modes that satisfy the user's requirements the best. Besides, it will also be a centralized tool for managing the resource of ASEAN earth observation satellites as a constellation.

Each satellite has its own mission planning system; therefore, the mission tasking plan is developed separately and does not take other satellites GISTDA is working on into consideration in aspect of accessibility and type of products. These constraints will get resolved by integrating a number of earth observation satellites as necessary in order to determine which one can complete the task soonest and meet the user's requirement. Besides, GISTDA also has a plan to encourage the establishment of collaboration amongst ASEAN member states on satellite constellation with an intention to co-manage the spare resources of earth observation satellite they possess in order to maximize the capacity in various areas such as revisit time and versatility of products.

II. EARTH OBSRVATION SATELLITE

Generally, earth observation satellite can be categorized into two categories which are optical and SAR 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 FOR (Field of Regard) from the satellite perspective as illustrated in Figure.1 and 2.

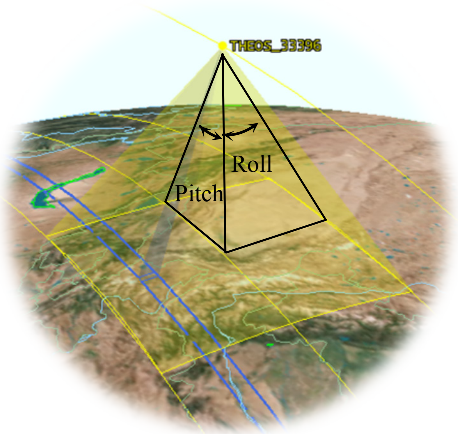


Figure 1. FOR projection resulting in access corridor for an optical satellite

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

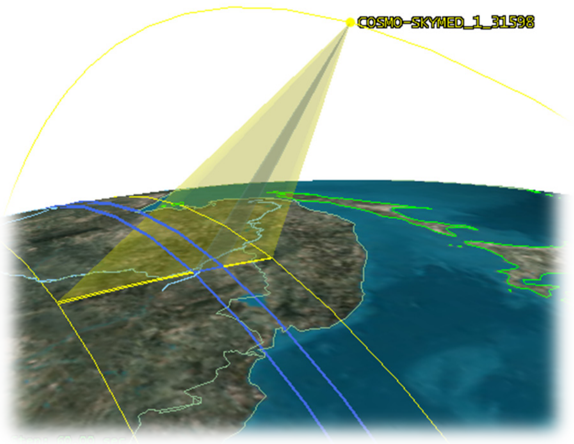


Figure 2. FOR projection resulting in access corridor for a SAR satellite

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

The access corridor can be varied depending on imaging modes that earth observation satellite is capable of. The imaging mode for an optical satellite are nadir, nominal and max angle modes which are slightly different from SAR which consists of nominal and extended imaging modes as presented in Figure.3.

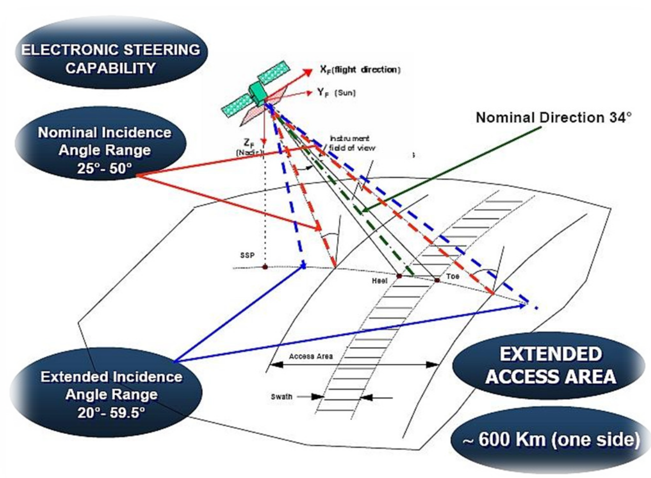


Figure 3. Cosmo Skymed imaging modes[8]

Another component for determining satellite revisit pattern is orbit cycle which is a unique characteristic for each satellite related to orbital period. THEOS and Cosmo-Skymed repeat their orbit cycle in 26 days and 16 days respectively. This tool is 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 limited amount of database.

