MISSION PLANNING TOOL FOR THAICHOTE EARTH OBSERVATION SATELLITE

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ABSTRACT

Mission planning plays a crucial role for space-based remote sensing, as it is one of the key processes that defines the success rate of each daily mission. From user's request, the Earth observation satellite mission-planner concerns with scheduling the acquisition plan that will be used to prepare the satellite command queue to perform the image acquisitions. On a long-term basis, the mission-plan should optimize a set of pre-defined goals, while on a daily basis the mission plan must be adapted to the observation condition.

This paper presents a mission-planning tool that is being developed for Thaichote Earth observation satellite to improve and optimize Gistda's space-based remote sensing resources. It is designed to take into account the problems from a real operation point of view, where rescheduling is necessary due to the change of observation conditions or the requirements for acquisition modification, while the changes to the long-term goal scheduling should be minimized.

The tool allows the mission-planner to manage the utilization of the satellite in four different time levels; long-term, medium-term, short-term, and post-mission. It consists of four main modules, which are user interface, feasibility assessment, planning optimization, and data management modules. It was implemented and tested with real input data based on Thaichote operation. The perspective to use this tool for satellite constellation and regional area acquisition is also discussed at the end of this paper.

1 INTRODUCTION

Thaichote is Thailand's first Earth Observation Satellite (EOS) that orbits around the Earth at the altitude of 822 km in sun-synchronous orbit with 98.7 degrees inclination. It revolves around the Earth every 101 minutes, which yields around 14 orbits per day. The satellite revisits the same ground track every 26 days. Therefore, to complete a revisit cycle, the satellite revolves around the Earth in approximately 364 orbits. It is these orbit parameters that limits the accessible time window for any area of interest on the Earth. Therefore, to optimize the use of satellite, an efficient planning is necessary.

Thaichote operation center operates the satellite through the process as illustrated in Figure 1. The users' requests that are generally sent to the satellite operation center consists of the area of interest (in a form of a coordinate or an area defined by a polygon), observation time-window and require image type (panchromatic, multispectral or pan-sharpening), etc. After receiving new order, the image catalog database compares the request with the archive image collection. If the requested order does not exist in the database, it will be sent to the mission planner in order to add to the acquisition queue for the satellite.

Initially, the ordered area of interest is devided into acquisition strips with the same angle and width as the satellite ground track and swath distance respectively. These new strips are added to the daily mission plan according to their priority, image type, and requested acquisition time-window.The daily product of the mission planner is a command queue (time series of satellite command) that will be sent to the satellite by satellite control center, in order to direct the satellite to perform the image acquisition. This command queue consists of a maneuvering queue (attitude maneuvering command for the acquisition of each strip), a payload queue (camera switch and configuration command), and a communication command queue (up-link and down-link command). These queues are constructed

