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On-board Re-planning of an Earth Observation Satellite for Maximisation of Observation Campaign Goals

Cheyenne Powell(1, a) **and Annalisa Riccardi**(1, b)

(1) *Department of Mechanical and Aerospace Engineering, University of Strathclyde, 75 Montrose Street, Glasgow G1 1XJ, United Kingdom.*
(a) *cheyenne.powell@strath.ac.uk.*
(b) *annalisa.riccardi@strath.ac.uk.*

Abstract

Earth Observation (EO) Satellite task planning entails careful temporal consideration of actions depending on the assigned mission goals required for scheduling. Mid term plans are derived on ground and uploaded to the spacecraft for execution. However once in orbit, to maximise scientific mission return, the satellite needs to have autonomous re-planning capabilities to account for unforeseen events. This compensates for the reliance of communication with the ground stations, especially due to the limited frequency of transmission.

In the specific case of EO satellites, experienced uncertainties can be due to environmental or observational conditions, which can affect the optimal execution of mid term plans. Autonomous on-board re-planning ensures the maximisation of the observation campaign goals within the problem constraints.

An autonomous recovery algorithm via a Stochastic Problem (SP) implemented through the generation of a model required for on-board re-planning of actions to reduce dependency on human interaction. This is to attain updates for an executable plan to maximise observation campaign mission goals. The updated decisions and data related to environment and operations, are used to provide explanations to ground operators, enabling a human understanding of the actions taken autonomously by the system on-board.

Keywords: Scheduling, Constraint Programming, Stochastic, Optimisation, Mission Objectives, Earth Observation, Recovery, Mid term, Short term

1 Introduction

The cost and logistics involved in a satellite's mission necessitates mid and short term planning throughout a satellites lifetime to ensure the mission objectives are achieved. Mid term planning entails the creation of plans for schedules containing tasks for execution over a varying span of days, to weeks or months, while short term planning considers the immediate upcoming days and weeks [1, 2].

The mission goals determine the objectives, forming part of a campaign, and will vary based on the type of satellite required to complete the tasks [3]. EO satellites over the years have undergone major improvements, with the development of technological advancements, and have contributed to advancing the understanding of dynamics on our planet through means of theoretical, practical and operational applications [4]. Some examples of EO satellites include: Greenhouse Gas (GHG) Sat to measure greenhouse gases [5, 6], COSMIC-2 (C2) to monitor elements of the weather patterns of the tropics such as temperature and water vapour [7, 8], and Landsat-8 and Sentinel-2 for land observations [9, 10].

Each task completed on-board by the satellite, in this paper also referred to as actions, make use of its on-board components and instruments that may be limited by temporal, geographic, or hardware constraints [3, 11, 12]. Satellite mission plans are therefore the list of tasks scheduled to be executed on-board, that take into account conditions such as; weather, time, seasons, instrument use such as calibration, maneuvering, and other factors to achieve predefined goals. However, in practice, when these plans are uploaded into the space segment, unexpected anomalies that cannot be foreseen by ground operators can happen. This requires immediate corrective actions in response to compensate for such events [3]. This has developed the need for more autonomous on-board capabilities to have a more efficient and effective way to enable system recovery, and limit the delay and cost of addressing the event by ground operators [13].

EO satellites that are planned to observe certain areas of interest (target areas), as set by their mission goals; each task within their plan will then require on-board resources, such as memory, power, and time, as well as any additional requirements to guarantee a successful execution. For example, based on the observation plane due to the field of view, and hardware available on-board; instruments may require time to reposition and power on, while also ensuring memory is available prior to being at that location of interest to complete data acquisition [14]. Fig. 1 represents an example of how fields of view overlap in green with the area of interest highlighted in red. This was done using the Envisat mission to monitor floods in the Fiji Islands in 2012 due to a storm approaching [15].

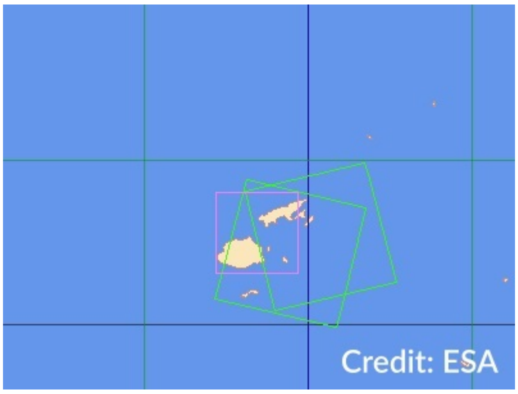


Fig. 1. Field of view overlap over Fiji for flood monitoring [15].