III. SPACE MECHANICS AND EARTH MODEL

In order to locate the satellite position precisely, orbit propagator must take the environment of space mechanics into account. SGP-4[Lane and Cranford, 1969] or simplified perturbation model is used which will be integrated to compute orbital state vector relative to ECEF coordinate system. This model predict the effect of perturbation caused by earth's shape (spherical harmonics) atmospheric drag, solar radiation and gravitation effects from other bodies such as Sun and Moon. SGP-4 is applicable to near earth objects with an orbital period less than 255 minutes with which Earth observation satellite is in compliance.

The earth model plays a crucial role in frame conversion from celestial to terrestrial coordinate system once the satellite position is obtained. Due to the earth oblateness, the non-spherical earth model must be considered in order to allow the tool to calculate precisely. The non-spherical earth model for this tool is WGS-84 which is commonly used.

IV. MULTI-OBJECTIVE OPTIMIZATION FOR MISSION PLAN

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 be able to photograph 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 possibilities of sequences for image tasking plan which is impossible to be all analyzed. The optimization algorithm is therefore necessary. Moreover, it is more natural to formulate a real world question as a multi-objective optimization problem. Thus, we consider the mission planning problem as a multi-objective optimization problem. For the solving method, genetic algorithm is the choice because of the complexity of the problem, which is 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. This 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 functions set for this case are quality of product and shortest time to complete the tasks that are related to roll angle.

The inputs for optimization are earliest and latest start time as well as acquisition duration. The earliest and latest start time is the point of time where the acquisition can be performed thanks to maneuver in pitch direction. The acquisition duration is the period of time each satellite payload needs for acquiring a strip and depending on strip length. In order to simplify the computation, the duration of each acquisition will be assumed equaling the length of strip divided by satellite velocity.

Each satellite constraints that were taken into consideration are satellite agility and instrument delay before acquisition. As in [1], 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 point 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 (1);

$$Ro[k,k^{'}]2 = 2arctan\frac{Di[k,k^{'}]}{2Hs} \quad (1)$$

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 (2);

$$Dt[k,k^{'}] = Dmin + \frac{Ro[k,k^{'}]}{Vr} \quad (2)$$

where Dmin is an incompressible transition time in seconds which is instrument delay before acquisition and Vr is the maximum 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 (Earth observing satellite of Thailand).

V. WEB-BASED APPLICATION

This tool was developed as a web-based application for world-wide accessibility. The web service is composed of several modules as follows; administrative, database management and accessibility determination modules as Figure.4 illustrated, integrated with API map for easing user' s utilization. The web-based part was firstly developed to enable the tool ready to use as soon as possible. Nevertheless, the tool needs satellite positions for accessibility determination, the satellite positions is for now manually created by STK based on orbit cycle, but will be replaced soon with orbit propagator (SGP-4) and earth model (WGS84) later on.