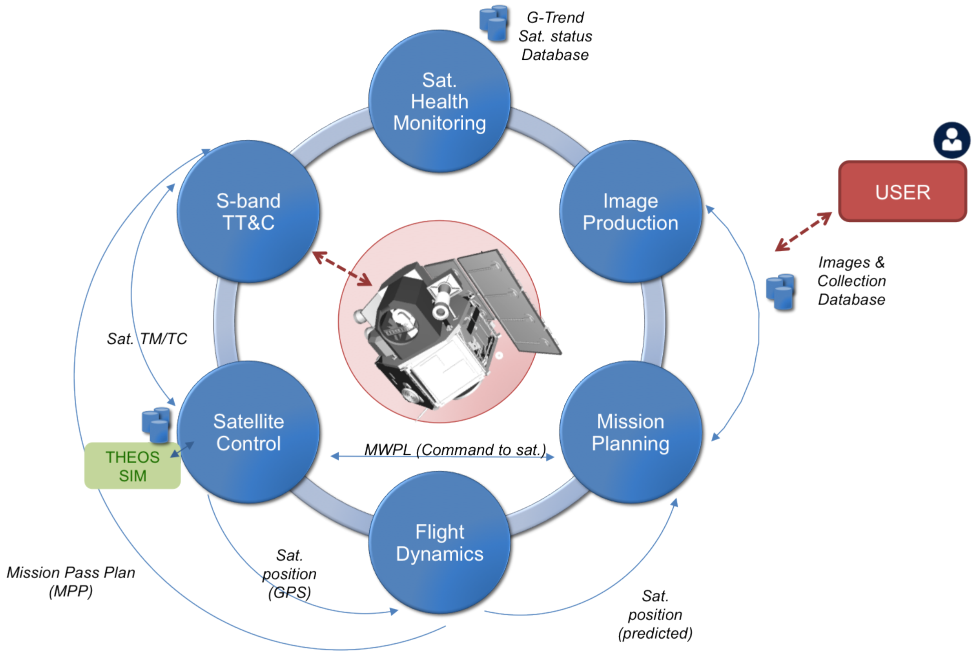

Figure 1: EOS mission operation process.

based on the users' requirements, satellite orbit (flight dynamics), and other important information, such as cloud coverage data.

Finally, after the satellite had performed the image acquisitions, the data, which includes the images, and satellite telemetries are transmitted back to the ground station. After the downlink is finished, the image production system processes the image and corrects them in both radiometrically and geometrically before sending them out as the final satellite imagery products. During this post-mission processing, if the quality of the image does not satisfy the standards or user's/customer's criteria, i.e. the percentage of area covered by the could exceeds the threshold value, the request has to be rescheduled by the mission planner.

Since each EOS satellite has limited resource in terms of energy and operation lifetime, the key process that determines the success rate of the EOS mission and overall life-time of the EOS satellite is mission planning. The main objective of mission planning is to maximize the uses of satellite, while minimizing the fail acquisition and payload operating time as much as possible. One main strategy is to take into account weather prediction such as cloud coverage in the mission planning process, and to carefully design the long term mission schedule of the satellite.

This paper presents a mission-planning tool that is being developed for Thaichote under the framework of the Operation Planning for Thailand Earth observation MISsion (OPTEMIS) project. The proposed tool aims to develop a planning and re-scheduling methodology for long-term (e.g. one year) mission plan management. It also looks forward to integrate the EOS operation from the users requests to post-processing phase. The following sections of this paper are organized as follows. Section 2 explains the proposed mission planning tool. In section 3, planning and re-scheduling methodologies are described. Next, in section 4, the algorithm that is used to produce the mission plan is demonstrated. Numerical results of the algorithm and the simulation results are presented in section 5. Finally, section 6 discusses the results and perspectives.

2 MISSION-PLANNING TOOL

The proposed mission-planning tool is being developed under the framework of OPTEMIS project. It focuses on developing an algorithm that allows the mission planner to manage the utilization of EOS satellite at its full capacity by taking into account the changes of observation conditions and the changes of input requests. Moreover, it also aims at developing a platform that simplifies the exchange of information between the user and the operators, and also between the subsystems in the EOS operation process. Figure 2 illustrates the overall structure of the proposed mission planning tool. It consists of four main modules, as follows:

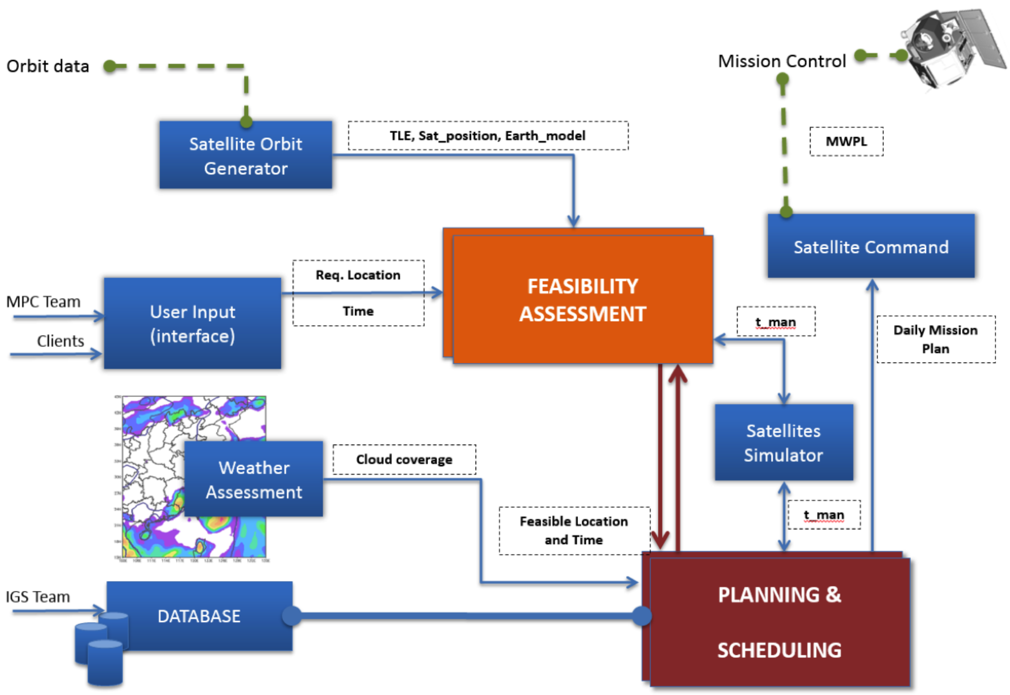

Figure 2: Overall structure of the proposed EOS mission planning tool for Thaichote satellite.

- **User interface and data management.** This module includes user-interface and database that allows the user to send their orders via internet, either by website or mobile application terminal. It also enables the user to know the approximate time to obtain the requested images. In addition, the operators are able to track the progress of each mission, as well as update post-operation results via this module. Figure 3 shows the user-interface of the mobile application that allows the user to input their requests. Figure 4 shows the user-interface of the web application that allows the mission planner to manage the mission plan.
- **Feasibility assessment.** After obtaining the orders from users, the requested areas are processed and divided into strips, where each strip can be acquired by the satellite from several orbits, attitudes, and dates. The feasibility assessment module generates all such combination of satellite acquisition attitude and date for each strip. To simplify, in the sequel of this paper, we call a combination of satellite position, attitude, and date to acquire an image of a given strip as an *acquisition*.
- **Planning and Scheduling.** This module consists of a *mission plan generator* sub-module that creates a routine mission plan, and an *optimization* sub-module that controls the search for an optimal mission plan that maximize the total gain, which is a function of the number of image and their priority, that can be acquired during a given time. The gain is evaluated by a sub-module called *mission plan assessment* module.
- **Satellite simulator.** This module concerns with the dynamics of the satellite which consists of, for instance, the maneuver time that the satellite needs to maneuver from the end of one strip to the beginning of the next strip with desired attitude. This maneuvering time also depends strongly on the time and the satellite position at which the transition maneuvering is activated. Therefore, it is time-dependent and it must be computed based on dynamic characteristic of the satellite. Then, the feasibility assessment module checks the overall feasibility of a given mission plan using such information.

To increase the efficiency of the mission planning process, we proposed that the planning and scheduling process should be executed in four levels as follows:

- **Long-term planning phase.** This phase concerns with scheduling acquisition queue that is made for large-scale area (such as a whole country, a continent or global scale). Mostly, this kind of schedule is required by the users in order to keep track of the change on any particular area.
- **Medium-term planning.** Despite satellite orbit is a systematic motion that can be calculated or propagated in advance, the longer-than-one-month orbit calculation is not accurate enough for mission scheduling in precise details, for instance, defining the start and end time of each acquisition. In addition, if the orbit track has a

