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Dynamic meshing for satellite acquisition of large areas using adaptive multi-agent system

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Abstract

As part of Earth observation missions, satellites are used to acquire areas on the Earth's surface. Large area coverage missions are large-scale acquisition projects. They require the use of a set of satellites that make several passes over a long acquisition period. Cutting an area of interest into sub-areas called meshes that can be acquired by satellites during their passes is a difficult optimization problem.

In this paper, we present the Glimpse system based on adaptive multi-agent systems for the dynamic cutting and positioning of meshes on a grid of elementary sub-areas. The experiments carried out and the comparison with an approach that is part of the operational state of the art show that a decentralised and dynamic approach to solving this problem is adequate.

Keywords

Satellite planning, adaptive multi-agent system, dynamic meshing, optimization, emergence

1 Introduction

The objective of low-earth orbit observation satellites is to take pictures of areas of interest on the Earth's surface. The most common missions of these satellites are related to urgent requests on small areas (Lemaître et al. 2002). These requests often concern temporary phenomena such as natural disasters. These requests can be processed by taking a picture or **acquiring** an image from a single satellite over a short period of time. Conversely, so-called **large area coverage** (LAC) missions concern requests to acquire larger areas, on a country or continental scale. LAC missions provide images used in areas such as mapping and monitoring. These missions are costly in terms of satellite resources and require images that are close in time to ensure the coherence of the connections between them. For these reasons, the completion of a LAC mission must be achieved in minimum satellite time and resources. The time required for a single satellite to complete a LAC mission is too long in relation to time constraints. A set of satellites must be used for a longer period than that allowed for urgent requests. These satellites can be heterogeneous, with

different characteristics and acquisition instruments, and operated by different independent planning centres. One of the challenges of current observation satellite missions is the coordination of planning centres for the successful resolution of LAC missions by heterogeneous satellites.

Sharing the area of interest between a set of satellites is both a geographical and a temporal problem. For each pass of a satellite a set of sub-areas called meshes that can be acquired must be defined. We will define the LAC problem as the division and distribution of the area of interest into meshes allocated to satellites for the optimization of time and satellite resources used. The meshing technique commonly used to solve this problem will be called **static meshing**. In this article we propose an innovative technique for cutting and placing meshes called **dynamic meshing**. This approach relaxes geographical constraints related to mesh size and allows for more accurate and relative placement of meshes depending on acquisition needs during the LAC mission. The resulting increase in search space requires the use of approximate method algorithms for the optimization of the LAC problem.

The rest of the article is organized as follows. The section 2 presents the formalization of the LAC problem as well as a state of the art of similar problems and the optimization methods used to solve them. The section 3 presents the Glimpse adaptive multi-agent system designed for the optimization of this problem. Finally, the section 4 provides results and a discussion on the comparison of the Glimpse algorithm with a state-of-the-art static meshing algorithm for simulated LAC scenarios.

2 Large area coverage problem

Problem description

The LAC problem is the optimization of the acquisition of an **area of interest** defined by a **client request** using a set of satellites.

A **satellite** is an acquisition tool following a polar **orbit** and operated by a **Mission Planning Facility** (MPF). Depending on its orbit and the rotation of the earth, the satellite flies over terrestrial areas at time intervals called **passes**. During a given pass, a geographical area called

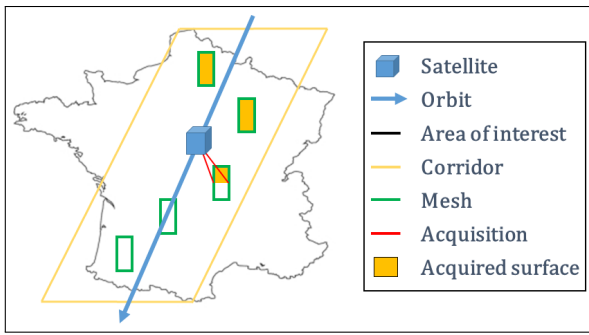


Figure 1: Acquisition of a set of meshes during a satellite pass

corridor is accessible by the satellite. The width of a corridor depends on the agility of the satellites, i.e. their orientation capabilities, and the minimum resolution of the images obtained by acquisition. The geographical entities that are involved in the acquisition of **meshes** are illustrated in the figure 1.

A first phase upstream of the LAC problem is to establish the set of satellites and their passes that can be used to acquire the area of interest.