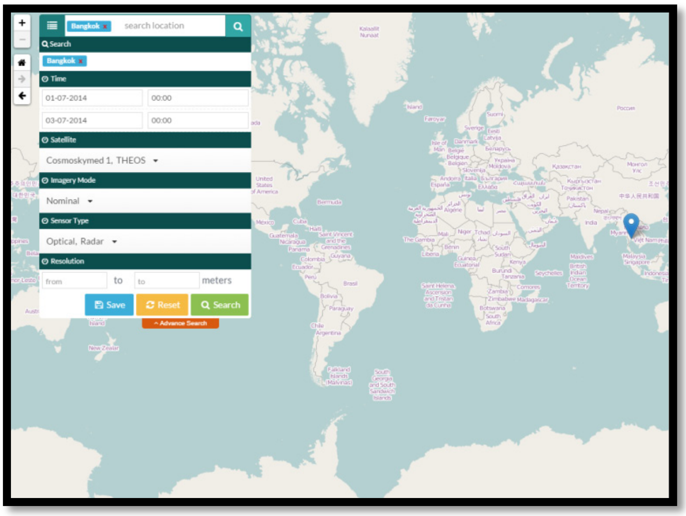
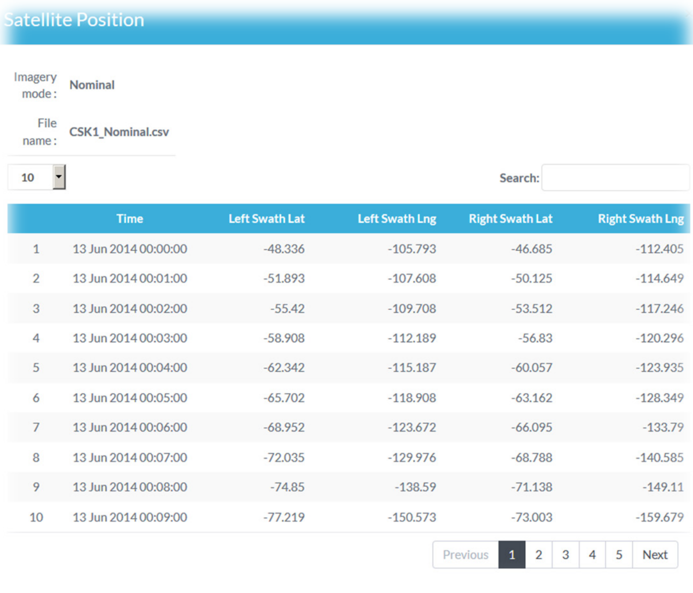


Figure 4. Program GUI, Accessibility Determination module

The database management module allows the administrator to add, remove and modify the database at will. The database necessary for accessibility determination is composed of satellite position and location database as present in Figure 5 and 6 respectively. The satellite database is the projection of satellite access corridor on earth according to imaging mode. This information was created with respect of time with 60 seconds of sampling. As for the location database, it is customized as users require such as continent, country or even province.


Satellite Position

Imagery mode : Nominal

File name : CSK1_Nominal.csv

10 Search:

	Time	Left Swath Lat	Left Swath Lng	Right Swath Lat	Right Swath Lng
1	13 Jun 2014 00:00:00	-48.336	-105.793	-46.685	-112.405
2	13 Jun 2014 00:01:00	-51.893	-107.608	-50.125	-114.649
3	13 Jun 2014 00:02:00	-55.42	-109.708	-53.512	-117.246
4	13 Jun 2014 00:03:00	-58.908	-112.189	-56.83	-120.296
5	13 Jun 2014 00:04:00	-62.342	-115.187	-60.057	-123.935
6	13 Jun 2014 00:05:00	-65.702	-118.908	-63.162	-128.349
7	13 Jun 2014 00:06:00	-68.952	-123.672	-66.095	-133.79
8	13 Jun 2014 00:07:00	-72.035	-129.976	-68.788	-140.585
9	13 Jun 2014 00:08:00	-74.85	-138.59	-71.138	-149.11
10	13 Jun 2014 00:09:00	-77.219	-150.573	-73.003	-159.679

Previous 1 2 3 4 5 Next

Figure 5. Program GUI, Cosmo-Skymed 1 database

Figure 6. Program GUI, Thailand provinces database

In order to estimate the accessibility, the user can input the condition for computation as follows; area of interest, acquisition period, type of sensor and imaging mode. The accessibility is thereafter determined by matching the access corridor of satellite and location on earth in LGCV coordinate system as Figure.4 illustrates;