The creation of a schedule details the time allotted for task execution. These tasks, based on the objectives and environmental conditions, are given a weighted value that determine their priority and importance to the mission [12]. For example, taking images during daylight hours, or down-linking while in contact with a ground station. Therefore, an algorithmic approach for computing an optimized sequence of tasks, and generate the total score for the observation campaign of an EO satellite [16] within a schedule.

The created schedule must have no conflicts or violation of the constraints, with all tasks scheduled to be executed sequentially as derived by the plan [12]. When a scheduled task has stopped, due to data corruption for instance, this may impact the following tasks within the schedule, thus a reactive response is required for that time to recover from this event. This must be followed by a regeneration of the schedule, as there may not be direct communication with a ground station to allow instructions to be received from the end user, these decisions must be taken autonomously on-board.

Due to the limited computational resources available on-board a satellite, there is a need for low cost algorithms to regenerate an efficient schedule with the implementation of constraints[17].

Stochastic Optimisation (SO) techniques are methods that can solve optimisation problems where objectives and/or constraints are not deterministic functions. Some examples of these are Pure Random Search (PRS), Accelerated Random Search (ARS), Hybrid and Multi-start (HM) algorithms, Markov Decision Process (MDP) [18].

In previous work, it was observed by Gentile et.al.[19], that the randomness of noise and interference are considered as stochastic sources, which created complex tasks to generate a schedule from heterogeneous ground stations.

Therefore, a SP is applied to this paper, where a simulation is investigated for a satellite's recovery, due to a randomized error in processing an image taken by an EO satellite, based on a previously derived schedule with the use of a Constraint Programming (CP)-SAT solver using Google OR-Tools [20].

Three questions were asked to understand how an unexpected event of an image processing task cancellation would impact an EO satellite mission schedule:

- What would happen to an on-board satellite schedule if an image processing task stopped due to poor image quality?
- How would an autonomous system recover due to the cancellation of an executed processed task without human intervention?
- Can a re-scheduler account for such random events without deteriorating campaign performances?

This paper is separated into six parts including this introduction.

- Section 2 provides a description of the previous work done [20], where a mid term schedule of an EO satellite was created using real data over a period of six months utilizing a CP technique, with the use of the Google-OR-Tools CP-SAT Solver [21].
- Section 3 provides an explanation and factors considered for the approach taken to create an autonomous response for an EO satellite schedule.
- Section 4 contains the steps and algorithmic approach taken for the recovery of a task and how the data was supplied to the solver to create a short term schedule.
- Section 5 displays the results from the steps of recovery, comparing the data before and after the process cancellation has occurred.
- Section 6 discusses the findings of the paper with respect to the aims and if the maximisation of observation campaign goals were achieved.

2 Previous Work

The mid term schedule of an EO satellite in sun-synchronous orbit was created with the aim to observe land in daylight through the execution of three tasks; taking images, processing taken images on-board, and down-linking of the processed data when within line of sight with a ground station [20]. Initially a schedule was created offline by the end user, by means of an heuristic strategy, that was then optimized by the CP-SAT solver of Google OR-Tools [21].

2.1 Satellite Scheduling Problem Definition

The data used for generating the schedule was collected over a 6 months period, with the combination of the satellite's coordinates on a 5 second interval incorporating day/night conditions. Four databases, accessible by the solver were created, storing information on:

- Land visibility
- Light/shade exposure
- Ground station access
- Schedule generated by the end user

The optimisation problem was formulated using information on land, light/shade, and ground station visibility time windows. The end user manually generated schedule was used as initial guess to aid the solver in converging faster to an optimal solution. The schedule accounts for three tasks that were defined along with their respective constraints:

- Taking images
  - The satellite must be in sunlight.
  - There must be available memory for images to be taken.
  - Utilizes 2.688 GB of memory for every occurrence.
- Processing of images
  - There must be at least one unprocessed raw image in memory.
  - There must be available memory for processing to take place.
  - Processing may occur at any time.
  - Each instance is assumed a processing rate of 50 MB/s, equation to a fraction of an image for each executed instance.
- Down-linking of images
  - The satellite must be in line of sight with a ground station.
  - Down-linking must not exceed the number of processed images in the memory.
  - Each instance has a data rate of 280 MB/s, removing a fraction of the image taken, along with the processed data from the overall memory.