For each pass of a satellite over an area of interest, the acquisition process follows the cycle illustrated in figure 2 and consists of the following phases:

1. **Meshing.** Cutting of the corridor of the pass in **meshes**.
2. **Request for acquisition.** Selection of a subset of the meshes and sending of a request for the acquisition of these meshes to the MPF that operates the satellite.
3. **Acquisition.** Following the calculation of the actual satellite acquisition plan by the MPF, a response is formulated containing the meshes of the request that have been selected for acquisition.
4. **Validation.** Response from the MPF containing the state of validation or rejection of the meshes and the corresponding images.

The programming of a LAC mission is ensured by an operator independent of the MPFs. This operator is responsible for meshing and transmitting acquisition requests to the MPF that operate the satellites. It should be noted that acquisition requests that are more urgent than those issued under the large coverage may be processed on a priority basis by the MPFs. Consequently, requests for the acquisition of meshes sent to MPFs are not guaranteed to lead to the acquisition of all these meshes. In addition, the successful acquisition of a mesh by a satellite depends on the weather conditions at the time of acquisition. The image obtained by an acquisition will be considered clear or blurred depending on its observed cloudiness rate. The acquisition of a mesh by a MPF may therefore fail due to differences between the weather forecasts made when the acquisition plan is sent to the satellite and the actual conditions at the time of the pass. For each mesh, three states are to be distinguished:

- **Active** : Awaiting planning on a pass.
- **Acquired** : Included in a satellite acquisition plan.
- **Validated** : Successful acquisition, a clear image of the mesh is available.

The LAC problem is to find a set of meshes to acquire for each satellite pass that minimizes both **time** and **satellite resources** needed to obtain clear images of the entire area of interest. Time is measured by the **number of passes** of the satellites since the beginning of the LAC mission or the equivalent in number of days. The satellite resources used up to the completion of the LAC mission are measured by a metric called **waste** defined as the surplus acquisition of areas during the large coverage. For example, the minimum waste of 0% is achieved if all validated acquisitions of the large coverage only concern areas that have been acquired only once.

State of the art

The LAC problem as presented in the previous section is not addressed as a whole in the industry. Currently, the following pre-treatment is performed:

1. division of the area of interest into several sub-areas,
2. exclusive distribution of sub-areas among MPFs,
3. acquisition by the MPFs of their respective sub-areas.

This pre-processing avoids overwhelming the MPFs with acquisition requests over the entire area of interest. Coordination between MPFs is not necessary because each sub-area is treated separately. The distribution between the MPFs thus avoids the complexity of the LAC problem over the entire area of interest. However, this approach implies that some satellite passes will be ignored for sub-areas because their MPF has been assigned another sub-area. Many acquisition opportunities are ignored to simplify the problem and the mission completion time increases significantly. The LAC problem, considered in its entirety, increases complexity but allows the coordination of MPFs for missions that are both faster and less costly in terms of satellite resources.

The planning of acquisition plans for a set of satellites is a known problem. (Bensana, Lemaitre, and Verfaillie 1999) and (Frank et al. 2001) offer different planning techniques. (Globus et al. 2004) compares 13 optimization techniques for this problem and gets better results with a simulated annealing optimization algorithm. Based on this work, (Bonnet 2017) proposes a multi-agent system adapted to the processing of new acquisition requests for the optimization of a set of acquisition plans. However, these examples consider satellite acquisitions as tasks planned by a single MPF and to be carried out over a short planning horizon.

There are few references in the literature to the LAC problem as a whole as we wish to consider it in this paper. (Fei and Zhi 2011) seeks to improve the industrial process, it proposes a greedy algorithm for a dynamic distribution of sub-areas between the MPFs. (Xu et al. 2018) describes