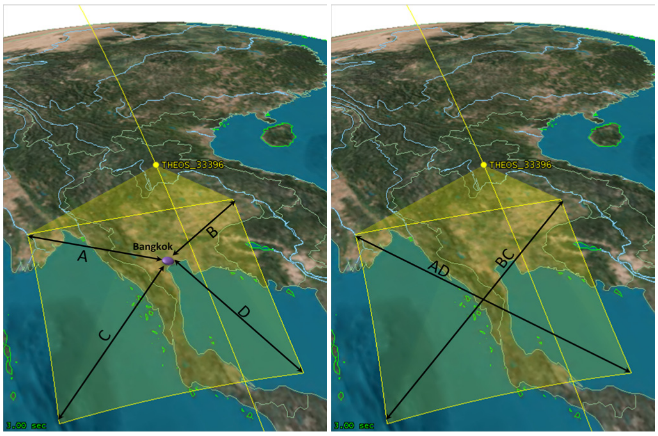


Figure 7. Accessibility determination over Bangkok, Thailand

If A, B, C and D are lesser than AD and BC, the acquisition is possible. The distance between two points on earth is calculated with the relation (3);

$$D = \cos^{-1}[\sin\varphi_1 \cdot \sin\varphi_2 + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \cos\Delta\lambda] \qquad (3)$$

The API map on web service application is consisted of two components; map display and map tile service. The choice of map display is leaflet which is java script API because it is easy to use and free of charge; however, its map tile service is not. For this reason, it is Openstreetmap selected as the map tile service which is free and quite reputational.

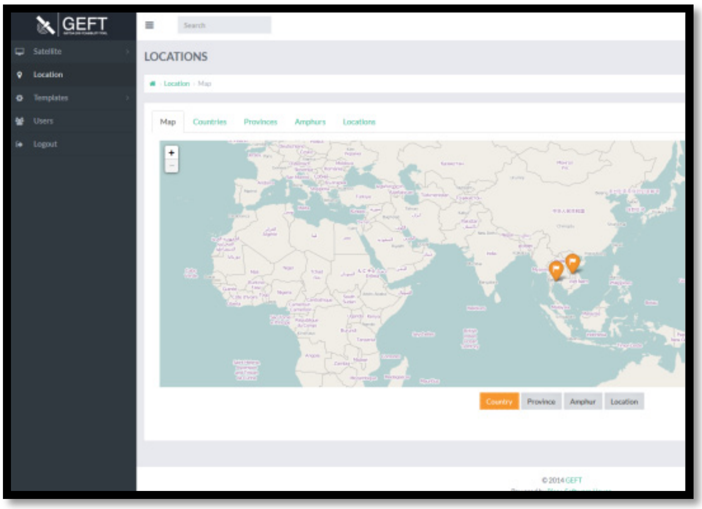


Figure 8. Program GUI, API map integration

VI. Test & Verification

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

In order to verify the result, an optical and SAR satellite are representative. THEOS and Cosmo-Skymed-1 are the choice. The imaging mode set is nominal mode for both. TABLE I presents THEOS imagery that was carried out over the 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 imagery over Stockholm, Sweden in nominal mode for the period 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/data for the computation load. Anyway, it is still enough for making decision which satellite is the most suitable for each request.

The test condition left for verification is a check for long-term prediction which the point of time is really away from satellite position contained in database. It requires quite a time for collecting positions of satellite from GPS data later on to ensure the trustworthy of computation.

VII. CONCLUSION

The tool is now available on http://geft.homeip.net/ that the user can determine which satellite in database can access the area of interest at specified date and time. A user can filter the result by specifying 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 photographing plan.

Besides, the web-based service will be more self-sufficient after the integration of SGP-4 propagator and earth model. TLE will be retrieved automatically from NORAD website on a daily basis resulting in near real-time computation which leads to more accurate and trustworthy computation. The propagator and earth model also have their task to supply data as follows to optimization algorithm; earliest/latest start time, acquisition duration and lat/long of each partitioned strip.

Moreover, it is also under consideration that the information page of satellite data might be included such as type of sensor, resolution and revisit time that suitable for each application; forestry, yield estimation and forecasting or even GIS application that is useful for data analysis. Consequently, the users can select the kind of service answer to their need.

Furthermore, this tool might be developed for mobile application like Android or IOS for versatile, compact use and accessibility. Nevertheless, it is still in question whether the tool will be able to finely run on mobile application or not considering the complexity of optimization computation which requires such a high capacity of computer.

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