The Development of Mission Planning Tool for Thailand's Earth Observation Mission

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Despite the fact that space based remote sensing has been proven as one of the most essential tool for various Earth observation activities, the satellite and its operation cost is tremendously expensive. From this reason, the operation of agile remote sensing satellites has to be performed and planned carefully in order to ensure the efficiency of the mission and utilize those space-borne sensors at their full capacity. In this case, mission planning plays a crucial role since it is the tool that determines the acquisition queues which need to be executed by the satellite. Importantly, these queues have to be deliberately optimized according to numerous conditions and also take into account the dynamic inputs from the users.

For remote sensing satellite operation in Thailand, the acquisition orders generally includes long-term, mid-term and urgent order, especially over the area of Thailand and Southeast Asia. In addition, since the satellites are equipped with the optical payload, cloud coverage is a major drawback that reduces directly the success rate of the mission.

Moreover, with the consideration of Thailand future remote sensing satellites programs and the constellation plan with alliance satellites, multi-satellite area acquisition has to be taken into account. The objectives of this development is to create the customized mission planning tool that is capable to cover all of these mentioned aspects with satellites utilization optimization in mind. This paper presents the mission planning tool that is currently developing by GISTDA to support Thailand Earth observation activities. The framework of this tool is shown and discussed. In this first development phase, the proposed mission planning methodology is presented in the form of discrete optimization problem which aims to maximize the total gains, as well as minimizing the changes made to the initial plan when re-planning is necessary. To solve the problem, we rely on metaheuristic optimization algorithms. The proposed methodology was implemented and tested with real-world input data. Simulation results of this mission-planning tool is also presented and discussed.

I. Introduction

During the past decade, space based remote sensing has become one of the most important tool for earth observation activities. As a result of the fast advancement of sensors technology along with the more competitive cost of the spacecraft platform, this has opened the window of opportunities for most of the nations or even private sectors to be able to own and operate Earth observation satellite.

Considering alone the countries in the South East Asia, where satellite technology and its applications have just emerged in this recent years, most of its countries already have their own remote sensing satellites operating in space, for example, LAPAN-TUBSAT (Indonesia), DIWATA (Philippines), X-Sat, TELEOS (Singapore), THAICHOTE (Thailand), VNREDSAT (Vietnam), etc. Official discussions to perform co-constellation among some of these satellites were made, however, there was still no conclusion in practical approach on how to share these agile remote sensing satellites resources equitably and optimally. In addition, in the case of disaster management and monitoring, if these satellite operators are able to perform their planning cooperatively and efficiently, the higher temporal resolution and wider coverage of the disaster affected area should be easily achievable.

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From these reasons, in 2015 Thailand's Geo-Informatics and Space Technology Development Agency (GISTDA) has initiated a project (so-called OPTEMIS) in order to find the solutions for these co-constellation requirements. In addition, the project also aims to response current mission planning operation limitations, for example, the cloud coverage, the long-term acquisition plan, etc. This paper shows the framework of the OPTEMIS system and its first phase development, which includes the optimized mission planning algorithm. The following sections of this paper includes the general mission operation for THAICHOTE satellite, then the framework and components of the OPTEMIS platform. After that, the proposed mission planning methodology that has already been developed is presented. Algorithm test results are shown and conclusion is discussed at the final section of this paper.

II. Mission Planning Operation

In this paper, THAICHOTE (formerly called THEOS), a remote sensing satellite operates by GISTDA, is chosen as a specimen for this development. THAICHOTE is an agile satellite in sun-synchronous orbit. It is placed at 822 km altitude with 98.7 degrees inclination. An orbit cycle consumes 101 minutes which yields around 14 orbits per day with 26 days nadir revisit time. For regular operation, mission planning division generates the mission plan on the daily basis based on the acquisition orders from users and the propagated satellite orbit information determined from the position telemetries. Single package consists of multiple acquisition queue is updated to the satellite once per day. After the satellite takes the acquisition, the images are downlinked and processed by the ground station. If the quality of the output image does not satisfy the order criteria, the acquisition of that particular image has to be rescheduled again by the mission planning division. The current process of THAICHOTE ground station operation is shown in figure 1.