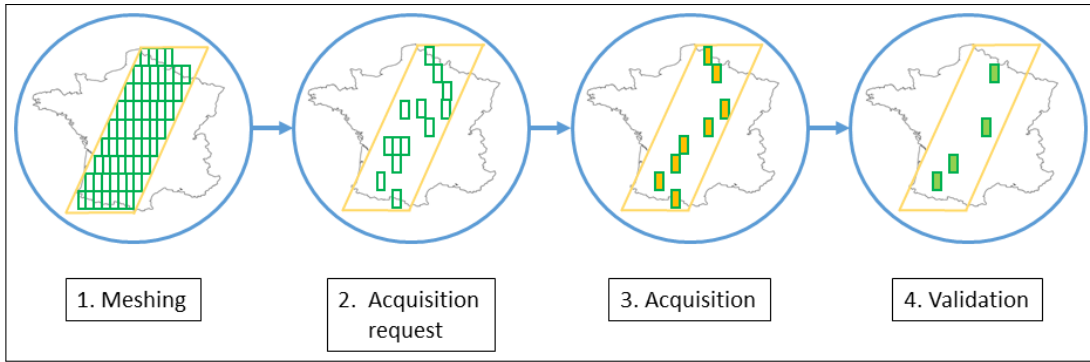


Figure 2: Acquisition and validation process for a satellite pass

phases of discretization of the area of interest, striping and acquisition planning by genetic algorithm, with good results obtained compared to a greedy algorithm. (Holvoet et al. 2018) and (Niu, Tang, and Wu 2018) consider a problem of coordinating heterogeneous satellites for observing disasters that cover large areas. The geometric problem they address is to define a set of strips that cover the length of the area of interest and are assigned to heterogeneous satellites. This problem is different from that of LAC because acquisition requests are considered urgent and always accepted by the MPFs, and acquisition failures due to weather conditions are ignored.

In the operational context, a mesh grid is established by the MPF once a sub-area of the area of interest has been assigned to them. This technique, which we will call **static meshing**, consists in building for each satellite pass, a set of meshes that can be acquired. A grid of joint meshes that describe a regular paving of the corridor of the pass is calculated when the client request is received. The meshes obtained are fixed and of constant size in the same pass. This size is defined according to the maximum of the satellite’s acquisition capacities for a single mesh. The positioning and fixed dimensions of the meshes means that they cannot be adapted to the geographical acquisition needs during the mission. These constraints may result in additional acquisitions of validated sub-areas.

We propose a new mesh technique called **dynamic mesh**. As part of this mesh, a grid of elementary sub-areas called **cells** is built on the area of interest. This discretization allows a more precise positioning of the meshes in the corridors of the passes, and in particular on their edges. The position of the meshes and their dimensions can also be adapted on the cell grid for a better use of satellite resources. Subparts of validated or cloudy corridors can be ignored in favour of subparts that are not validated and have a higher probability of validation. The mesh types, static and dynamic, are illustrated in figure 3.

The problem of distributing meshes on a cell grid for each satellite pass is complex. A large number of entities are considered and the size of the research space is related to

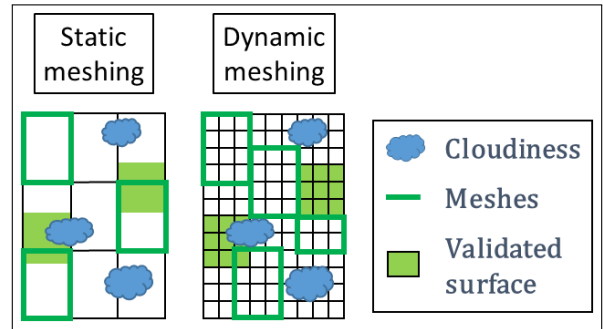


Figure 3: Example of mesh placement in the same subpart of a corridor by meshing technique (static vs. dynamic)

the possible placement and dimensions of the meshes in all pass. We have chosen to implement a multi-agent system to optimize the LAC problem by dynamic meshing. The Glimpse system presented in this article is based on the AMAS theory (Gleizes 2011). Adaptive multi-agent systems have proven their effectiveness in addressing optimization highly combinatorial problems that include a large number of entities by the emergence of global functions of good quality through the cooperation of distributed agents with simple local behaviors (Verstaevl 2016). The optimization process of the Glimpse system is presented in section 3.

Formalization of the problem

In this section we propose a formalization of the LAC problem with discretization of the area of interest into cells. Given that:

A zone Z on which is placed a grid of width X and length Y of cells $c_{11}, \dots, c_{ij}, \dots, c_{XY}$, with i and j the geographical coordinates of the lower left corner the cell c_{ij} .

All cells $C_{int}^Z = \{(i, j) | c_{ij} \cap Z \neq \emptyset\}$ inside or partially inside the area. The cells are characterized by:

- a width l and a length L per kilometer.
- An acquisition status $st(c_{ij}, t) \in \{Active, Acquired, Validated\}$ indicating respec-

tively if the cell c_{ij} is waiting for planning, included in an acquired mesh or included in a mesh validated at time t .

The set of satellites $S = s_1, \dots, s_k, \dots, s_K$ of minimum acquisition width $f_k^{min} * l$ and maximum acquisition width $f_k^{max} * l$ with $f_k^{min}, f_k^{max} \in N$; and minimum acquisition length $g_k^{min} * L$ and maximum acquisition length $g_k^{max} * L$ with $g_k^{min}, g_k^{max} \in N$.