In addition to the constraints mentioned above, only one task may occur at any instance of time i, which we assume covering a period of 5 seconds, with an idle task created when no other task could occur, and 80% of the overall memory (1920 GB) must not be exceeded at any time.

To represent the tasks, a binary matrix X, as shown in equation 1. Where $\{a_p, a_r, a_d, a_e\} = A$ is the set of possible actions, namely taking an image (a_p) , processing an image (a_r) , down-linking an image (a_d) , and idle time (a_e) and T is the discretised time horizon

$$X \in \{0,1\}^{T \times A} \tag{1}$$

Constraints where formulated mathematically as follow:

$$\sum_{a \in A} X_{i,a} \leq 1 \qquad \forall i \in 1, ..., T \tag{2}$$

$$d_i = \sum_{j=1}^{i} X_{j,a_d} \frac{D_m}{I_m} \tag{3a}$$

$$d_i \leq r_i \qquad \forall i = 1, ..., T \tag{3b}$$

$$p_i = \sum_{j=1}^{i} X_{j,a_p} - d_i \qquad \forall i \in 1, ..., T \tag{4}$$

$$r_i = \sum_{j=1}^{i} X_{j,a_r} \frac{R_m}{I_m} - d_i \tag{5a}$$

$$r_i \leq p_i \qquad \forall i = 1, ..., T \tag{5b}$$

$$m_i = I_m(p_i + r_i) \qquad \forall i = 1, ..., T \tag{6a}$$

$$m_i \leq M_{max} \qquad \forall i = 1, ..., T \tag{6b}$$

To reiterate, only one task can be executed at i across the time horizon T, as represented in equation 2. Three auxiliary variables were created, d_i, p_i, r_i, representing respectively the total fraction of down-linked images at time instant i (Equation 3a), the total fraction of images taken stored in memory at time instant i (Equation 4), the total fraction of images processed in memory at time instant i, (Equation 5a). m_i is an additional variable, representing the total memory utilised at time instant i (Equation 6a). Constant values are used to calculate when executing each action for every i are as follows:

- Image taking - I_m (2.688 GB)
- Processing - R_m (250 MB)
- Down-linking - D_m (1400 MB)

A down-linked and processed instance equates to a fraction of an image, thus they both are converted into the form of images, hence D_m/I_m is used in equation 3a and R_m/I_m is used in equation 5a; noting that for every i, to calculate p_i and r_i, d_i is subtracted to attain the total for those time instances. Meanwhile, equation 3b represents the constraint that down-linking shall only occur if there is a processed image in memory, and in equation 5b, processing cannot occur unless there is an unprocessed image in memory.

The memory at any point in time, as shown in 6a is calculated with the total images and processed images keeping in mind that the total down-linked images up to that point have already been subtracted. Also, for equation 6b, the total memory at any point, shall not exceed the maximum memory.

The schedule was generated using the objective function defined below that aims at minimising the idle time, by maximising the sum of the three tasks at each instant in time.

$$max\left(\sum_{i=1}^{T} X_{i,a_p} + \sum_{i=1}^{T} X_{i,a_r} + \sum_{i=1}^{T} 2X_{i,a_d}\right) \quad \text{(f1)}$$

A randomised variable was added to the model, to model the event of an image processing task failing at a particular time interval. This adds stochasticity to the problem and the need of re-scheduling the tasks that were planned subsequently to the random event with the objective of recovering the lost observation.

3 Satellite Task Recovery

Short term scheduling is necessary to enable a satellite to recover from any anomaly that can impact a mission, without compromising the mission goals. Depending on the random events that may occur during an execution of a schedule, the goals of the mission, and the time available for the recovery, will determine the amount of computing resources required.

For example, if a cancelled task is immediately required for the next task to execute, the demand for computing resources are increased at that specified time until a solution is derived. Otherwise, time is allocated for the recovery of the failed task thus not requiring an extensive amount of computing resources. For task recovery to be successful, the system will need to seek the next opportunity for that affected task to be re-executed.