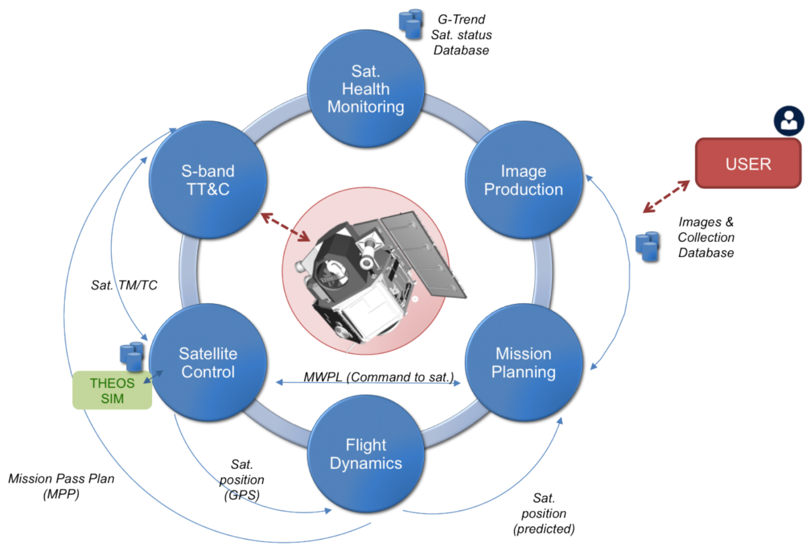

Figure 1. THAICHOTE Ground Control Segment

In case of the mission planning operation for disaster response, the urgent mission plan can be updated and uplinked to the satellite as soon as it is within the ground station communication coverage.

III. OPTEMIS Framework

As a matter of fact that every remote sensing satellite has a limited lifetime, its operation, especially the mission planning, should be performed efficiently and optimally in order to maximize the use of satellite resource. The fail acquisition, as well as unproductive payload operating time should be minimized as much as possible. Also, acquisition by non-homogeneous satellite constellation has to be taken into account. Hence, a new mission planning platform so-called OPTEMIS is developed in GISTDA in order to achieve these goals.

The structure of the OPTEMIS platform is illustrated in figure 2. Its main components can be define as follows;