Known satellite passes P_k s_k on a planning horizon H in number of passes, and characterized by :

- a date of occurrence t_{P_k}
- a set of accessible cells $C_{P_k} = \{(i, j) | c_{ij} \in Corridor_{P_k}\}$
- a maximum mesh number threshold $|M_{P_k}| < \frac{|C_{P_k}|}{f_k^{max} * g_k^{max}}$ to avoid overloading the MPFs with mesh acquisition requests. This threshold is defined as the number of meshes of maximum size sufficient to cover all cells in the corridor of the pass.

Goal. The goal of the resolution is to determine for each pass a set of meshes $M_{P_k} = (i_0, j_0, f, g)$, with i_0, j_0 the coordinates of the lower left corner of the mesh and $f_k^{min} \leq f \leq f_k^{max}$ and $g_k^{min} \leq g \leq g_k^{max}$, to include in an acquisition request.

Objectives. The main objective is to minimize the time required to complete the LAC mission. This objective is reflected in the validation of all cells in the area of interest. The completion of the mission is reached at a time noted t_{comp} .

The measure of progress in completing the project is noted as

$$Progress(Z, t) = \left(\frac{\sum_{i,j | c_{ij} \in C_{int}^Z \wedge st(c_{ij}, t) = Validated} c_{ij}}{\sum_{i,j | c_{ij} \in C_{int}^Z} c_{ij}} \right)$$

with $Progress(Z, t_{comp}) = 1$.

The secondary objective is to minimize the waste, i.e. the surplus of acquisition of surfaces already acquired during the mission. With the discretization of the area of interest into cells, a mission without waste can be represented as the acquisition of all cells once only. We note the waste

$$Waste(Z, t) = \frac{Nb_{acq}}{Nb_{C_{acq}}} - 1$$

with Nb_{acq} the total number of cell acquisitions in the Z area from the beginning of the work to the moment t , and $Nb_{C_{acq}}$ the number of cells of Z acquired at least once from the beginning of the mission to the moment t . For example, if all cells of Z were acquired only once, $Nb_{acq} = Nb_{C_{acq}}$ and $Waste(Z, t) = 0$.

3 Glimpse system

Glimpse has three types of agents: Cell, Mesh and Pass agents. In this section, we describe the behaviours of these agents, their objectives and their interactions.

The static meshing technique commonly used and described in section 2 is a mesh placement heuristic within the passes that has the advantage of not allowing overlap between meshes. The dynamic mesh proposed in Glimpse provides an additional degree of freedom to the meshes that can be placed on any coordinate (i, j) belonging to the corridor of their passes. The first objective of the agents' behaviors in Glimpse is to find for each Mesh agent a cooperative placement taking into account the criticality of the Cell agents that will be acquired with the Mesh agent.

Cell agents

In Glimpse, the **Cell agent criticality** represents the importance of acquiring the area covered by the cell for a given pass. The criticalities of several cells can be compared to determine their order of importance in terms of acquisition over a pass. The comparison follows a leximin order: the criteria are compared in a fixed order until a differentiating criterion is found that indicates the most critical Cell agent. The comparison of criteria from the entities of the problem implies the definition of a relative importance of these entities. In this work, the importance of each criterion is based on analyses by experts in the field. The criticality of Cell agents in a given pass is based on the following normalized criteria:

1. **Validation.** The criticality of a cell that has already been validated is void.
2. **Likelihood of validation.** Probability of validation of the cell if acquired in this pass. For cells also acquired in previous passes this criterion is weighted by their probability of validation in these pass.
3. **Likelihood of future validation.** Probability of validation of the cell in the remaining passes on the planning horizon for which the corridor covers this cell.
4. **Proximity to validated cells.** Ratio of neighbouring validated cells.
5. **Remaining passes.** Ratio of remaining passes on the planning horizon for which the corridor covers this cell.

The objective of a Cell agent is to be acquired and validated on any pass on the planning horizon that contains the cell in its corridor. The behavior of a Cell agent is based on its local knowledge, including the Mesh agents visible by the Cell agent in each pass, to maximize the probability of its acquisition. The visibility of Cell agents is limited to the meshes that cover them or are directly adjacent to them on the cell grid. The behaviour of the Cell agents follows algorithm 1.

