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Remote Sensing Satellites Planning System

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Abstract— A Remote Sensing Satellites Planning system (RSSP) for satellite constellations is responsible for managing these satellites by assigning the imaging tasks to each satellite in the constellation such that the loads are balanced and the resources are well used. The proposed system can be used with heterogeneous constellations that consist of satellites whose different specifications, different orbits' types and/or different payload types. This problem is a combinatorial optimization NP-hard problem modeled in this paper as a Constraint Satisfaction Problem using the Constraint Programming Technique. The output plan is obtained using one of three objective functions (gain maximization, area maximization, and image quality maximization) using four search algorithms (simulated annealing, hill climbing, tabu search and late acceptance) and different planning horizons (one track, one day and one month).

Keywords— Agile satellites, remote sensing, planning, constraint satisfaction problem, heterogeneous constellation.

I. INTRODUCTION

The output plans from a RSSP system should satisfy the customers by performing the maximum number of their requests in addition to optimize the usage of the constellation's resources taking into consideration all the system and operational constraints to assure obtaining a feasible output plan.

The paper introduces the related work in Section(II). Then the proposed RSSP system formulation in Section(III) is discussed. The system architecture is introduced in Section(IV). Section(V) clarify the system performance and introduces some comparisons with other systems from CPU time point of view. The final Conclusion and recommendations for future work are introduced in Section(VI).

II. RELATED WORK

The constraint programming technique were used by two references, in 2015 Erik Demeulemeester et al [1] used non-agile earth observing satellites in their system. The used planning horizons were multiple tracks and one day. They used branch and price search algorithm and column generation heuristics. While in 2002 M., Verfaillie, G., Jouhaud, F., Lachiver, J., & Bataille and N. Lemaitre [2] used single agile satellite with the Greedy search algorithm and the simulated annealing. They describe their system for the illuminated half of the track.

III. PROBLEM FORMULATION

The problem model can be partitioned into the following four parts:

1) Input Data

For the set of input requests R, there exists r ∈ R, whose gain G_r and surface area A_r. Let I be the set of images obtained from R by the geometric cutting up process. For each image i ∈ I:

E_i : earliest shooting time, L_i : latest shooting time, D_i : duration of shooting, A_i : surface area. For each possible pair of images (i, j), M_{ij} is defined as the transition time between shooting the two images consecutively. B is defined as the set of pairs of images (i, j) such that i and j are images for the same strip with opposite pitch angles and S be the set of pairs of stereoscopic images.

2) Decision Variables

a) X_i … is One if the image i ∈ I is selected, and Zero otherwise.
b) t_i … the shooting start time of image i if selected.

3) Constraints

The following constraints have been implemented in the proposed system:

a) Observation Time Window Constraint: $\forall \mathbf{i} \in \mathbf{I}: (\mathbf{X_i} = \mathbf{1}) \Rightarrow (\mathbf{E_i} \leq \mathbf{t_i} \leq \mathbf{L_i})$ (1)

b) Transition Time Constraint: $\forall (\mathbf{i},\mathbf{j}) \in \mathbf{I}: (\mathbf{X_i},\mathbf{X_j} = \mathbf{1}) \Rightarrow (\mathbf{t_i} + \mathbf{D_i} + \mathbf{M_{ij}} \leq \mathbf{t_j})$ (2)

c) Request End Time Constraint: $\forall \mathbf{i} \in \mathbf{I}, \mathbf{I} \subset \mathbf{r}, \mathbf{r} \in \mathbf{R}: (\mathbf{X_i} = \mathbf{1}) \Rightarrow (\mathbf{t_i} < \mathbf{end_r})$ (3)

d) Mono Image is Shot Once Constraint: $\forall (\mathbf{i},\mathbf{j}) \in \mathbf{B}: \mathbf{X_i} + \mathbf{X_j} \leq \mathbf{1}$ (4)

e) Stereo Image Constraint: $\forall (\mathbf{i},\mathbf{j}) \in \mathbf{S}: \mathbf{X_i} = \mathbf{X_j}$ (5)