Fig. 2 represents an example of a change when task c is cancelled during the execution of a mid term schedule, leading to the creation of a short term schedule. The short term schedule works towards recovering the lost data, by executing other tasks to then re-execute task c before attempting to match the mid term schedule.

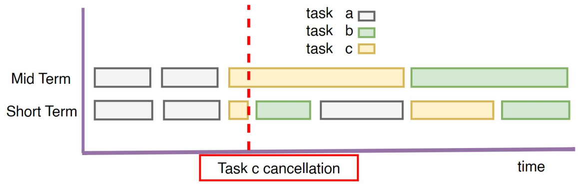


Fig. 2. Recovery from task c cancellation.

The cancellation of an image processing action is simulated, due to the image being unusable which requires the retaking of the original image. To determine the next opportunity, the orbit of the satellite must be calculated. The system can then generate a predicted path to estimate when the position of interest will be re-approached to create a short term schedule with the action execution opportunities. This would not only be applicable to one instance but any other future instances that may occur, resulting in a gradually increasing database with multiple opportunities for the previously cancelled actions to be re-executed. Thus requiring the reserved 20% of the overall memory until recovery is complete, followed by a re-generated schedule, as 80% of the overall memory, previously mentioned in Section 2.1, is used for storing and processing images. Fig. 3 represents an example of a predicted path of an EO satellite in sun synchronous orbit.

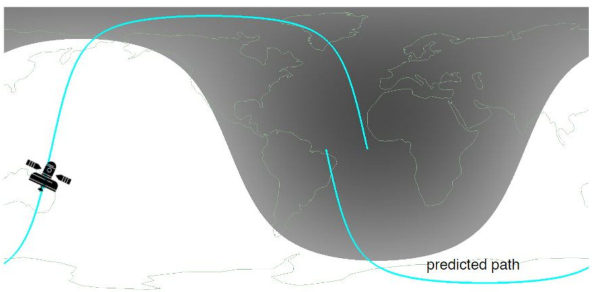


Fig. 3. The predicted future path of a satellite.

Depending on the path, field of view and swath of the satellite, the area of interest may not be fully visible. It was thus assumed that attaining 50% of the deleted image should be considered an opportunity for the task to be scheduled for re-execution.

When a processed instance has been cancelled, it is essential to know the date and time, as well as the coordinates of the satellite, when the image was taken. Fig. 4 represents a satellite at different points in time. Satellite at position a on day n represents when a processed instance was cancelled. This is then backtracked to time t for satellite at position b on day $n-\delta t$ when the image was taken over the point of interest, where the coordinates are extracted and stored. The satellite's on-board system would then calculate a predicted path from day n so that at any future time t, when the field of view for satellite at position c overlaps with the area of interest on day $n+\delta t$, by approximately 50%, the deleted image can be scheduled to be retaken, taking into account the constraints of sunlight and shade.

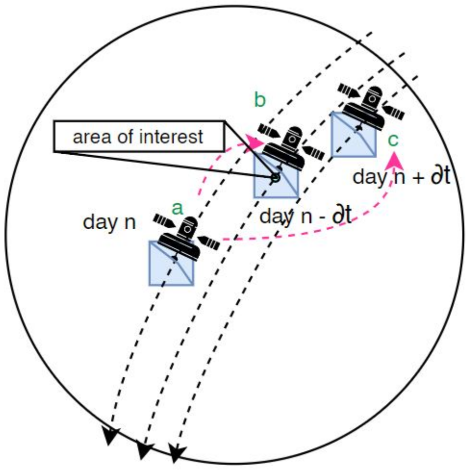


Fig. 4. The position of image processing cancellation of satellite a on day n, with it's respective field of view, and a backtracked position using a pink arrow pointing to satellite b on day $n-\delta t$, and it's future predicted opportunity for image retake using satellite c on the predicted day $n+\delta t$.