The objective of the Cell agents is satisfied through a notion of **adhesion** to meshes on known passes. The adhesion of a cell to a mesh describes the willingness to be part of the cells covered by this mesh. A cell can only adhere to one mesh per pass, which is the mesh it prefers among the meshes it knows in that pass and that has accepted an adhesion request. The objective of adhesion is to promote the distribution of meshes of the same pass over the surface the corridor. This distribution is necessary in dynamic meshing

Algorithm 1 Cell agent behavior

```
for each known  $P_k$  do
  sorting of known meshes  $M_{P_k}$  by criticality
  for each  $m_{P_k} \in M_{P_k}$  do
    if non adhered cell and no adhesion request then
      mesh adhesion request to  $m_{P_k}$ 
    end if
  end for
end for
```

to avoid the grouping and overlapping of meshes of the same pass on the most critical cells in the corridor. The Cell agents choose the mesh to which they prefer to adhere following the criticalities of the visible mesh agents in their neighbourhood. The **criticality of Mesh agents** is composed of the sorted criticalities of the Cell agents that adhere to it.

Mesh agents

The objective of the Mesh agents is to be acquired and then validated in their pass. To do this, they use the Cell agents adhesion requests in their neighbourhood to alter their geometry and placement in the corridor in order to maximize their probability of acquisition and validation. Their behaviour is described in algorithm 2.

Algorithm 2 Mesh agent behavior

```
for each adhesion request of  $c_{ij}$  do
  if criticality of cells that have requested mesh adhesion
  is greater than the criticality of adhering cells then
    inclusion of  $c_{ij}$ 
    adhesion request acceptance
  else
    adhesion request rejection
  end if
  reduction of edges without adhesion
end for
```

An adhesion request processed by a Mesh agent can lead to three types of alteration of its geometry on the cell grid:

- **Movement.** The coordinates (i_0, j_0) of the mesh are modified.
- **Extension.** The f width factor or the g mesh length factor is extended in a given direction.
- **Reduction.** The f width factor or the g mesh length factor is reduced in a given direction.

The inclusion of a cell leads to mesh extension when the mesh has not yet reached its maximum width f_k^{max} or maximum length g_k^{max} , depending on the relative direction of the requesting cell. When the maximum width or length is reached, a movement has to be made. This movement would cause the inclusion in the mesh of a set of cells and the exclusion of cells on the opposite edge to the direction of movement. A comparison between the criticalities of the cells to be included following the potential movement and those of the cells to be excluded is simulated within the Mesh agent.

The movement is performed if the criticality of the cells that will adhere to the mesh following the movement is higher because this alteration increases the criticality of the mesh itself. The free mesh geometry also allows the reduction of mesh edges that do not include adherent cells. The reduction of the edges without adhesion reduces waste caused by the overlap between meshes with the same pass and tends to distribute the meshes according to a regular paving.

Pass agents

The behaviour of the Cell and Mesh agents aims to place the meshes in their local environment to maximise their probability of being acquired and validated. The alterations and movements of the meshes are based on their proximity to cells that emit adhesion requests. These local behaviours are not sufficient to ensure coverage of the most critical cells on the scale of a corridor. Subparts of the corridor can thus trap the meshes in an optimum of local criticality. The creation of meshes by the Pass agents in their corridor corresponds to a jump in the search space to avoid local optima.

The objective of the Pass agents is to maximize the coverage of the most critical cells within their corridor. Their behaviour is linked to the placement of the meshes on the corridor and must allow the most critical cells to be covered dynamically, for example following an update of meteorological data that modifies the criticality of the cells. The behavior of a Pass agent is described in algorithm 3.

Algorithm 3 Pass agent behavior

```
if stabilization of meshes  $M_{P_k}$  then
  for each cell  $c_{ij} \in C_{P_k}$  do
    if  $c_{ij}$  not covered and highly critical compared to the
    covered cells in the corridor then
      creation of a mesh  $m = (i, j, 1, 1, 1)$ 
      if maximum number of meshes threshold exceeded then
        removal of the least critical mesh
      end if
    end if
  end for
end if
```

In order to allow the local placement of the meshes to take place through interactions between Cell and Mesh agents, the behaviour of Pass agents is only carried out after the stabilization of the meshes of the pass. The meshes of a pass are stabilized when all cells covered by meshes are adhering to a mesh of the pass. Following the stabilization of the meshes, the cells belonging to the corridor of the pass are parsed until an uncovered cell with a criticality higher than the reference point in criticality of the first mesh candidate for replacement, i.e. the most critical cell of the least critical mesh, is found. The replacement of a mesh is necessary to ensure that the number of meshes in the pass remains below the maximum threshold defined as the number of meshes sufficient to fully cover the corridor of the pass. The goal of this maximum threshold is to avoid overloading the MPF

with mesh acquisition requests.

4 Results and discussion

This section presents the evaluation and performances of the Glimpse system for the optimization of the LAC problem. The results of the experiments are followed by a discussion and our perspectives for future works.