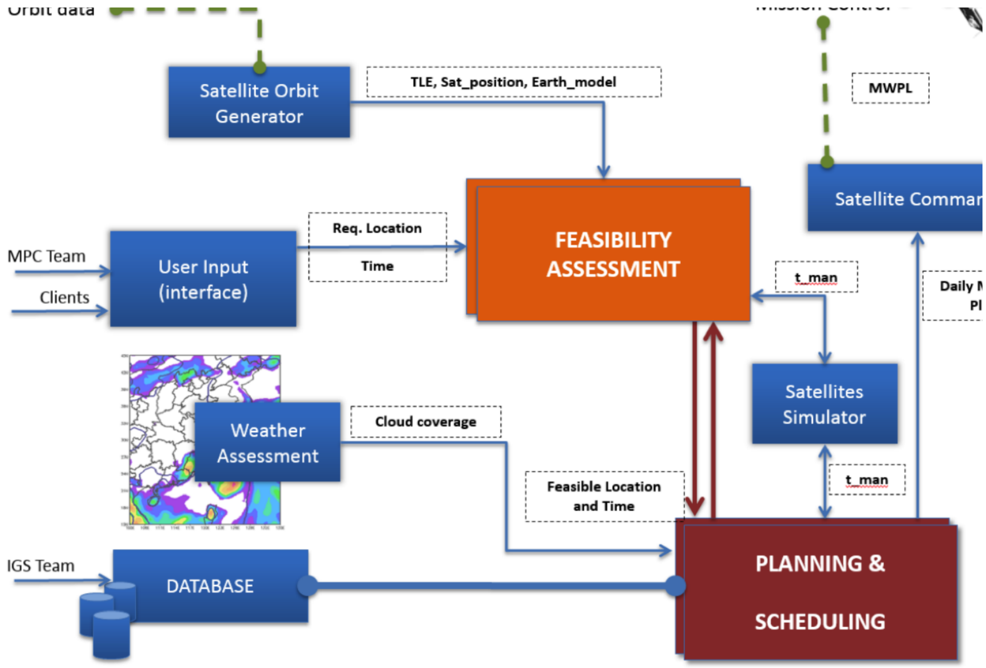

Figure 2. THAICHOTE Ground Control Segment

- Feasibility Assessment is a module that generate the tables of feasible acquisition based on propagate satellites orbit information (predicted satellite position and velocity) and user's requests order (acquisition target, maximum incidence angle, expiration time). This module will give the output, for each particular strip, as a possible satellite revolution to perform the acquisition of the target area, the earliest and the latest possible acquisition time.
- Satellite Simulator, since the specimen satellite is an agile satellite, the attitude control dynamics of the satellite is needed in order to determine the attitude maneuver time that is required (ΔT) in order to maneuver the satellite from one to the next acquisition. This module have to be run iteratively in accordance with the Planning and Scheduling module so as to check the possibility of the continuing strip.
- Planning and Scheduling this module is to be executed by to the satellite operator when the satellite command queue is needed to be updated. It retrieves the feasible acquisition table that is already computed by the feasibility assessment module, then perform the scheduling by taking into account the cloud coverage data. The Planning and Scheduling module is also able to generate multiple satellite command queue in the case of large coverage area and multiple satellite is used.

These mission planning platform is also designed to streamline the acquisition request procedures. The user's can request and check the possibility of their request in near real time via mobile or web terminal as shown in figure 3 and figure 4

IV. Mission planning methodology

The main objectives of the mission planning problem for EOS are to select and schedule the candidate strips, then assigning an efficient or optimize sequence to the satellite.[1] The general description of the problem of scheduling of an EOS is given in 2. According to 3, it is not always possible to acquire all strips, therefore we consider another action to *ignore* a strip, by introducing a penalty for such action.

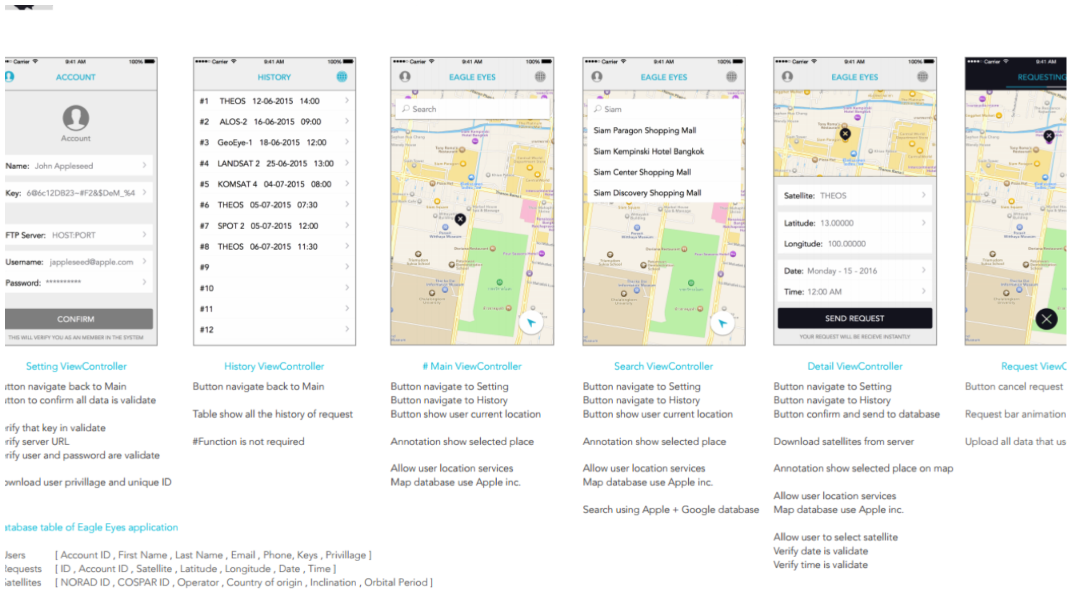

Figure 3. Mobile-terminal user interface.

