Remote Sensing based on CubeSats: is there any added value?

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Abstract

The CubeSats have become very popular, mostly as a low cost means to train students and young researchers in the space engineering and science. However, since the cost of accessing the space is still quite relevant the educational motivation could be sustained somewhat for people and institutions to invest in a satellite mission. From this need to understand if satellite based remote sensing could take advantage of the potential availability of teams of micro satellites.

According to Planet Labs, a private start-up company of San Francisco owner of the Flock-1 constellation, CubeSats could enhance the Earth Observation capability of the present available systems. This advancement is mainly based on the possibility to construct constellation of hundreds of satellites which will allow a daily coverage of the Earth at very high spatial resolution.

However, there are some constraints that remote sensing pose to fully exploit the data acquired, namely: constant solar illumination conditions, accurate repeat track of the ground coverage, multispectral observation.

Now, at the present time, no one of these conditions is respected by the constellation presently settled-up by Planet Labs. However, some of these constraints could be made more flexible to be obtainable by using CubeSat based images.

The present paper will explore some applications which could really benefit of remote sensing systems based on CubeSat. In other words, CubeSats are cheap and light, so their launching is cheap as well. This enables the structuring to constellations, which provide better coverage and revisit time than any other solution. However, larger satellite still present advantages for which CubeSat should be seen as a system which could provide the opportunity to build constellation of satellites at low cost devoted to special applications.

Introduction

Question: "which elements must be considered in order to provide an assessment of the usefulness/efficiency of the remote sensing systems from the point of view of security issues?"

When we talk about security, according to the indications of EU (European Union) we refer to both civil and military security, response to terrorism, natural disasters (especially those which cause rapidly such as earthquakes and tornadoes), industrial accidents and shared threats. Once the context has been defined we can consider the existing systems and identify the gaps between perceived requirements and current capability. The identified needs and requirements form a comprehensive list of the gaps and requirements in this field and with respect to these needs we can assign a value to each present and future space-based remote sensing system.

Figure 1. Sensor orbit altitude with respect to the security-related operations

As it could be easily understood, the main limit of EO (Earth Observation) space systems is represented by the reduced capability to respond to phenomena occurring simultaneously high spatial and temporal resolutions.

Data and Methods

1. Rating Satellite Systems Against Emergency/Security Related Applications

Some of the possible security fields for which remotely sensed information can be used are: Terrorism, Piracy and Piracy, WMD of Mass Destruction, Regional Conflict/Natural Disaster, Local Instability, State Failure, Organized Crime, Potential Threats/Disaster, Fraudulent, Critical, Strategic, Engagement, etc.

A way to gather information using satellite based data consists in defining a series of keys elements characterizing the searched "objects." Jamieson (2006) the "Keys" then obtained be used to identify, in satellite imagery, several facilities in a number of states, once the validity of the "Keys" has been established, object-based image analysis methods can be used to broadly classify a large-area image, in this way an analyst could narrow down areas of interest.

Then other applications of the optical remote sensing systems pose new issue to them. In general, in the space segment three distinct parts can be distinguished, Platform (Position & Attitude), Sensor (Spectral band, resolution, etc.), Configuration (Repetition rate, etc.) which, all of them in making a satellite sensor (system) suitable to provide the required information. In the following we are at introducing a new way to define the suitability of a given satellite (considering both sensor and orbital characteristics) to provide the required information, which can be helpful analysts to better orientate themselves among all the available space systems.

In order to define a score for comparing sensors performances and assess their suitability to provide information with respect to a given observational problem we have to consider that different applications pose different require (see Table 1).

Table 1. Spatial (m) and temporal (hours) resolution necessary for different levels of analysis on targets/objects of interest (Grappin 1994)

<table>
<thead>
<tr>
<th>Level of Analysis</th>
<th>Spatial Resolution (m)</th>
<th>Temporal Resolution (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target identification</td>
<td>≤50</td>
<td>≥120</td>
</tr>
<tr>
<td>Event identification</td>
<td>≤20</td>
<td>≥60</td>
</tr>
<tr>
<td>Event occurrence</td>
<td>≤10</td>
<td>≥30</td>
</tr>
<tr>
<td>Event occurrence</td>
<td>≤5</td>
<td>≥15</td>
</tr>
</tbody>
</table>

In this way, as expected, according to the index values, only the SPOT sensor is able to satisfy the constraints characterizing this example. Fig. 1 shows the results obtained by applying the above described technique, without weights, to a collection of 85 space-based remote sensing systems.

The procedure herein introduced aims at providing anyone, even not aware about satellite remote sensing spatial-temporal resolution constraints, with a means for judging the suitability of a space-based system to gather the required information.

As far as the authors know, no efforts in such a direction are available in literature.