4 Method

A solution was applied to the mid term schedule, where upon execution, a random chance of image lost was applied to any processed instance, to account for any data corruption, cloud coverage, or other image quality issues, simulating the effects of the cancelled action on the short term schedule. With an assumed processing rate of 50 MB/s, an image size of 2.688 GB and a time instance of 5 seconds, as stated in section 2.1, using equation 5a in the form of processed instances generates equation 7

$$R_{num} = \left\lceil \frac{r_i - \lfloor r_i \rfloor}{\frac{R_m}{I_m}} \right\rceil \qquad \forall i = 1, \ldots, T \tag{7}$$

This equation was used to determine the number of processed instances (R_{num}) to be deleted from the memory related to the removed image. Each stage of processing was assumed to contain sequential steps to analyze an image. This means the equation allowed for the calculation of memory value increments of an image for each instance i.

Fig. 5 details a summary of the processes of the algorithm involved with recovery before the short term schedule can be generated.

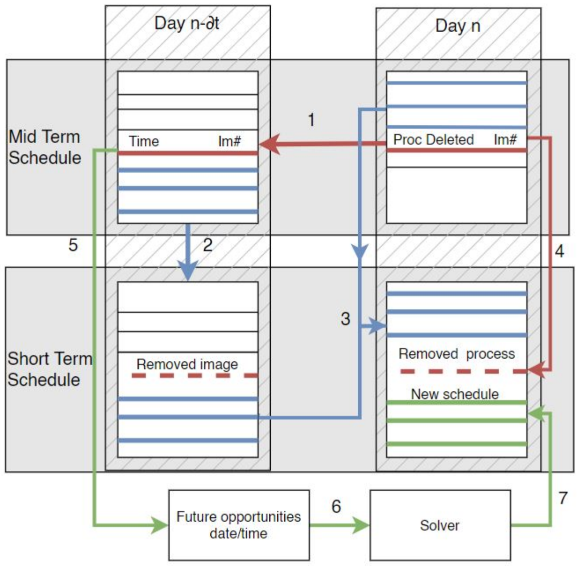


Fig. 5. Steps required to recover when the next opportunity for an image can be retaken. Red represents changes that have negatively impacted the schedule, blue represents already executed tasks, green represents the steps for recovery by the system that positively impacted the schedule, in return creating the short term schedule.

1. Starting with day n, in the mid term schedule, a cancelled processed task occurred at instance i on image number ($Im\#$); upon stopping, a backward search is done to remove the other processed instances from memory, if the removed instance was not the first for the respective image.

   An additional search was done to find the image taken previously on day $n-\delta t$, as shaded in red, and once identified is removed from the memory.

2–3. Following the removal, an update of the memory and previous objective profiles, with the executed actions, is conducted, as shown in blue, with their respective times to allow easy searching for future cancellations for both days $n-\delta t$ and n.

4. In addition, despite the processed instance/s being removed, a flag is placed in memory for when and where the removal occurred allowing for future investigations to be traced to the time of the incident, therefore is carried over to the short term schedule for day n shown with a red arrow.

5. While the memory profile is being updated, the time and coordinates for the image of interest $Im\#$ is extracted and a Forward Search (FS) is done throughout the predicted path for the next set of opportunities, shown with a green arrow. Using a swath value of 290 km (that of Sentinel-2, for example) [22], the calculation was done to ensure the satellite will be within 145 km of the area of interest, covering at least 50% of the original image taken.

6. After the search has detected the next opportunity, the information is fed to the solver.

7. The solver would then prioritise the task for taking the image, with an adapted objective function, for the specified time intervals Y, as shown in function f2. For any other time interval where $i \notin Y$, the objective function f1 is used across the time horizon. For a successful execution, it is necessary memory is available on-board for retaking the image over the area of interest, unless instructions are received that the area of interest is no longer required by the ground station operator.

$$\max\left(\sum_{i\in Y}^{Y} X_{i,a_p}\right) \tag{f2}$$

Algorithm 1 was created using the steps as previously discussed in figure 5 to create a short term schedule. Once completed, during an execution of any future processed action that has been cancelled, the steps displayed in algorithm 1 would repeat creating a closed loop within the system.