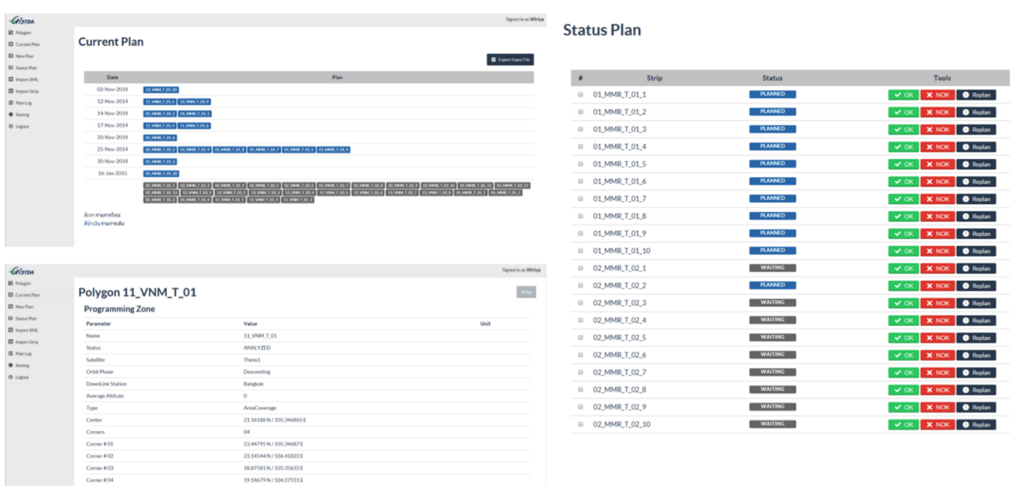

Figure 4. Web-terminal user interface.

There are several methods and strategies that have been proposed to solve the EOS mission planning problem. One strategy is to consider top-down decomposition of the planning and scheduling task. First, the sequence of strips to be acquire during a given planning horizon is determined. Then, the satellite maneuvers according to the sequence are calculated. This can cause uncertainty to the low-level plan, since some of the maneuver may not feasible.[3]

Another bottom-up strategy is to decompose the planning task by precomputing all possible maneuvers between all requested strips. Then, generate a sequence of strips according to the list of feasible maneuvers. This strategy, however, requires excessive memory and computation time.[3]

Therefore, several researches proposed mission planning that considering interdependency of a sequence generation and maneuver feasibility. The For example, in 4, the authors relied on an algorithm combining simulated annealing and genetic algorithm to solve the problem. In 5, four resolution algorithm were used to solve a simplified problem of scheduling of agile EOS. The methods are a greedy algorithm, a dynamic programming algorithm, a constraint programming algorithm, and a local search method.

The previously-mentioned works consider the scheduling of EOS when the requests are obtained from one user. However, in real-world application, the requests usually obtained from several users. Therefore, fairness among the users has to be taken into account when solving the problem. The works that consider such fairness are, for example, 6, 7, 8, 9, and 1.

In addition, in real-world application, the users' request arrives at different time. This can be handled by performing the scheduling with rolling time horizon. However, at least to our knowledge, the problem of scheduling for EOS with consideration of re-scheduling due to the change of observation conditions, the arrival of new requests, and the change of request priority, while minimizing the changes made to the initial plan are not well explored. Therefore, in this work, we present a methodology for scheduling for EOS that allows the mission planner to re-schedule the mission plan with respect to constraints while minimizing the change to initial plan.

This paper presents a EOS mission planning algorithms that have been developed for the mission planning in long-term, medium-term and short-term planning phase. The proposed algorithm is capable of generating acquisition plan and reschedule the plan in the case that the observation condition is not optimal or in case of urgency when there are new high priority requests from users (e.g. disaster monitoring).

A. Scheduling method for Thailand's EOS

In this subsection, we describe the methodology to solve the mission planning problem for Thailand's EOS.

Input. The user-provided input data of the proposed methodology are as follows:

- List R of N customer-requested strips to be observed.
- For each strip, i, where $i = 1, \ldots, N$, the following information are given.
  - Priority P_i;
  - Penalty Pe_i associated to strip i, if strip i is ignored;
  - User-provided observation start date d_i^s;
  - User-provided observation end date d_i^e;
  - User-provided maximum satellite roll angle $\phi_{i,max}$, and maximum pitch angle $\theta_{i,max}$.
- If strip i is already scheduled, the assigned start time, denoted Ts_i, of strip i, is also provided by the operator.