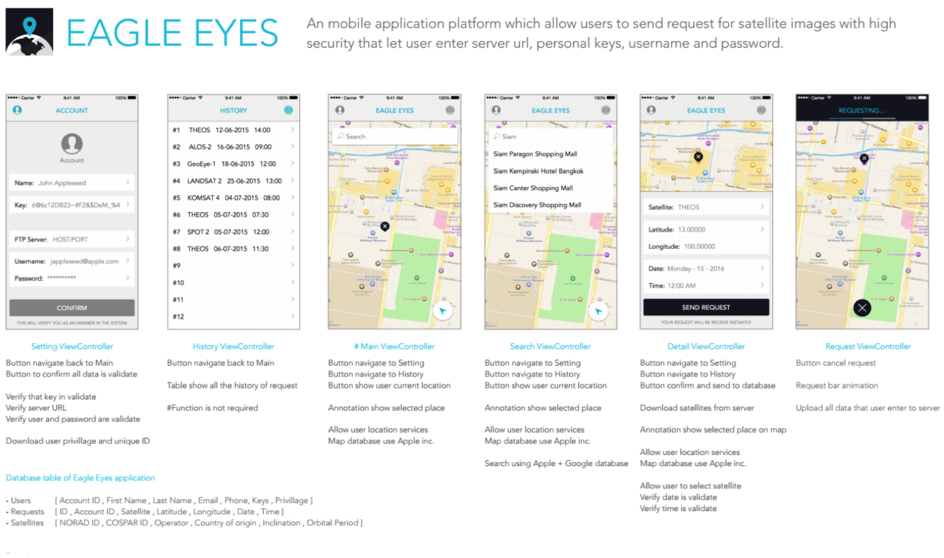

Figure 3: Mobile application user-interface of the proposed mission planning tool.

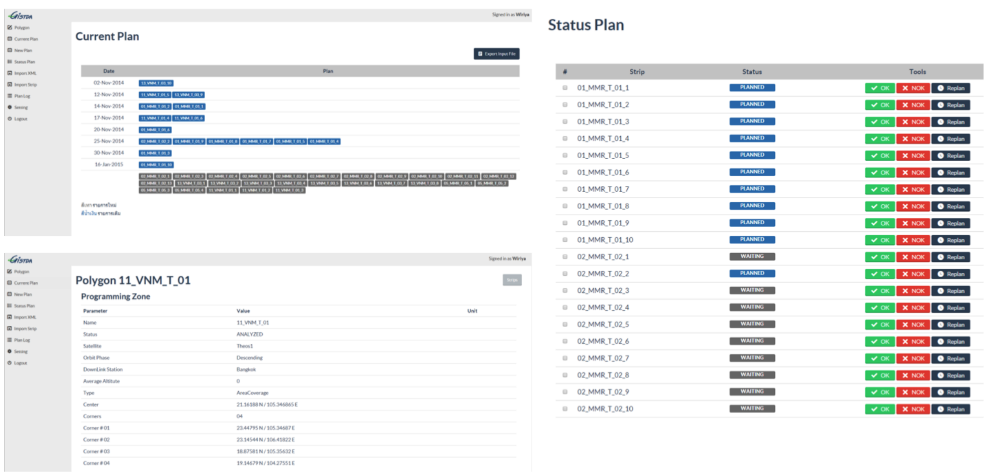

Figure 4: Web application user-interface of the proposed mission planning tool.

slight shift due to the small estimation errors or slight perturbations, some acquisition might not be feasible and have to be rescheduled to put in the next pass. Therefore, medium-term scheduling, i.e. one-month span or less have to be done in order to ensure the correctness of the plan.

- **Short-term and daily planning phase.** Daily planning is set at the final stage before exporting the schedule to satellite command. This final plan can be scheduled or rescheduled subjected to the additional and more update information, for example, the mission planner might need to modify the daily schedule according to new disaster events or the cloud coverage data. In other words, in the case that disaster, it is necessary for the satellite to take an urgent acquisition, the plan has to be modified, or if the cloud data shows that the cloud will cover the requested area during the acquisition, the plan can be rescheduled in order to avoid cloudy image. These rescheduling has to be made with minimizing the changes made to the long-term planning at the same time.

- **Post-mission analysis phase.** For post-mission phase, after the image production had analyzed the processed image. If the quality of the image does not satisfy the standards or the requirements, the re-scheduling has to be performed.