Experimentation methodology

Mission scenarios. The mission scenarios considered include the inputs necessary for the Glimpse system to optimize the problem, namely the following elements:

- The client request containing:
 - The area of interest to be acquired,
 - The MPFs,
 - The satellites and their characteristics,
 - The satellite passes over the area.
- Weather data for the cells of each pass,
- The size of the grid cells,
- The length of the planning horizon.

Simulation modules. The acquisition process described in section 2 (figure 2) involves the action of elements external to the resolution of the problem, such as the MPFs. The planning of the meshes to be acquired by a MPF, for example, is dependent on the other tasks of the satellite that are unknown to the programming system of the LAC. For the purpose of experimentation, we simulated the behaviour of the MPFs using decision modules relating to the acquisition and validation phases.

The acquisition phase includes a selection of meshes that have been the subject of acquisition requests to include in the satellite acquisition plan. This planning is carried out by an hierarchical greedy algorithm (Agn et al. 2007; Hall and Magazine 1994) which represents the operational state of the art in the field of short-term satellite acquisition planning. The behaviour of this algorithm consists in sorting the meshes of the pass in order of importance, i.e. here by criticality, and selecting meshes until a fixed limit of satellite acquisition capacity is reached. For the validation phase, meshes are selected in quantity relative to the average validation probability of the meshes of the passes and in decreasing order of criticality.

Elements of comparison. As described in section 2, the state of the art for optimizing the LAC problem is to subdivide the problem and divide it into separate planning centres. To evaluate our approach we chose to compare the static meshing technique used by MPFs to the dynamic meshing of the Glimpse system. In addition, we consider mission scenarios in which the satellites are characterized by the dimension of meshes they can acquire. Scenarios will be described as having **homogeneous** satellites they acquire meshes of the same size, and **heterogeneous** otherwise.

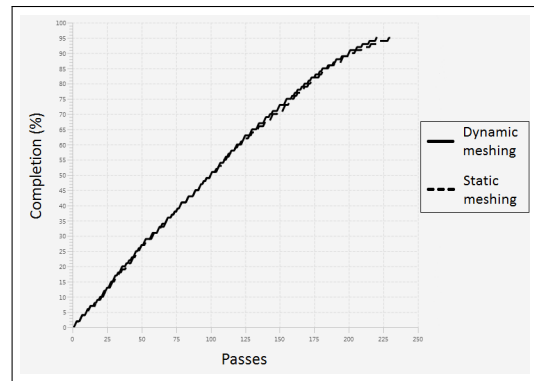


Figure 4: Evolution of the completion rate by meshing type for a scenario with homogeneous satellites

Experiments

For each experiment, the observed metrics are, by order of importance:

1. The completion time at 95% of the LAC, in number of passes.
2. The waste, surplus acquisition of surfaces during the large coverage, in percentage.

The progression of the resolution over time is represented by the successive validation of the passes. The evolution of the metrics and their final measurements are presented.

The first experiment proposes a mission scenario with the following characteristics:

- Australia as area of interest,
- Grid cells of size 30km,
- 4 **homogeneous** satellites with meshes 60km wide and 120km long,
- A planning horizon of 10 passes.

The evolution of the progress and waste during the resolution of the LAC are presented respectively in figures 4 and 5. The table in figure 6 contains the final measurements for these metrics at 95% completion.

The second experiment proposes to reuse this scenario by modifying the dimensions of the meshes acquired by satellites in order to make them **heterogeneous**. The 4 heterogeneous satellites in this new scenario can respectively acquire meshes of the following dimensions: 60km/90km, 60km/120km, 90km/150km and 90km/180km. The progression curve, the waste curve and their final measurements are respectively presented in figures 7, 8 and 9.

Discussion

The results obtained show the advantages of the dynamic meshing computed by Glimpse compared to a traditional static meshing. For scenarios with homogeneous satellites as presented in the first experiment, we observe a reduction in the number of passes required to reach 95% completion

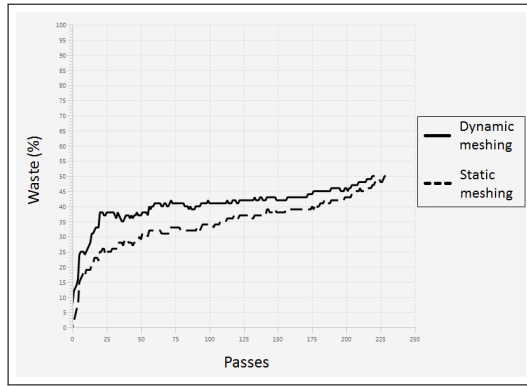


Figure 5: Evolution of waste by mesh type for a scenario with homogeneous satellites