Constraints. The acquisition of images is subjected to the following constraints.

- **User-requested observation time constraint.** The acquisition of the image must be done during the user-preferred observation time window.
- **Satellite maximum roll and pitch angle constraint.** The roll and pitch angle of satellite during acquisition affects the quality of the resulting image. If the roll angle is large, the level of distortion in the resulting image is also large. However, limiting the small value of the maximum roll angle will result in less observation opportunity.

- **Feasible time window constraint.** The image of the target area can be acquired only when the area is visible to the satellite. For non-agile satellite, the observation can be done only when the satellite flies over the target area. However, for agile satellite as Thaichote, the observation of a given target area can be done from many different pitch and roll angles. Therefore, there are much more observation opportunities for each target area.

- **Satellite maneuvering constraint.**

  Due to limitation on satellite maneuverability (e. g. maximum roll, pitch and yaw rate) not every selected sequence of strips and be acquired consecutively during the same date or the same orbit revolution. When performing the image acquisition task, after the EOS finishes acquiring an image of a given strip, i, at a given position and attitude (roll, pitch, and yaw angle), it has to maneuver from the end point of strip i to the starting point of the next chosen strip, j, with desired attitude to acquire strip j.

Decision variables The goal is to schedule observation time for each strip by creating a sequence of observation to be performed by the satellite for each orbit revolution. To determine start time, we associate a start time for image acquisition, Ts_i to each strip i. As mention earlier that it may not be possible to schedule an observation time for all strips due to several constraints. Therefore, for strip $i = 1, \ldots, N$, we set a parameter, f_i, such that

$$f_i = \begin{cases} 0, & \text{if strip } i \text{ is ignored} \\ 1, & \text{otherwise.} \end{cases} \tag{1}$$

Objective. The objective of the proposed EOS mission planning methodology is to maximize the total gain, taking into account priority of each task such that it is more preferable (but not necessary) to perform high priority task before the lower-priority one. In this preliminary phase, one aims at maximizing:

$$\sum_{i=1}^{N} f_i P_i + (1 - f_i) Pe_i, \tag{2}$$

for $i = 1, \ldots, N$. In case of re-planning, one also aims at minimizing the changes made to the initial mission plan. This is taken into account implicitly by the ranking criteria which will be describe in the following subsection. The resolution algorithm to solve this problem is presented in the following subsection.

B. Mission planning methodology

In order to reduce complexity of the mission planning problem, at first we decompose the planning horizon into sub-horizon according to the satellite orbit. Then each orbit, a list of visible strips, respecting maximum observation angle (maximum pitch and maximum roll angle) is created. After that, the strips are ranked according to the following operational criteria (from higher to lower).

- Stereo left/right with one access completed, or with a possible couple on this programming sub-horizon;
- Programming request priority, P_i;
- Remaining number of days with theoric accesses;
- Cloud coverage;
- Scheduled / un-scheduled;
- Aperiodic requests : up to the end of validity;
- Periodic requests : up to the end of current period;
- Stereo left/right;
- Minimum satellite roll value for the access.

Finally, a sequence of strips to be acquired for a given sub-horizon is determined using a hybrid-metaheuristic optimization algorithm. This process is repeated until at least one action is assigned for all N strips.

In order to solve the EOS mission planning problem, we rely on a hybrid-metaheuristic algorithm based on a simulated annealing and a local search method. This algorithm is adapted from the one presented in[10] and[11] that were developed for a large-scale discrete optimization problem.

Simulated annealing[12] is inspired by the annealing process in metallurgy where the state of material can be modified by controlling the cooling temperature. The physical annealing process consists in heating up a material to bring it to a high energy state. Then, it is slowly cooled down, keeping each given temperature stage for a sufficient duration until a thermodynamic balance is reached. The temperature is reduced according to a pre-described temperature reduction schedule, until the material reaches a global-minimum energy state and forms a crystallized solid. Decreasing too rapidly the temperature can however yield a non-desirable local minimum energy state.