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f) The Stereo Pair Pitch Angles Constraint: $\forall\, (\mathbf{i},\mathbf{j}) \in \mathbf{S} : \mathbf{Pitch_i} = -\mathbf{Pitch_j}$ (6)

g) The Stereo Pair Roll Angles Constraint: $\forall\, (\mathbf{i},\mathbf{j}) \in \mathbf{S} : \mathbf{Roll_i} = \mathbf{Roll_j}$ (7)

h) The Stereo Pair Satellite Constraint: $\forall\, (\mathbf{i},\mathbf{j}) \in \mathbf{S} : \mathbf{Satellite_i} = \mathbf{Satellite_j}$ (8)

i) Onboard Memory Constraint: $\forall$ planning horizon, $\forall\, \mathbf{i} \in \mathbf{I} : \sum_i \mathbf{X_i} \le \mathbf{N_{max}}$ (9)
Where N_{max} is the maximum allowable number of selected images for this planning horizon.

j) Payload Duty Cycle Constraint: $\forall\, (\mathbf{i},\mathbf{j}) \in \mathbf{I} : \mathbf{t_j} - (\mathbf{t_i} + \mathbf{D_i} + \mathbf{M_{ij}}) \ge \mathbf{t_P}$ (10)
Where t_P is the payload duty cycle or the so called technological break.

4) Objective Functions

The three objective functions implemented in the proposed system are defined as follows:

a) Gain Maximization function: $\forall\, i \in I : f(x) = \max(\sum_i G_i * X_i)$ (11)

b) Area Maximization function: $\forall\, i \in I : f(x) = \max(\sum_i A_i * X_i)$ (12)
Where $A_i = D_i * W_s$ (13) and W_s…is satellite's swath.

c) Image Quality Maximization function: $\forall\, i \in I : f(x) = \max\,(\sum_i (R_{worst} - R_i) * X_i)$ (14)
R_i… is the resolution of image $i \in I$ and R_{worst}… resolution at maximum roll and pitch angles.

IV. PROPOSED SYSTEM ARCHITECTURE

The operation through the proposed system architecture in Fig. 1 is explained as follows:

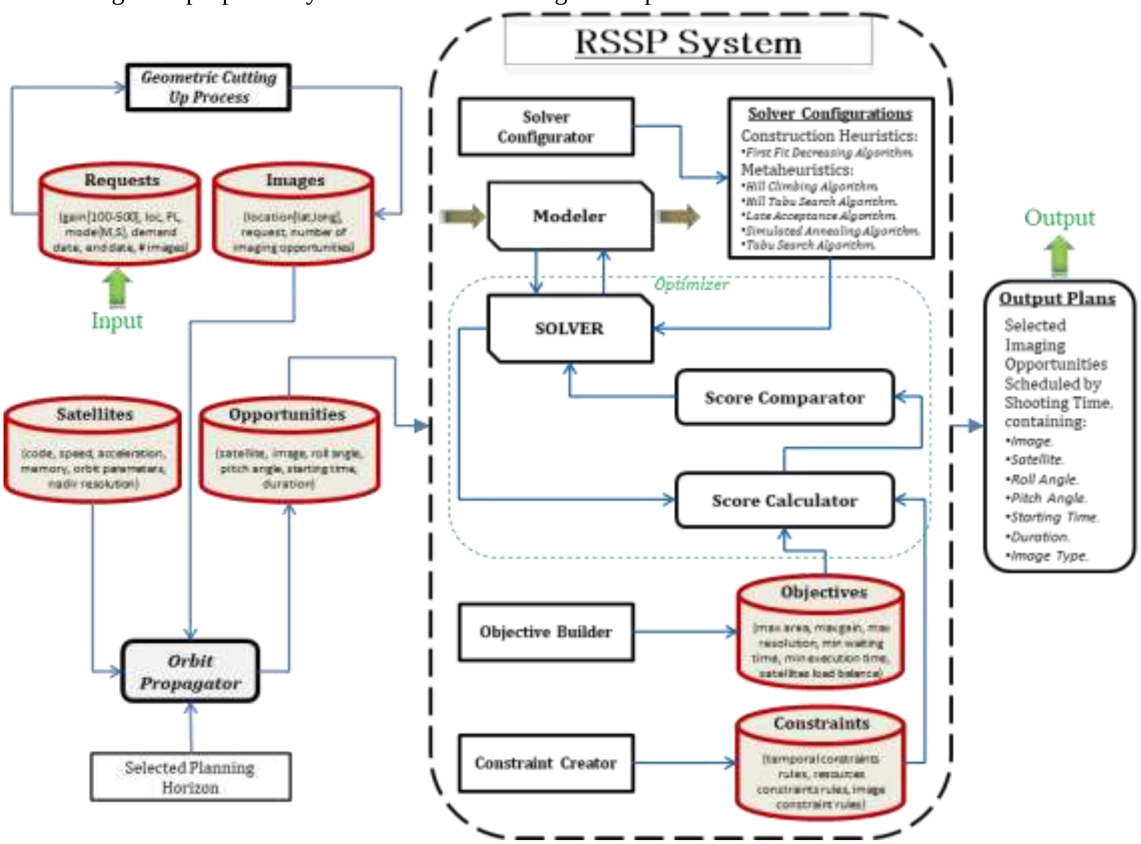

Fig.1: Proposed System Architecture

Requests database will contain the input requests with their data. The Geometric cutting up process will produce images in Images database that is fed to the Orbit Propagator with the satellites in Satellites database and the selected planning horizon. The Orbit Propagator outputs the imaging opportunities for each image. The Opportunities database will contain all the imaging opportunities for all the images with all the satellites. The operation in the RSSP system begins with modeling the input via the Modeler to be sent to the SOLVER that is configured using a Solver Configurator. To build the

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Constraints database and the Objectives database, the Constraint Creator and the Objective Builder is used respectively. The Score Comparator takes the created constraints and the built objectives as inputs. The SOLVER searches for solutions in the search space and selects feasible solutions during the algorithm-running lifetime. Each time, the selected solution is score calculated via the Score Calculator. This score is compared with the previous scores via the Score Comparator until reaching the optimum score.

V. TESTS AND RESULTS ANALYSIS

To determine the system's performance, it is tested for three case studies with different problem sizes and measure the CPU time (efficiency) and the Normalized Score (quality). The first case study consists of (1) satellite, (1) track planning horizon and (25) targets while the second is (2) satellites, (1) day and (120) targets and the third one uses (3) satellites, (1) month planning horizon and (2500) targets. Fig. 2 illustrates the system's behavior in the (3) objectives using the (4) search algorithms and measures the (2) metrics.