	Passes	Waste(%)
Dynamic meshing	222	50
Static meshing	227	50

Figure 6: Number of planned passes and waste at 95% completion for a scenario with homogeneous satellites

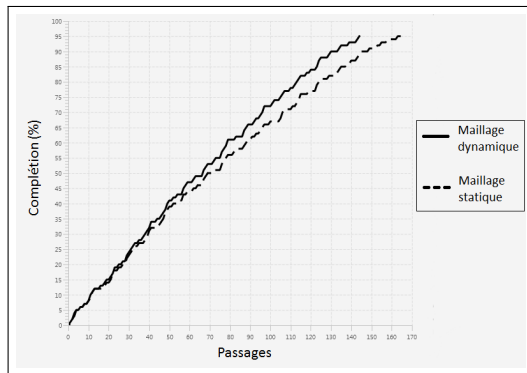


Figure 7: Evolution of the completion rate by meshing type for a scenario with heterogeneous satellites

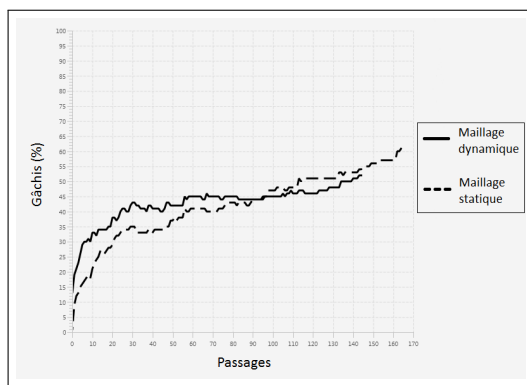


Figure 8: Evolution of the waste by meshing type for a scenario with heterogeneous satellites

	Passes	Waste(%)
Dynamic meshing	144	52
Static meshing	163	61

Figure 9: Number of planned passes and waste at 95% completion for a scenario with heterogeneous satellites

using Glimpse. This reduction can be explained by the precision of the dynamic meshing which allows Glimpse to place meshes that did not belong to the pre-constructed static meshing grid, particularly on the edges of corridors where mesh placement is more constrained. The overlap between meshes allowed in dynamic meshing creates waste early in the mission. This phenomena is compensated by better mesh placement and validation rate, which results in similar final waste measurements for both meshing techniques.

The distribution of meshes for homogeneous satellites is the best case scenario for static meshing thanks to the superposition of all meshes between passes. Within the operational context of LAC missions, the MPFs operate different satellites. The distribution of meshes for heterogeneous satellites is therefore closer to the conditions of operational resolution. The results obtained in the second experiment, which involves heterogeneous satellites, show an increase in the waste obtained when using static meshing. The grids pre-constructed by the static meshing have overlapping meshes due to the variable mesh dimensions between satellites. Cells validated in previous passes are therefore acquired again because the static meshes cannot be resized. In addition, the acquisition of validated cells reduces the number of non-validated cells that can be acquired in a pass because of the limit in satellite acquisition capacity, which delays the overall completion time. In the case of the dynamic meshing carried out by the Glimpse system, the waste remains constant compared to the first experiment because the meshes can alter their geometry to avoid overlapping with already validated cells. By avoiding these cells, the meshes maximize the number of cells that can be acquired within the limit in satellite acquisition capacity. The completion time and waste obtained by dynamic meshing with Glimpse are equivalent or better than those obtained by static meshing for homogeneous satellites scenarios, and better for heterogeneous satellites scenarios. These results show the adequacy of the proposed dynamic approach to optimizing the LAC problem.

Perspectives

The current optimization of the problem by Glimpse is highly dependent on the criticality value of the Cell agents. This criticality is calculated using criteria identified by experts in the field. Our next studies will replace the leximin sorting present in the criticality calculation of Glimpse agents by more efficient evaluation methods. We want to improve criticality estimation by integrating reinforcement learning techniques into agents. A more

accurate assessment of the probability of cell acquisition will help distribute the meshes between passes to maximize the probability of successful acquisitions over the planning horizon. The threshold of the number of meshes sent to each MPF can also be optimized. By observing the number of meshes integrated into the satellite plan for each acquisition request, a number of meshes better adapted to the constraints of the MPF will be estimated for the following passes.

