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"Remote Sensing with Small Satellite Constellations & Formations"

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Remote Sensing with Small Satellite Constellations and Formations

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1. Introduction: Definitions

Small Satellite:

satellite having a mass between 100 and 1000 kg

- Carlo Gavazzi Space SpA is prime contractor under ASI of MITA
- Advanced Technology Italian Minisatellite
- MITA is a multi-purpose platform with a baseline mass of 150 kg

1. Introduction: Definitions

Constellation of Satellites:

space system having the space segment made up by two or more identical satellites carrying the same payload and acting in the same way on the same subject

Typically, satellites of a constellations allows to perform certain coverage and re-visit features that would not be possible by a single satellite system

Formation of Satellites:

space system having the space segment made up by two or more different satellites carrying different payloads and acting in different way on the same subject

Typically, satellites of a formation are "complementary" to each other for their specific tasks they have on the mission subject

2. Rationale on Constellations and Formations Need (1/2)

Certain missions are better fulfilled by more satellites when:

- re-visit and coverage requirements are strict (constellations)
- coverage requirements are unfeasible for a single satellite (constellations)
- different instruments of same mission would need too large distances for a single satellite (formations)
- new satellites can add value to already existing missions (formations)
- new satellite bringing in-orbit spare (formations)

2. Rationale on Constellations and Formations Need (2/2)

Why using small satellites for constellations and formations:

- thanks to new miniaturised technologies, they can have components that allow to reach same performances of larger satellites
- thanks to new production technologies such components are aligned with low-cost philosophy
- a small satellite allows a straightforward implementation of the "faster, better and cheaper" paradigm

3. Constellation Classes (1/2)

- **Global Coverage Systems**
  e.g.: Intelsat, Imarsat, Skynet, Iridium, Globalstar, Teledesic, Hellipso, Orbcomm

- **Continuos Coverage Systems (of a given geographic area)**
  e.g.: NATO

- **Regional Monitoring/Patrol Systems (strict re-visit time of a given geographic area)**
  e.g.: COSMO Skymed

3. Constellation Classes (2/2)

- **Regional Observation System (strict coverage and re-visit time of a given geographic area)**
  e.g.: studies for regional scientific programmes

- **Multi-Probe Systems (tridimensional measurement)**
  e.g.: Cluster, LISA

4. Formation Classes (1/2)

- **Interferometric System (tandem system allowing interferometric measurements)**
  e.g.: ERS1 & ERS2, and some remote sensing mission under study

- **Synthetic Aperture Systems (large aperture achieved by splitting instruments on more satellites)**
  e.g.: SM/OS

- **Split Remote Sensing Systems (instrument of same mission on more satellites)**
  e.g.: ERM split scenario

4. Formation Classes (2/2)

- **Payload Replacement Systems (a small satellite brings in orbit a spare of a failed payload of a larger existing satellite)**
  e.g.: ESA studies on in-orbit spare payloads for large platforms

- **Combination Mission Systems (a new payload is flown to combine with existing mission for providing new observation product)**
  e.g.: ACE

- **Atmospheric Tridimensional Observation Systems (atmosphere is observed both from above and limb-to-limb**
  e.g.: STRATUS 3D, ACE

5. Observation with Small Satellite Constellations (1/7)

In the field of remote sensing, constellations are mainly needed to fulfil coverage and re-visit requirements that cannot be fulfilled by a single satellite.

For a single satellite:

- given a swat width and
- a certain area to cover with more passages,
- re-visit time and re-visit schedule result fixed

That can be not acceptable if scientific re-visit time needs to be shorter than the resulting one.

