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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 sometime not enough for planning and execute a CubeSat mission. From this the need to understand if satellite based remote sensing could take advantage of the potential availability of tens of micro satellites.

According to Planet Labs, a private start-up company of San Francisco owner of the Floke-1 constellation, CubeSats could enhance the Earth Observation capability of the present available systems. This enhancement is mainly based on the possibility to construct constellation of hundred of satellites which will allow a daily coverage of the Earth at very high spatial resolution (2 - 3 m). However, there are some constraints that remote sensing pose to fully exploit the data acquired, namely: constant solar illumination conditions, accurate repetition of the ground track, global coverage, multi-spectral 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 those 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 satellite at low cost devoted to special applications.

Introduction

Question: ***"which elements must be considered in order to provide an assessment of the usefulness/quality/effectiveness 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 occur rapidly such as earthquakes and tsunamis), 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 possible needs 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.

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 needing simultaneously high spatial and temporal resolutions.

The main part of Envisat is around 10 m long, compared to Cubesats, which are around 30 cm long.

Data & 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, Proliferation of WMD (Weapon of Mass Destruction), Regional Conflict/Natural Disaster, Local Instability, State Failure, Organized Crime, Potential Conflict/Natural Disaster, Frozen Conflict, Active engagement, etc.

A way to gather information using satellite based data consists in defining a series of keys elements characterizing the searched **"Objects"** [Jasani, 2006]: the **"Key"** thus obtained can be used to identify, in satellite imageries, 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.

These new applications of the space-based remote sensing systems pose new issues 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 concur in making a satellite sensor (system) suitable to provide the required information. In the following we aim at introducing a new way to define the suitability of a given satellite system (considering both sensor and orbital characteristics) to provide the required information, which can help unskilled users 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 requirements (see Table 1, (Gupta, 1994)). For instance:

treaty monitoring => temporal resolution not critical but high spatial resolution is required, border monitoring => high temporal resolution and medium/high spatial resolution are required.

As a consequence, to judge a satellite system the following parameters must be considered:

- A = pixel/km^2,
- B = observations/day,
- C = frame size/ event extent,
- D = spectral bands,
- E = interval of the electromagnetic spectrum sampled/(VIS+NIR+SWIR+TIR+MW).

Emergence	Phase	Spatial Resolution	Time Resolution
Floods	Monitoring	30 m – 100 m	12 hours
	Management	10 m – 100 m	3 – 12 hours
Landslide	Monitoring	30 m – 250 m	1 day
	Management	10 m – 100 m	3 – 12 hours
Earthquake	Management	30 m – 100 m	3 – 12 hours
Volcano	Monitoring	30 m	1 day
	Management	10 m – 30 m	6 hours – 1 day
Fires	Monitoring	100 m	1 – 3 hours
	Management	30 m	0.25 hours
Sea pollution	Monitoring	1 km	1 day
	Management	100 m	6 – 12 hours
Border monitoring	Monitoring	1 m – 10 m	3 hours
Humanitarian emergency	Management	1 m – 10 m	1 – 3 hours

Table 1. Image spatial (m) and temporal (hours) resolution necessary for different levels of analysis on targets/events of interest (Grupta 1994)

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·B·C in the case of SPOT/HRV, LANDSAT/ETM, IRS-1D and MSG/SEVIRI.

SPOT	A = 160000	B = 0.03846	C = 0.1052	Ind = A·B·C = 647
IRS-1D	A = 40000	B = 0.2	C = 0.1	Ind = A·B·C = 800
LANDSAT	A = 4444	B = 0.0625	C = 1	Ind = A·B·C = 278
MSG	A = 0.0629	B = 96	C = 1	Ind = A·B·C = 6.04

In the same way we can define an index describing how much demanding is the particular phenomenon or security related issues to be monitored or detected properly. As a consequence, in order to characterize the suitability of a given sensor with respect to a certain phenomenon, by using a single index, a weight has to be introduced.

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

Ar=160000 Br=0.033 Cr=0.1 ➔ Indr = f(Ar·1) ·f(Br·0) ·f(Cr·0) =160000

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

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 selection of 85 space-based remote sensors..

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.

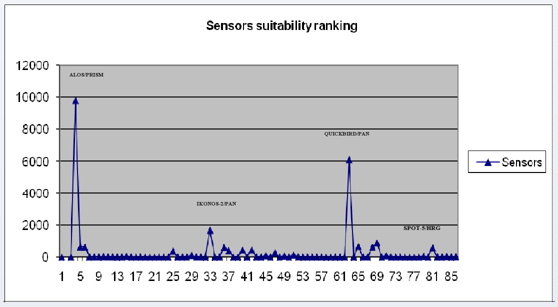

Figure 1. Sensors suitability score with respect to the security related applications. The numbers on the x-axis refer to the 85 remote sensing sensors considered as an example for the analysis. Some of them are reported on the graph.

2. Assessing EO CubeSat performances

If we look at the characteristics of the instruments on board of some of the most common very high spatial resolution EO satellites we can observe as these, in order to obtain the desired spatial resolution, need a focal length presently unreachable with CubeSat systems. The requirements, in terms of: focal length, optics diameter, detector dimension can be easily computed by using the well-known relationship:

$$GSR \cong 2.44 \cdot \frac{\lambda \cdot h}{D} \quad \text{and} \quad GSR = \frac{d \cdot h}{f}$$

3. Enhancing the revisit time

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 (Ulivieri et al., Castronuovo 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 plane 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 Homogenous 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 $\Delta\Omega$ and ΔM_p are the relative right ascension and the mean anomaly, respectively, between two satellites on the orbital planes, after d days, the longitude at the orbit node of the i-th satellite on the plane p, in the range $\pm S_t/2$, with respect to the longitude of the satellite 1 of the plane 1 at the day 0, is given by:

$$\lambda_{p,l,d} = \lambda_{1,1,0} + S_t mod\left[d\frac{k}{m} + \frac{l-1}{N} + \left(\frac{\Delta M_p}{360} + \frac{\Delta\Omega}{S_t}\right)\right]$$

The uniform distribution of the ground tracks capable to reduce the minimum tracks distance is obtained is the satellites and orbital planes are phased according to equation:

$$\frac{1}{P} = frac\left[lcm\left(\frac{\Delta M_p}{360} + \frac{\Delta\Omega}{S_t}\right)\right]$$

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

$$0 = frac\left[lcm\left(\frac{\Delta M_p}{360} + \frac{\Delta\Omega}{S_t}\right)\right]$$

In this case the number of observations obtainable in the repetitivity period of a single satellite m, is equal to $P \cdot m \cdot N/lcm$ corresponding to a revisit time, in nodal days, $r = lcm/P \cdot N$.

	r (nodal days)	S_m [km]	m/r
P (highest revisit frequency)	$lcm/P \cdot N$	S_t/lcm	$P \cdot m \cdot N/lcm$
P (minimum ground track spacing)	lcm/N	$S_t/P \cdot lcm$	$m \cdot N/lcm$

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

Satellite	Focal length [m]	Aperture Diameter [cm]	Spatial resolution [m]	Temporal resolution [days]
World-View	13.3	110	0.46	4
Deimos	5.5	42	1	2
Ikonos	10	70	1	3
Quickbird	8.8	60	0.6	6
Pleiades	12.9	65	0.7	4

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

Conclusions

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 aims at understanding if remote sensing could take advantage of the potential availability of tens 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.

Thanking into account the above, we come out 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 care 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 plane. This will introduce differences in the illumination condition of the observed area which should be taken into account during a change detection analysis (disaster 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.