An iterative-improvement local search is an algorithm that starts from a given initial solution, and then iteratively replaces the current solution with a better solution chosen in a pre-defined neighborhood. Given an initial solution, the iterative-improvement local search generates a neighborhood solution, and then accepts this new solution only if it yields an improvement of the objective-function value. The algorithm stops when a maximum number of iteration is reached. The quality of the solution found by the local search depends on the initial solution and the definition of the neighborhood structure.

To implement the hybrid metaheuristics, we have to determine a structure to control the level of hybridization between each metaheuristics algorithm. For simplicity in this preliminary implementation, the simulated annealing and the iterative-improvement local search are hybridized in a self-contained (high-level) manner where each algorithm is sequentially run. The simulated annealing is used as the main optimization algorithm, searching for a candidate solution that maximizes the objective function given in Equation 2.

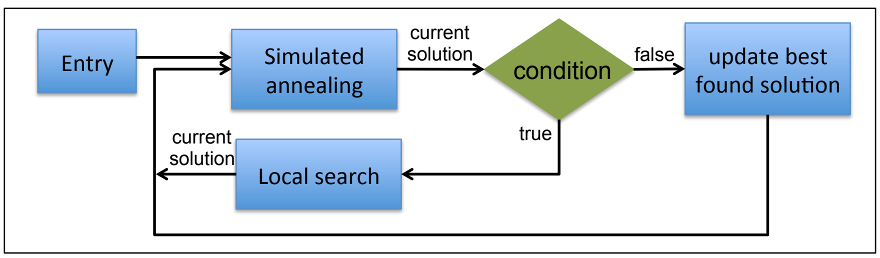

Figure 5. Hybrid simulated-annealing / iterative-improvement local search algorithm.

A neighborhood solution is generated by applying a so-called *neighborhood function* (or transformation operator) that generates a local change to the current solution. This change should be computed rapidly, but should not involve a drastic change in the current solution. Otherwise, the characteristics of the simulated annealing will become those of a pure random search.

C. Numerical experiments

The proposed mission planning methodology was implemented in Java and tested on a 2.4 GHz Core 2 Duo 8 GB DDR3 Unix platform. We tested the planning algorithm using real customer request to take images of Asian region. The requested region can be decomposed into 262 strips as depicted in figure 6. The user-provided parameters are given in table 1. The customer requests that all image must be observed during a time window of 5 months, with satellite pointing at nadir angle (roll and pitch angle less than 12 degree) to the observation site.

The proposed mission planning algorithm is able to schedule the start time for all requests as shown in figure 7. The resulting mission plan, which is a sequence of image to be acquired on each operational day, is able to complete the customer request within the requested time window. The feasibility of each acquisition sequence are validated with the currently-using Thaichote's mission planning software. An example of one acquisition sequence consists of strip number 53 158 and 230 is illustrated in Figure 8.

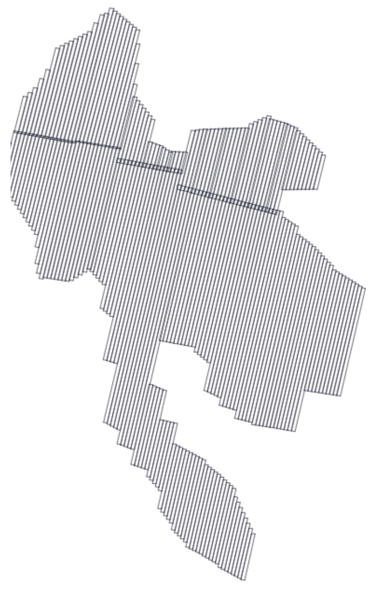

Figure 6. Decomposition of customer request over the Asian region into strips.

parameter	value
Priority P_i of each strip i;	1 (Urgent)
Penalty Pe_i associated to strip i if strip i is ignored;	-2
User-provided observation start date d_i^s;	1 November 2014
User-provided observation end date d_i^e;	30 March 2015
User-provided maximum satellite roll angle $\phi_{i,max}$,	12 degree
User-provided maximum pitch angle $\theta_{i,max}$.	12 degree

Table 1. User-defined parameter values specifying the customer request.