5. Observation with Small Satellite Constellations (2/7)

The realities to face are the following:

- **remote sensing is best performed by LEO, with orbital periods ranging from 85 to 110 minutes**
- **revolution of Earth is about 24 hours (from 15 to13 orbit/day circa)**
- **nodal drift of orbit (ranging from + 6 to - 6 deg/day circa, in most cases Sun-synchronous) is determined by orbit inclination**

- **swat width determines the pattern of subsequent ground tracks**
- **swat width is linked to resolution on target by available technology, typically the better the resolution, the narrower the swat width**

5. Observation with Small Satellite Constellations (3/7)

Case study

Remote sensing of an area which is as follows:

- **it extends for 10° of Longitude**
- **from +22° up to +32° in Latitude**

And following coverage and re-visit requirements:

- **area coverage within 20 days**
- **starting a new observation cycle in 20 days**

5. Observation with Small Satellite Constellations (4/7)

Instrumet having following features:

- ground resolution of 10 m (from 570 km altitude)
- swat width of 60 km (from 570 km altitude)

Orbit class:

- for illumination requirements it must be Sun-synchronous
- to repass on same area it must also be Earth-synchronous

5. Observation with Small Satellite Constellations (5/7)

Coverage of area

- subsequent ground tracks should be spaced by a distance at maximum equal to instrument swat, 60 km
- at given latitudes, 1° of longitude is circa 100 km
- so, 60 km correspond to circa 0.6° of latitude

5. Observation with Small Satellite Constellations (6/7)

Results:

- a simple Sun-synchr. - minimum drift orbit having ground traks spaced of 0.6° deg each would take:

- circa 17 days to cover the whole area
- but circa 40 days to repeat an observation cycle
- resulting in a blind period of 23 days

5. Observation with Small Satellite Constellations (7/7)

The requirements cannot be fulfilled by a single satellite

in a first approximation, a small constellation made up by:

- **3 satellites**
- **their crossing nodes having an argument of 120° each other**
- **their orbit argument being the same**

can fulfil the mission requirements

6. Observation with Small Satellite Formations (1/5)

In the field of remote sensing, satellite formations are used to:

- **observe the same target by different positions and/or angles**
- **observe the same target with different payloads on different satellites because of certain given convenience**

6. Observation with Small Satellite Formations (2/5)

Concurrent observation of same target by different payload on different satellites can be of two different types:

- **Passively Concurrent Observation**
- **Actively Concurrent Observation**

6. Observation with Small Satellite Formations (3/5)

Passively Concurrent Observation (PCO):

because of:

- **target extension**
- **measurement relaxed accuracy**

the observation of same target by payload on different satellites:

- **can occur from each satellite in an autonomous way**
- **there is no need of actively controlling the combined pointing of formation satellites**

6. Observation with Small Satellite Formations (4/5)

Actively Concurrent Observation (ACO):

because of:

- target limited extension
- high measurement accuracy

the observation of same target by payload on different satellites:

- must occur from each satellite in a co-ordinated way
- there is the need of actively controlling the combined pointing of the whole formation of satellites

6. Observation with Small Satellite Formations (5/5)

Usually, both kind of concurrent observations need orbit control:

either because satellite have different overall layout, so that theirs orbits are afflicted in a different way by space environment (usually the case of PCO)

or because, even though they have same layout, their orbit must be carefully controlled (usually the case of ACO)

7) Impact on Space System Design (1/13)

Example of impact on a small satellite based on MITA platform, according to constellation / formation mission requirements by means of a practical example

7) Impact on Space System Design (2/13)

IMPACT: PAYLOAD RESOLUTION

Example of mission requirements:

Subject	Requirement
Observation Subject	Mediterranean coastal waters
Payload Resolution	15 m
Orbit Altitude	LEO (around 560)
Orbit Inclination	sun-synchronous
Coverage	10° of longitude in 90 days
Re-Pass	90 days
Mission Duration	4 years
Launch Date	year 2003

7) Impact on Space System Design (4/13)

IMPACT: PAYLOAD RESOLUTION (continued)

- The higher the resolution, the higher should the **satellite stability** be.
- The higher the resolution, the higher should the **attitude determination precision** be

From 675 km, with existing requirements we have:

jitter stability (short term)	1 μrad over 1 ms (about 0.05 deg/s)
medium term stability	0.005 deg over 3 s (about 0.002 deg/s)
star sensor attitude determination precision	0.005 deg in nominal mode
Need for gyros	yes TBC

7) Impact on Space System Design (5/13)

IMPACT: PAYLOAD RESOLUTION (continued)