In addition, the properties of the dynamic meshing allow the LAC problem to be addressed with a technique called partial validation. This type of validation concerns cells instead of meshes. In partial validation, the validation of a cell is based on the clearness of the sub-area corresponding to the cell on the image obtained. As a result, the partially blurred images obtained are no longer entirely rejected but partially validated as well as the cells relating to the clear subparts. Isolated cells may exist following their individual rejection, but dynamic meshing allows the creation of meshes of variable sizes adapted to the acquisition of a small number of cells using minimal satellite resources. Partial validation allows for more targeted image processing that reduces the need to reacquire sub-areas of interest and improves completion time.

Finally, the problem will be extended to improve its realism and add operational constraints. Differences between forecast and actual weather conditions and satellite plan occupancy profiles will be modelled. The rotation manoeuvres performed by the satellite to direct it towards the meshes to be acquired will be estimated and taken into account in the placement of the meshes in dynamic meshing. Scaling up will also be evaluated. The Glimpse system can currently handle a problem that requires local interactions between thousands of agents such as those presented in the 4 section. Scenarios at the scale of larger countries and smaller cell sizes will be constructed. The decrease in cell size will allow the dynamic meshes to be placed more precisely on highly critical cells in the corridors.

5 Conclusion

This article presents our method for the optimization of the large area coverage problem based on dynamic meshing by adaptive multi-agent system. The method of resolution in the industry relies on human expertise to sub-divide the problem as to avoid its combinatorial aspect. We implemented an adaptive multi-agent system called Glimpse using the ADELFE and AMAS4Opt methods. In order to evaluate Glimpse we compared dynamic meshing with the static meshing technique commonly used in the operational context. The results we obtained on simulated large area coverage scenarios in the general case of heterogeneous satellites show that dynamic meshing allows us to achieve 95% completion of the mission over a shorter period while reducing the waste of satellite resources.

Our future work will add unknown data to the problem such as the probability of realization of predicted weather

values for specific areas of interest and the probability of a positive response to a mesh acquisition request by a mission planning facility. These data are difficult to model and we plan to integrate reinforcement learning techniques into the Glimpse system to estimate them. The purpose of this integration will be to better calculate the importance of cell acquisition during specific passes in an uncertain context.

References

- Agn, J.-C.; Bataille, N.; Blumstein, D.; Bensana, E.; and Verfaillie, G. 2007. Exact and approximate methods for the daily management of an earth observation satellite. *RAIRO-Oper. Res.* 41(4):381–398.
- Bensana, E.; Lemaitre, M.; and Verfaillie, G. 1999. Earth observation satellite management. *Constraints* 4(3):293–299.
- Bonnet, J. 2017. *Multi-Criteria and Multi-Objective Dynamic Planning by Self-Adaptive Multi-Agent System, Application to Earth Observation Satellite Constellations*. Ph.D. Dissertation, Université Paul Sabatier-Toulouse III.
- Fei, W., and Zhi, L. 2011. Research on the optimization method of dynamic partitioning area target for earth observation satellites. *Procedia Engineering* 15:3159–3163.
- Frank, J.; Jonsson, A.; Morris, R.; Smith, D.-E.; and Norvig, P. 2001. Planning and scheduling for fleets of earth observing satellites.
- Gleizes, M.-P. 2011. Self-adaptive complex systems. In *European Workshop on Multi-Agent Systems*, 114–128. Springer.
- Globus, A.; Crawford, J.; Lohn, J.; and Pryor, A. 2004. A comparison of techniques for scheduling earth observing satellites. In *AAAI*, 836–843.
- Hall, N. G., and Magazine, M. J. 1994. Maximizing the value of a space mission. *European journal of operational research* 78(2):224–241.
- Holvoet, N.; Vongsantivanich, W.; Chaimatanan, S.; and Delahaye, D. 2018. Mission planning for a non-homogeneous earth observation satellite constellation for disaster response. In *SpaceOps 2018*.
- Lemaître, M.; Verfaillie, G.; Jouhaud, F.; Lachiver, J.-M.; and Bataille, N. 2002. Selecting and scheduling observations of agile satellites. *Aerospace Science and Technology* 6(5):367–381.
- Niu, X.; Tang, H.; and Wu, L. 2018. Multi-satellite observation scheduling for large area disaster emergency response. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences* 42(3).
- Verstaevel, N. 2016. *Self-organization of robotic devices through demonstrations*. Ph.D. Dissertation, Université de Toulouse, Université Toulouse III-Paul Sabatier.
- Xu, Y.; Liu, X.; He, R.; Chen, Y.; and Chen, Y. 2018. Multi-objective satellite scheduling approach for very large areal observation. In *IOP Conference Series: Materials Science and Engineering*, volume 435, 012037. IOP Publishing.