3 SCHEDULING METHODOLOGY

The problem of scheduling for EOS have been studied by various researchers. The main objectives are to select and schedule the candidate photographs or strips, then assigning an efficient or optimize sequence to the satellite (Tangpattanakul, 2013). The general description of the problem of scheduling of an EOS is given in (G. Verfaillie and Lachiver, 2002). In this work, the authors describes a simplified problem description, decision variables, constraints to be consider, and the optimization criterion, as a challenge for ROADEF 2003 .

There are several methods that have been proposed to solve the problem. For example, in (M. Lemaître and Bataille, 2002), the authors relied on an algorithm combining simulated annealing and genetic algorithm to solve the problem. In (Li et al., 2007), 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, (Bianchessi et al., 2007), (Lemaître et al., 2002), (Bataille et al., 1999), (Lemaître et al., 1999), and (Tangpattanakul, 2013).

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).

3.1 Mathematical modeling

In this subsection, we present the proposed EOS mission planning methodology in a mathematical framework. In this preliminary work, the proposed methodology is modeled as a single objective optimization problem aiming at maximizing the total gain.

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

- User-provided mission planning start date, denoted D_s;
- User-provided mission planning end date, denoted D_e;
- List R of N user-requested strips to be observed.
- List r of M user-requested strips, where $r \in R$, to be re-scheduled due to priority changed (urgency situation) or observation condition is no longer optimal (cloud coverage condition).
- For each strip, i, where $i = 1, \dots, N$, the following information are given.
  - List of k feasible acquisitions, A_i.
  - Priority P_i of each strip i;
  - 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 was already planned, the chosen acquisition of strip i, denoted a_i^c, where $a_i^c \in A_i$ 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 photograph of the target area can be acquired only when the area is in the visibility of 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.

  In our case, a set of possible observation opportunities (or acquisitions) for each strip i are given by an off-the-shelf software, called MISEO, provided by the satellite manufacturer. For each strip i, the software provides a list of possible acquisitions, respecting the maximum roll and maximum pitch angle constraints, for one month span. These initial set of acquisitions are, then, used to construct a list A_i of all possible acquisitions for each strip i according to a user-provided observation time window, taking into account the maximum roll and pitch angle constraints.
- **Feasibility constraint.**

  After assigning a feasible acquisition for each strip, one can construct a sequence of K_d strips to be observed during each operational day. However, 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, p, 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, q, with desired attitude to acquire strip q.

Decision variables. In order to generate an EOS mission plan, one wishes to assign a feasible acquisition for each strip. Thus, one has to determine optimal acquisition a_i for each strip, for $i = 1,\ldots,N$. However, during a given time period, the acquisition of some strip may not be able to performed due to the feasibility constraint. Therefore, for $i = 1,\ldots,N$, we set a parameter, f_i, such that

$$f_i = \begin{cases} 0, & \text{if strip } i \text{ cannot be acquired during } [d_i^s, d_i^e] \\ 1, & \text{otherwise.} \end{cases} \tag{1}$$

Therefore, our decision variables for each strip are a pair (a_i, f_i), , for $i = 1,\ldots,N$.

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:

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

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 implicitly performed by the mission plan generator. The resolution algorithm to solve this problem is presented in the following section.

4 HYBRID-METAHEURISTIC ALGORITHM FOR SATELLITE MISSION PLANNING

In order to solve the EOS mission planning problem presented in the previous section, 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 (Chaimatanan et al., 2014) and (Chaimatanan, 2014) that were developed for a large-scale discrete optimization problem. In this section, we present a brief overview of the simulated annealing, the local search method, and our proposed hybrid-metaheuristic optimization method to solve the EOS mission planning problem.

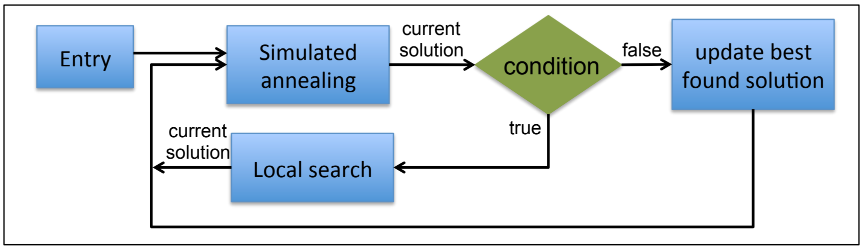

Figure 5: Hybrid simulated-annealing / iterative-improvement local search algorithm.