2. Assessing EO CubeSat performances

CubeSat could provide, in our opinion, a useful means to respond to the need of a high temporal frequency of the observation (of the order of hours) posed by applications concerning the use of satellite images for the management of disasters (Table 1). It is well known that a constellation of (Oliveris et al. Contromonos et al., etc.) satellites located on the same orbital plane could reduce the revisit frequency down to about 12 hours (at equatorial latitude), assuming a sensor which could operate both in day or night-time. In order to reduce the revisit frequency to fraction of days (3 - 4 hours) a multiple orbital plane constellation should be constructed. Adding one or more orbital planes to the constellation it become possible to improve the revisit frequency down to few hours as well as the spatial coverage. In the case of an UHC (Uniform Homogeneous Constellation) the relationship between satellites and orbital plane of the constellation to maximize the number of revisit in the repetition period of the single satellite could be written. If we consider a constellation of P planes, with N satellites equally displaced on each plane and δt and δh are the relative right ascension and the mean anomaly, respectively, between two satellites on the orbital planes, all the longitudes at the orbit node φ of the jth satellite on the plane p are given by

\[ \delta \phi_{j,p} = \delta \phi_{0,j} + \frac{2 \pi}{P} (j - 1) \]

The uniform distribution of the grid tracks capable to minimize the minimum tracks distance is obtained in the satellites and orbital planes are planned to be according to equation

\[ \delta t_{min} = \frac{1}{P} \left( \frac{1}{N} \sum_{i=1}^{N} \delta \phi_{i} \right) \]

If the objective is the increase of the revisit frequency (with observations performed at different local time), the satellites and orbital planes should be planned according to the following equation:

\[ \delta t_{min} = \frac{1}{P} \left( \frac{1}{N} \sum_{i=1}^{N} \delta \phi_{i} \right) \]

In this case the number of observations obtained in the repetition period of a single satellite is equal to \( P \) in N days corresponding to a revisit time, in modals days, \( r = \ln N \ln P \).

In this paper we have at understanding if remote sensing could take advantage of the potential availability of teams of micro satellites (e.g. Flock-1 constellation).

The CubeSat systems are becoming a very popular way to reduce the costs for accessing the space and train students and young researchers in the space engineering and science. However, CubeSats constellations could be the only way to overcome the revisit frequency limits of the very high spatial resolution satellite systems which reduce their operational use for the management of disasters.

Therefore, this paper is aimed at understanding if remote sensing could take advantage of the potential availability of teams of micro satellites (e.g. Flock-1 constellation). In order to reach this objective, in the paper a simple way to judge a single satellite performances with respect to a given observational problem have been identified.

Then, the equation needed to distribute the cube-micro satellite on a homogeneous, uniform constellation have been written. Finally, the main characteristics of the optical systems of EO very high resolution sensors have been recalled. Thanksing into account the above, we come with the main conclusion that in order to be effective in increasing the remote observation opportunity of a given area after a disastrous event particular case should be devote to spatial resolution of the instrument as well as to the revisit frequency, because a revisit frequency of the order of hours (3 - 5) requires that the satellite are located on different orbital planes. This will introduce differences in the illumination condition which have to be taken into account during a change detection analysis (detector monitoring) in order to avoid false results.

However, larger satellite still present advantages for which CubeSat should be seen as a system which could provide the opportunity to build constellation of satellite at low cost devoted to special applications.

Table 2. All the possible enhancement obtained from a UHC on a single or multiple planes

Table 3. Main characteristics of the most common very high spatial resolution EO satellites

Conclusions

The CubeSats systems are becoming a very popular way to reduce the costs for accessing the space and train students and young researchers in the space engineering and science. However, CubeSats constellations could be the only way to overcome the revisit frequency limits of the very high spatial resolution satellite systems which reduce their operational use for the management of disasters.

These terms would be considered all together and opportunely weighted, in accordance with the particular application, in order to define an index able to characterize the remote sensing system performances allowing the selection of the most suitable one with respect to the given application.

Let us multiply A x B x C in the case of SPOT/RW, LANDSAT/TM, IRS-ID and MSG/SEVIRI

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Spatial Resolution (m)</th>
<th>Temporal Resolution (hours)</th>
</tr>
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<tbody>
<tr>
<td>SPOT</td>
<td>A = 30.000</td>
<td>B = 0.3046</td>
</tr>
<tr>
<td>IRS-ID</td>
<td>A = 40.000</td>
<td>B = 0.2</td>
</tr>
<tr>
<td>LANDSAT</td>
<td>A = 44.44</td>
<td>B = 0.0625</td>
</tr>
<tr>
<td>MSG</td>
<td>A = 0.0629</td>
<td>B = 0.1</td>
</tr>
<tr>
<td>MSG</td>
<td>A = 0.0629</td>
<td>B = 0.1</td>
</tr>
</tbody>
</table>

In this way, we can define an index describing how much is demanding the particular application on related issues to be monitored or detected properly. As a consequence, in order to characterize the suitability of a given sensor we need to have a certain planning for each single plane, a single sensor, and a single interest.

In accordance with these remarks and taking into account the introduced weights, for the above indicated monitoring of critical structures cases, it results

\[ \text{Index} = 0.6 \times \text{A} + 0.4 \times \text{B} \times \text{C} \]

where A defines a function that provide 1 if the internal product is 0 otherwise the same result of the internal product.

Figure 2. Sensor spatial resolution with respect to the security-related operations

The numbers on the x-axis refer to the slide remote sensing sensors considered as an example for the analysis. Some of them are reported on the graph.