5 Results

A simulation was done with a stochastic method applied to cancel processing tasks. A short term schedule for the mid term schedule for days $n-\delta t$ and n as shown in figure 5 were created to allow data to be compared and traced. Thus, a file containing the summary of future opportunities for images to be retaken was created containing the dates and times for the action to be prioritised using the objective functions f2 and f1. These

Algorithm 1 Recovery for task execution

```
while Search through the list of processed actions
for the respective image. do
    Remove each processed action from memory, locate original image with coordinates and delete
    raw image from memory.
end while
Update the memory and objective profile.
while Search through the calculated predicted path
for coordinates. do
    calculate overlap distance for every future coordinate with the coordinate of removed image.
    if Coordinates overlap by at least 50% then
        Check they satisfy environment constraints.
        if Coordinates are in light and over land. then
            Store time as an opportunity for retaking and
            feed to solver with updated objective.
        else
            Continue search.
        end if
    else
        Continue searching for predicted coordinates.
    end if
end while
```

opportunities were observed to range from at least 24 hrs to several days into the future with a full coverage of appriximately 99.5% on the tenth day of an EO satellite in sun synchronous orbit, with an orbital period of 90 minutes and an altitude of 786 km.

Additionally, due to an instance i being set to 5 second intervals, based on the path of the satellite in orbit, the field of view may overlap the area of interest for more than one instance, resulting in several opportunities being considered for that path. However, it was considered that a time interval of 1 second would produce more accurate results, but would significantly increase demand on computational power and resources.

Table 1 contains two sets of data for day n, a short term and a mid term data-set. Initially, all processed actions were scheduled to be executed, however, during execution at a start time of 71 seconds (highlighted in a red box), the processed instance was cancelled, thus removing the memory profile for the previously successful processed actions for the same image, changing their task executed states from ’Y’ to ’N’ (in red boxes); creating a short term schedule with updated values of the onboard memory, processed instances in memory, total processed instances and the image number being processed (in blue boxes). This was done with the use of equation 7 as a guide to mark and determine how many processed instances needed to be removed, as stated in

Table 1. A representation of the day n memory profile and the effect in the database when a processed instance was cancelled from the mid term schedule during execution at 71 seconds, creating an updated list, deleting the previous instances related to the image.

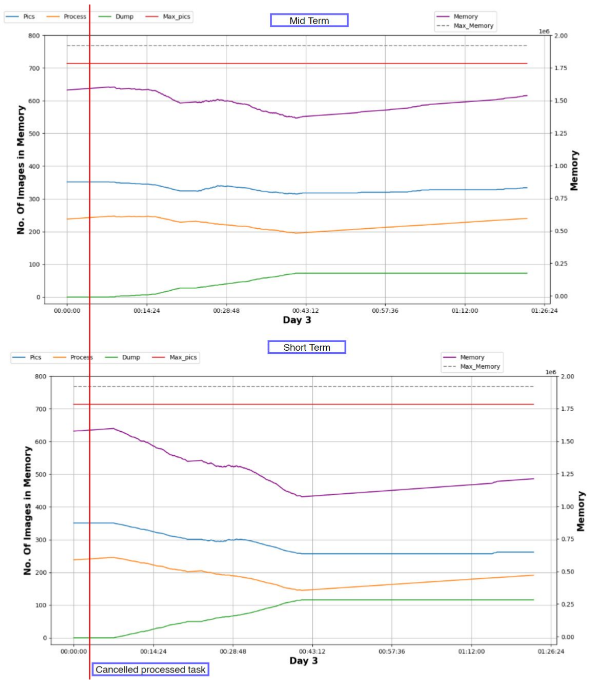
Time stamp (s)	Task	On-board memory	Images in memory	Total number of images	Processed instances in memory	Total processed instances	Image number being processed	Total down-linked instances	Total down-linked images	Task Executed
Mid Term Schedule										
41	Process	1581796	351.91	1992	2571.6	20234	1881.88	3154	1642.7	Y
46	Process	1582046	351.91	1992	2572.6	20235	1881.97	3154	1642.7	Y
51	Process	1582296	351.91	1992	2573.6	20236	1882.06	3154	1642.7	Y
56	Process	1582546	351.91	1992	2574.6	20237	1882.16	3154	1642.7	Y
61	Process	1582796	351.91	1992	2575.6	20238	1882.25	3154	1642.7	Y
66	Process	1583046	351.91	1992	2576.6	20239	1882.34	3154	1642.7	Y
71	Process	1583296	351.91	1992	2577.6	20240	1882.44	3154	1642.7	Y
Short Term Schedule										
41	Process	1579108	350.91	1991	2571.6	20234	1881.88	3154	1642.7	Y
46	Process	1579358	350.91	1991	2572.6	20235	1881.9	3154	1642.7	Y
51	Process	1579358	350.91	1991	2572.6	20235	1881.9	3154	1642.7	N
56	Process	1579358	350.91	1991	2572.6	20235	1881.9	3154	1642.7	N
61	Process	1579358	350.91	1991	2572.6	20235	1881.9	3154	1642.7	N
66	Process	1579358	350.91	1991	2572.6	20235	1881.9	3154	1642.7	N
71	Process	1579358	350.91	1991	2572.6	20235	1881.9	3154	1642.7	N