V. Conclusion

In this paper, we present a framework and the development of mission planning platform for Thailand satellite based earth observation activity. The tool allows the remote sensing satellite operator to be able to get the request orders from the users and generate mission plan automatically. This also allow the planner to re-schedule the mission plan whenever there are requirements, for example, changes in observation condition, changes of priority, arrival of new request, etc.

The mission planning tool is tested with real world user request data considering large area over the South East Asia region. The numerical experiment shows viability of the proposed mission planning methodology. However, this paper able to show only the progress of the development of the planning and scheduling module up until present. The complete OPTEMIS platform is expected and planned to be finished in 2017.

VI. Acknowledgement

The authors would like to thank the OPTEMIS team for their contributions, THAICHOTE mission planning division for validating and evaluating the results and GISTDA for sponsoring this project.

Day	Revolution No.	# of acquisitions	Acquisition sequence:		
305	133	2	57	155	
306	138	2	88	188	
308	122	2	4	95	
309	127	1	19		
310	132	3	49	50	150
311	137	2	82	243	
312	142	1	212		
313	121	1	5		
314	126	1	13		
315	131	3	43	44	217
316	136	2	76	175	
317	141	1	207		
318	120	2	0	96	
319	125	1	8		
320	130	2	36	136	
321	135	2	68	231	
322	140	1	201		
324	124	2	6	102	256
325	129	2	31	130	250
326	134	2	63	224	257
327	139	3	93	194	229
329	123	2	7	97	251
330	128	1	24	156	252
331	133	2	58	189	230
332	138	3	89	118	248
334	122	1	9	218	253
335	127	2	20	182	254
336	132	2	51	112	249
337	137	2	83	143	
338	142	1	213	237	
339	121	1	98	107	
340	126	2	14	219	
341	131	2	45	232	
342	136	2	77	163	
343	141	1	208	195	
344	120	1	99	124	
345	125	2	10	157	
346	130	2	37	190	
347	135	2	69	149	
348	140	1	202	244	
350	124	1	11	144	
351	129	1	32	238	
352	134	2	64	137	
353	139	3	94	169	
355	123	1	12	135	
356	128	2	25	225	
357	133	3	59	258	
358	138	3	90	128	
360	122	1	100	220	
361	127	1	21	191	
362	132	2	52	119	
363	137	2	84	158	
364	142	1	214	183	
365	121	1	101	145	
366	126	1	15	239	
367	131	2	46	138	
368	136	2	78	233	
369	141	1	209	131	
370	120	1	1	226	
371	125	1	16	259	
372	130	2	38	125	
373	135	2	70	221	
374	140	1	203	192	
376	124	1	17	153	

Day	Revolution No.	# of acquisitions	Acquisition sequence:	
377	129	2	33	184
378	134	2	65	146
379	139	2	196	240
381	123	1	18	139
382	128	2	26	234
383	133	2	60	132
384	138	3	91	227
386	122	1	103	260
387	127	2	22	140
388	132	3	53	222
389	137	3	85	255
390	142	1	215	223
391	121	1	104	185
392	126	1	23	241
393	131	2	47	141
394	136	2	79	235
395	141	1	210	
396	120	1	2	
397	125	1	27	
398	130	2	39	
399	135	2	71	
400	140	1	204	
402	124	1	105	
403	129	2	34	
404	134	2	66	
405	139	2	197	
407	123	1	106	
408	128	2	28	
409	133	2	61	
410	138	3	92	
412	122	1	108	
413	127	1	29	
414	132	2	54	
415	137	3	86	
416	142	1	216	
417	121	1	3	
418	126	1	30	
419	131	2	48	
420	136	2	80	
421	141	1	211	
423	125	1	109	
424	130	2	40	
425	135	2	72	
426	140	1	205	
428	124	1	110	
429	129	2	35	
430	134	2	67	
431	139	2	198	
433	123	1	111	
434	128	2	41	
435	133	2	62	
436	138	2	193	
439	127	1	120	
440	132	2	55	
441	137	3	87	
444	126	1	113	
445	131	1	56	
446	136	2	81	
449	125	1	114	
450	130	2	42	
451	135	2	73	
452	140	1	206	
454	124	1	115	

Figure 7. Produced mission planning.