From 675 km, with a relaxed requirement of 100 m we would have:

jitter stability (short term)	1 μrad over 1 ms (about 0.05 deg/s)
medium term stability	0.09 deg over 3 s (about 0.03 deg/s)
star sensor attitude determination precision	0.05 deg in nominal mode
Need for gyros	no TBC

7) Impact on Space System Design (6/13)

IMPACT: ORBIT ALTITUDE

- The higher the altitude, the higher the spacecraft stability for same ground resolution
- The higher the altitude, the lower the residual atmospheric drag perturbing effects on the orbit
- The higher the altitude, the higher the deorbiting ΔV requirements

Orbit altitude is also selected according to coverage and re-pass requirements.

7) Impact on Space System Design (7/13)

IMPACT: ORBIT INCLINATION

- Orbit inclination can just be ADJUSTED by on board propulsion
- MAJOR CHANGES (around 20 deg) in orbit inclination CANNOT BE reasonably ACHIEVED
- For sun-synchronous orbits, inclination is function of orbit altitude. Since orbit altitude is function of coverage and re-pass requirements, these latter ones univocally determine sun-synchronous orbit inclination (unless tolerance margins are considered)

7) Impact on Space System Design (8/13)

IMPACT: COVERAGE

Coverage impacts orbit design from following inputs:

- target area (position and extension, in terms of latitude and longitude)
- swat front (in terms of the coverage that can be carried by a single pass)

Coverage impacts also re-pass:

- the more densely packed is coverage, the longer is the re-pass period
- the wider (mainly in terms of longitude) is the target area, the longer is the re-pass period

7) Impact on Space System Design (9/13)

IMPACT: RE-PASS

Re-Pass is traded-off among following requirements/parameters:

- frequency of observation (mission requirement)
- maximum available payload swat (payload requirement/parameter), via coverage (mission requirement)
- target area extension and position (mission requirement), via coverage (mission requirement)

7) Impact on Space System Design (10/13)

IMPACT: ORBITAL LAYOUT

If there are:

more orbital plane on which to place satellites
and such orbital planes have a non negligible nodal angular distance (>1° to 10°)

then:

more launches are needed

7) Impact on Space System Design (11/13)

IMPACT: ORBITAL LAYOUT (continued)

Deployment of the satellites in their own station on the same orbit plane can occour:

- by means of a flexible launch vehicle
- by means of autonomous on board propulsion system

if on board propulsion is already present for orbit maintenance,
then the second option is to be preferred

7) Impact on Space System Design (12/13)

IMPACT: CONCURRENT OBSERVATION

With PCO, there is no need of inter-satellite communication to manage the pointing
With PCO, orbit control has generally relaxed requirements

With ACO, there could be the need of inter-satellite communication to manage the pointing
With ACO, orbit control has generally stringent requirements

7) Impact on Space System Design (13/13)

IMPACT: MISSION DURATION

Mission duration has an impact on ground segment costs and on board electronic costs.

- The more the mission lasts, the more man-hours are needed on the ground segment
- The more the mission lasts, the higher the total radiation dose that the spacecraft electronics should be able to bear without any major failure

8. Advantages / Disadvantages of Constellations and Formations (1/2)

Advantages:

- constellations and formations can fulfil requirements that a single satellite cannot afford
- they allow a further extension of redundancy concept thanks to in-orbit spare and readjustments
- their space segment cost can be lower than the same cost of a single satellite (if feasible)

8. Advantages / Disadvantages of Constellations and Formations (2/2)

Disadvantages:

- constellations and formations are more tricky to design and operate
- their launch can easily be more expensive than for a single satellite (if feasible)
- their ground segment cost is usually higher than the same cost for a single satellite (if feasible)

9 Envisaged Applications of Constellations and Formations

I can list few...

But, for the future

it is YOUR task to find new applications allowing you to accomplish new scientific missions !!!

10 Conclusions

Constellations and formations allows to widen the range of feasible missions, especially for scientific purposes

Small satellites, as building block of constellations and formations, allow cheaper solutions

Constellations and formations also have disadvantages, so very careful tradeoffs are necessary in order to generate a robust and cost-effective space system