Table 2. A representation of day $n - \delta t$ depicting what happens in the database when the located scheduled image has been removed from the mid term data, represented in the short term data.

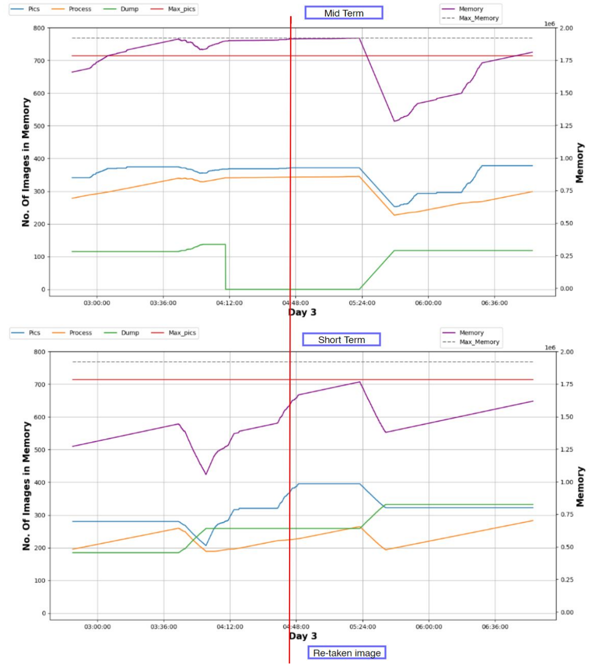
Time stamp (S)	Task	On-board memory	Images in memory	Total number of images	Processed instances in memory	Total processed instances	Image number being processed	Total down-linked instances	Total down-linked images	Task Executed
Mid Term Schedule										
79436	Take Image	1103916	265.83	1882	1585.2	18990	1766	3108	1618.8	Y
79441	Take Image	1106604	266.83	1883	1585.2	18990	1766	3108	1618.8	Y
79446	Take Image	1109292	267.83	1884	1585.2	18990	1766	3108	1618.8	Y
Short Term Schedule										
79436	Take Image	1103916	265.83	1882	1585.2	18990	1766	3108	1618.8	Y
79441	Take Image	1103916	265.83	1882	1585.2	18990	1766	3108	1618.8	N
79446	Take Image	1106604	266.83	1883	1585.2	18990	1766	3108	1618.8	Y

section 4.

At the time of removing the processed task, a backward search was carried out by the system, to locate the image that was deleted during processing to remove it's memory from the on-board memory and history. In this scenario, image number 1883 was located at executed time stamp 79441 seconds on day $n - \delta t$ and was removed from the mid term data, thus being reflected in the short term schedule as shown in table 2 (shown in red boxes). Following this, the next image executed was relabelled to keep future tracking in sync with the number of processed instances. This means the removed image memory was cascaded throughout the previously executed schedule to the point of cancellation. Thus forward tracking data back to table 1, where images in memory and total number of images of the updated list are 1 less than in the initial data, including it's equivalent memory value (shown in orange box). In both tables 1 and 2, however, the down-linked data profile was not affected.



(a) Process Cancellation comparison between mid term and short term schedules



(b) Image retake comparison between mid term and short term schedules

Fig. 6. Day 3 before and after the process task removal, and image retaken on the same day. Purple - overall memory, Blue - Images in memory, yellow - Processed images in memory, green - Down-linked images in memory (frequently resets to zero)

Table 3. Proposed times for image retake opportunities from the recovery algorithm.