Simulated annealing 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, N_{Loc}, 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.

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.

In order to minimize the changes made to the initial mission plan, we first construct a list, denoted $\tilde{r}$, consisting of all strips in the list r of M strips to be re-scheduled and all inter-related strips that can be scheduled to the same date as a given strip $i \in r$. Therefore, we limit the neighborhood function to modify only flights $i \in \tilde{r}$. The list $\tilde{r}$ is constructed as a pre-processing phase before the optimization process. To generate a neighborhood solution, first a strip i to be modified is chosen. Then, one has to determine a new acquisition $a_i \in A_i$ that satisfies all the above-mentioned the constraint.

5 SIMULATION RESULTS

In order to test the proposed mission planning tool, we developed and implemented the feasible acquisition generator, the mission plan generator, the feasibility assessment, the mission plan assessment, and the optimization modules in Java. Then, the tool was tested using real-world user requests. Initially, the first request concern with second priority requests that can be divided into 12 strips consists of

$$R = \{S00, S01, S02, S03, S04, S05, S06, S07, S08, S09, S10, S11\},$$

with associated priority set, denoted P, as follows:

$$P = \{1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1\}$$

The proposed scheduling tool manages this request, and produce an initial mission plan as presented in Table 1. Then, it is assumed that the first 4 strips are subjected to priority changed event, thus $P_0 = 5, P_1 = 4, P_2 = 3, P_3 = 2$. Therefore, the planning and scheduling module of the mission planning tool manages these changes and re-schedules the plan as presented in Table 2.

Day	Revolution	Strip id.	Priority
308	122	S03	1
309	127	S11	1
313	121	S01	1
318	120	S02	1
319	125	S09	1
324	124	S06	1
325	129	S10	1
329	123	S00	1
334	122	S05	1
339	121	S07	1
345	125	S08	1
350	124	S04	1

Table 1: Initial mission plan.

Day	Revolution	Strip id.	Priority
308	122	S00	5
309	127	S11	1
313	121	S01	4
318	120	S02	3
319	125	S09	1
324	124	S03	2
329	123	S04	1
330	128	S10	1
334	122	S07	1
339	121	S06	1
345	125	S08	1
350	124	S05	1

Table 2: Re-planned mission plan when subjected to priority change.

One can notice that the planning and scheduling module modifies the mission plan such that the higher priority strips are concerned before other strips. However, the proposed algorithm shall be improved such that the total time required to finish all mission is minimized.

6 CONCLUSIONS AND PERSPECTIVES

In this paper, we present a tool for remote sensing satellite mission planning, that aim to aid the mission-planner to manage and to generate mission plan for the Thaichote satellite. It allows the mission planner to prepare the mission plan according to four different time levels: long-term, medium-term, short-term, and post-mission analysis. The proposed tool also allows seamless flow of information from the user requests through all EOS processes. This allow the operator to track the status of each request and prepare the mission plan accordingly. Moreover, in case of change of observation condition, or arrival of new request, the proposed tool allow the operator to generate new mission plan with minimum change to the initial plan. We also present a methodology to generate a mission plan based on hybrid-metaheuristic optimization algorithm. Simulations are performed based on realistic input. Numerical results of the proposed methodology shows viability of the proposed methodology for mission planning.

In the following, we aim at improving the planning and scheduling module in order to minimize the total time to complete the mission, and also enhancing the optimization tool such that it could handle multi-satellite mission plan We also aim at fine-tuning the feasibility assessment module in order to increase the accuracy of the maneuvering time. In addition, the overall planning methodology will be tested will large-scale real world scenario, with long-term (1 year) planning time span. Finally, the performance of overall mission planning tool shall be improved by introducing more user-friendly interfaces.

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