Satellite Image Mosaic Combination Problem

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1 Introduction

The space industry is continuously growing, and it is no longer an exclusive market for governmental and military applications. According to the most recent European Union Agency for the Space Programme (EUSPA) report [1], the Global Navigation Satellite System and Earth Observation (EO) market had revenues of around €200 billion in 2022 and is expected to reach €500 billion by 2031. As access to space has become cheaper, more private companies have entered the space business, increasing its popularity. There even exist companies that use space data without owning any space assets, thanks to services such as satellite-as-a-service [2].

Due to the advances in satellite design and high-resolution remote sensors, the EO sector has been experiencing significant development in the last few years. In 2021, the number of satellite launches dedicated to EO was bigger than the sum of launches between 2012 and 2016 [3]. In 2020 more than 100 terabytes of satellite imagery were generated per day [4].

There are several applications based on EO that analyse a vast region or area of interest (AOI) that can be covered only by combining several adjacent images into a bigger one, usually called a mosaic. Mosaics are crucial for applications like crop classification [5], environmental monitoring [6], urban development analysis [7], among others.

Mosaicking satellite images present several challenges such as geometric correction of the images [8, 9], colour harmonization [10], and image stitching [11]. Also, another important problem is the presence of clouds in satellite images. Some research has been done to minimize the cloud covering percentage in the final mosaic [12, 13]. As the number of available images is significantly increasing, a new challenge arises: choose the optimal combination of images to be utilised to produce the mosaic by optimizing one or more criteria. This is equivalent to finding the best cover of the AOI. In theory for n images there could exist 2^n possible covers. To the best of our knowledge, there is no research about the former challenge.

This research focuses on the combinatorial optimization problem of choosing the set of satellite images to form a mosaic that covers the AOI. The objective is to recommend a set of images that meet the user criteria, optimizing some parameters, for example, the total cost of the images or the image resolution. The main contribution of this abstract is to present and model the previously described problem, which we named as Satellite Image Mosaic Combination Problem (SIMCOP).

2 Problem definition

Consider an EO application that is interested in a specific AOI, big enough to be covered with only one satellite image. Then, for the study of that AOI, a mosaic is needed. Depending on the application, the images that form the mosaic must meet certain requirements, such as minimum resolution, cloud coverage percentage, incident angle, and the range of dates. The set of possible images that could be used to build the mosaics is formed by all the images that intersect the AOI and meet the requirements. Each image has an associated weight that represents its cost or one of the requirements (resolution, cloud coverage, etc), and the objective is to minimize the total weight of the mosaic.

Formally, the problem is defined as follows. Given a polygon A, an array of requirements MR where each value MR_j represents the maximum allowable value of requirement j, and a set I of n convex quadrilaterals (corresponding to all the satellite images in the range of date), where each quadrilateral i has a weight w_i, and an array of requirement values, with r_{ij} corresponding to the value of requirement j for quadrilateral i, we have the following objective:

$$min \sum_{i \in B} w_i \tag{1}$$

subject to the constraints

$$A \subseteq \bigcup_{i \in B} i \tag{2}$$

$$\forall i \in B, r_{ij} \leq MR_j \tag{3}$$

where B is a cover of the AOI.

This problem differs from the classical geometric weighted set cover [14], where given a finite set of points P and a set I of weighted objects in the plane, the objective is to find a cover of P with minimum weight. The set to be covered here is not a set of points but a region in the plane with infinite cardinality; this makes it harder to verify that a certain configuration is a cover as we cannot check if all the points in the set are covered. Moreover, in this problem, each object (image) is characterized by an array of requirements.

3 Experiments

This section introduces some preliminary results on a particular use case of SIMCOP using a first problem specific heuristic to obtain an approximate solution. This use case considers a situation in which a user has access to images that meet their requirements (resolution, date range, etc.) and intercept certain AOI. The objective is to select a set of images that covers the AOI while minimizing the images' total cost. For simplicity, we assume that the cost of an image is proportional to its area, which is true in many real satellite marketplaces, considering images with the same resolution. We can then minimize the total cost of the set of images by minimizing the total area. In our scenario, the weight of each image is equal to its area.

The proposed heuristic always selects the image that has the highest ratio *image area inside the AOI/image area* and stops when a cover is achieved, and consequently, a mosaic can be built with the selected images.

We have compared the performance of our heuristic against a random image selection strategy run 100 times using the same AOI and satellite images. The AOI is an area of approximately 1640 km^2, comprehending Mexico City. The image's dates are between 01-01-2020 to 01-10-2022 and were taken by the Pleiades satellite constellation [15]. In this initial experiment, the total number of images was limited to 30 per AOI. We obtained the images' geolocation data (corners coordinates) through the satellite marketplace Up42 [16].

The evaluation parameter is the ratio between the total area of the images forming the cover and the area of the AOI, with 1 the lower bound for this optimization problem. Initial results demonstrated the better performance of the proposed heuristic with a fitness score of 4.56 compared to all random selection runs which obtained between 5.06 and 9.16 with an average of 6.78 and a standard deviation of 0.84. Besides being a simple greedy heuristic, our strategy was 32.74% better than the average random selection. The next steps of this work will consider proving the NP hardness of SIMCOP, proposing novel optimisation approaches, and tackling additional and larger real-world instances.

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