Image retake times		
day	Time stamp (s)	Coverage %
3	16846	50.20
...	...	...
5	19216	55.66
5	19251	68.65
5	19256	57.95
...	...	...
6	17451	65.49
6	17456	60.19
...	...	...
8	19821	60.92
8	19826	66.05
...	...	...
9	18026	69.97
9	18031	79.05
...	...	...
12	79436	99.54
12	79441	99.54

Table 3 provides an example of the data output showing when the image can be retaken with their respective percentage of coverage using the predicted path and constraints. It was observed, the next suggested opportunity for retaking the image was possible on the same day n when processed failed which is day 3 in this simulated scenario. Over the 10 day period from the original deleted image that was taken on day 2 ($n-\delta t$), there were 92 opportunities identified to retake the deleted image with 3 opportunities covering over 99% of the area of interest. Due to the large data set, only a small sample of opportunities for retaking the image were listed.

After the execution of the solver using the variable objective function, the short term schedule was analyzed to check if the scheduler executed the output from the recovery algorithm. Shown in table 4, the solver successfully received the instructions and re-scheduled the prioritised task for both the suggested time intervals (comparisons are shown in red boxes).

Figs. 6 (a) and (b) represent a comparison between the mid term and short term schedules generated by the solver. At the point of process cancellation, looking at the data, they remained the same until the processed

Table 4. Section of regenerated schedule from the solver due to the predicted coordinates from recovery algorithm.

Time stamp (S)	Task	On-board memory	Images in memory	Total number of images	Processed instances in memory	Total processed instances	Image number being processed	Total down-linked instances	Total down-linked images	Task Executed
Mid Term Schedule										
16836	Take Image	1907986	369.63	2147	3688.2	22829	2123.2	3418	1780.2	N
16841	Take Image	1907986	369.63	2147	3688.2	22829	2123.2	3418	1780.2	N
16846	Take Image	1907986	369.63	2147	3688.2	22829	2123.2	3418	1780.2	N
16851	Take Image	1907986	369.63	2147	3688.2	22829	2123.2	3418	1780.2	N
16856	Take Image	1907986	369.63	2147	3688.2	22829	2123.2	3418	1780.2	N
Short Term Schedule										
16836	Process	1524574	422.95	2348	1583.8	22315	2075.4	3702	1928.15	Y
16841	Take Image	1527262	423.95	2349	1583.8	22315	2075.4	3702	1928.15	Y
16846	Take Image	1529950	424.95	2350	1583.8	22315	2075.42	3702	1928.15	Y
16851	Take Image	1532638	425.95	2351	1583.8	22315	2075.42	3702	1928.15	Y
16856	Process	1532888	425.95	2351	1584.8	22316	2075.52	3702	1928.15	Y

was cancelled. Fig. 6(*a*) after cancellation, shows the variance of the values of the plots with a slight similarity. Whereby the blue line represents images in memory, yellow as processed images in memory, green as downlinked images (resets as it constantly increases), and purple for total memory at any point in time. Fig. 6(*b*) shows where the image was scheduled to be retaken on the same day, with the variations in plotted data due to the process cancellation earlier in the schedule.

6 Conclusion

A SP was applied and simulated on an existing EO mid term satellite schedule to see the behaviour of a derived recovery algorithm on the system. A task responsible for processing images within a schedule was randomly chosen to be cancelled, and based on the stage of processing, additional processing tasks previously executed may need to be removed from the schedule if the image had already started to be processed. A backward and forward search algorithm were used to located the image and predict future opportunities for retaking the images of the area of interest.

These generated results were fed to a solver with an adaptive objective function that prioritised the retake of the image creating a short term schedule, where the campaign goals were deemed maximised when compared to the mid term schedule, that was used to simulate the deleted action. The recovery algorithm proved to be accurate and efficient in facilitating the recovery of deleted images, without the need for human interaction and is therefore autonomous and suitable for more expansive and challenging tests and applications.

Future Works

Different recovery techniques such as Machine Learning (ML), Predictive Solving (PS) based on historical data of weather patterns, component calibrations, power consumption and other anomalies will be investigated. Additionally, to improve the end user's understanding of the system, an Explainability Artificial Intelligence (XAI) layer will be built containing an internal argumentation layer to support explanations in the form of Natural Language Processing (NLP) to allow users to interact with the system.

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