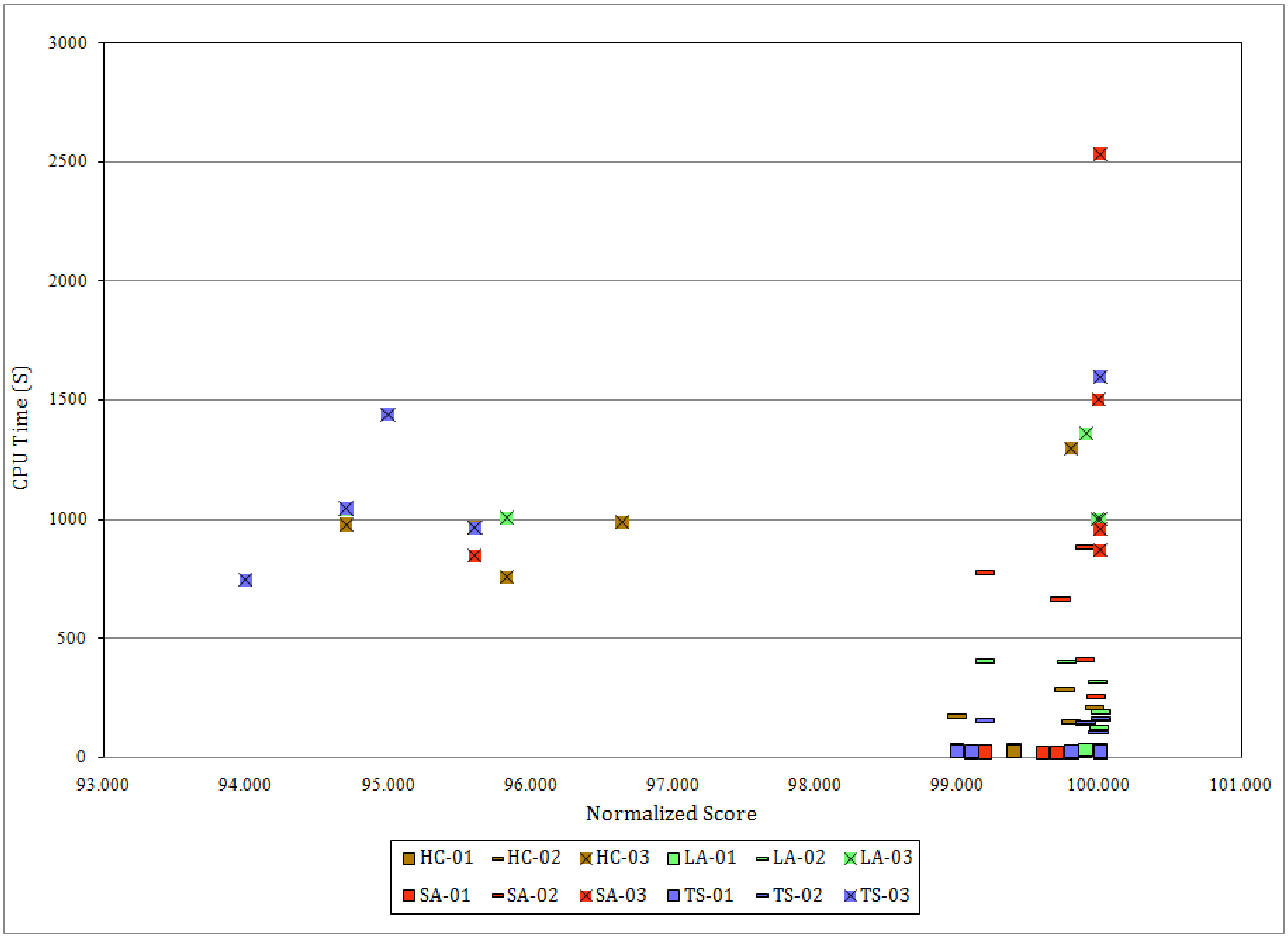

Fig.2: System Performance in the Three Objectives

It is clear from the figure that almost all the results lie in the left bottom part of the graph which means that these results has high normalized score and low CPU time. This emphasizes that the system is qualified and efficient. We compared our results, from the CPU time point of view, with those published for similar systems according to the problem size.

The comparison introduced in TABLE I clarifies that the proposed system performs very well compared with the listed references.

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TABLE I
COMPARISON WITH OTHER SYSTEMS

Serial #	Sat's no.	The Reference Results			Proposed System Results	
		Ref.	# of Targets/ Imaging Opportunity	CPU Time (seconds)	# of Targets/ Imaging Opportunity	CPU Time (seconds)
1	1	[3]	30	153.2	25	32 (Max)
2	2, 3	[1]	100 (3 Satellites)	486.12	120 (2 Satellites)	304 (Average)
3	3	[4]	250 Imaging Opportunities	2995.5	86195 Imaging Opportunities (2500 Targets)	2532 (Max)

VI. CONCLUSION AND FUTURE WORK RECOMMENDATIONS

The proposed system is implemented and tested to be used with different target types, different planning horizons and different constellation types. The system is designed with many constraints and four search algorithms. Three different objectives for creating the output plan are used. The tests results are relatively good compared with some other similar systems.

It is recommended for the future work to include more objectives and use other search algorithms.

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