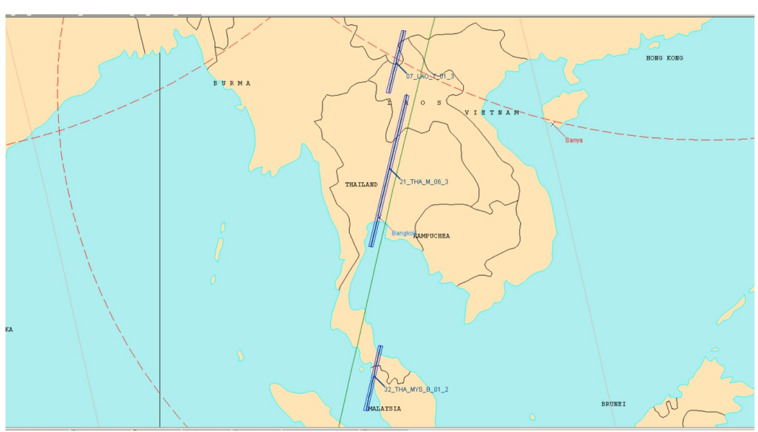

Figure 8. Example of one acquisition sequence consists of 3 strips.

References

[1]Tangpattanakul, P., *Optimisation multi-objectif de missions de satellites d'observation de la Terre*, Ph.D. thesis, UPS Univ., Toulouse, France, 2013.

[2]G. Verfaillie, M. Lemaître, N. B. and Lachiver, J., "Management of the mission of earth observation satellites challenge description," Tech. rep., Centre National d' Études Spatiales, Toulouse, France, 2002.

[3]J. Lhr, J. Aldinger, S. W. and Willich., G., "Planning for Agile Earth Observation Satellites," *Proceedings of the 16th international joint conference on Artificial intelligence-Volume 1*, Morgan Kaufmann Publishers Inc., 1999, pp. 206–211.

[4]M. Lemaître, G. Verfaillie, F. J. J. L. and Bataille, N., "Selecting and scheduling observations of agile satellites," *Aerospace Science and Technology*, Vol. 6, No. 5, 2002, pp. 367 – 381.

[5]Li, Y., Minqiang, X., and Wang, R., "Scheduling Observations of Agile Satellites with Combined Genetic Algorithm," *Natural Computation, 2007. ICNC 2007. Third International Conference on*, Vol. 3, Aug 2007, pp. 29–33.

[6]Bianchessi, N., Cordeau, J., Desrosiers, J., Laporte, G., and Raymond, V., "A heuristic for the multi-satellite, multi-orbit and multi-user management of Earth observation satellites," *European Journal of Operational Research*, Vol. 177, No. 2, 2007, pp. 750 – 762.

[7]Lemaître, M., Verfaillie, G., Fargier, H., Lang, J., and J.M. Lachiver, N. B., "Sharing the use of earth observation satellites," *3rd Workshop on planning and scheduling for space, Houston, Texas*, 2002.

[8]Bataille, N., Lemaitre, M., and Verfaillie, G., "Efficiency and Fairness when Sharing the Use of a Satellite," *Artificial Intelligence, Robotics and Automation in Space*, Vol. 440, 1999, pp. 465–470.

[9]Lemaître, M., Verfaillie, G., and Bataille, N., "Exploiting a common property resource under a fairness constraint: A case study," *Proceedings of the 16th international joint conference on Artificial intelligence-Volume 1*, Morgan Kaufmann Publishers Inc., 1999, pp. 206–211.

[10]Chaimatanan, S., Delahaye, D., and Mongeau, M., "A Hybrid Metaheuristic Optimization Algorithm for Strategic Planning of 4D Aircraft Trajectories at the Continental Scale," *Computational Intelligence Magazine, IEEE*, Vol. 9, No. 4, Nov 2014, pp. 46–61.

[11]Chaimatanan, S., *Planification stratégique des trajectoires d'avions*, Ph.D. thesis, UPS Univ., Toulouse, France, 2014.

[12]Dreo, J., Petrowski, A., Siarry, P., and Taillard, E., *Metaheuristics for hard optimization*, Springer, 2006.