

SMALL SATELLITES – A TOOL FOR EARTH OBSERVATION?

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ABSTRACT:

Small satellites with a mass between 10 to 500 kg have become a competitor to large satellites with a mass of over 1000 kg. This development has come about through the technological advances in micro-electronics. Small satellites are obviously less costly for launch. However, limitations for uses of small satellites exist through special requirements imposed in particular for remote sensing missions such as orbital and attitude control, sensor design and data readout. About 500 small satellites have been launched so far, but only a small percentage of these for earth observation. Nevertheless sensing with 8 m ground pixels has been achieved. The International Academy of Aeronautics and its biannual symposia on small satellites in Berlin promote the future uses of small satellites as a cost-saving measure.

1. INTRODUCTION – WHAT ARE SMALL SATELLITES?

The first satellite, Sputnik-1, launched on October 4, 1957 was a small satellite. The success of launching a manmade object into earth orbit was a phenomenal achievement, even though its user performance of sending a few radio signals was minimal.

It took an equivalent large effort to develop a usable platform for lunar, planetary and earth observation with components assuring orbital performance, attitude control, sensor operation, telecommunication of signals and ground reception and ground processing of these.

While the U.S. lunar missions succeeded in building the Lunar Orbiter missions 1 to 5 to achieve this goal in preparation for the lunar landing in the years 1966 and 1967, it took until 1972 to launch a general earth observing platform in the Landsat program of the U.S.

Earth observation is a relatively minor application branch of satellite technology, and the use of satellites is primarily important for telecommunications, and to a lesser extent to scientific missions.

Large satellites have always been built by governments and large consortia, which had sufficient funding to assure reliable long range operation without severe mass and power restrictions. E.g. the communication satellite Intelsat 6 was built for 10 to 14 year operation with a mass of 6 x 4 x 12 meters dimension and 4600 kg producing 2600 W power by solar panels. A medium size small satellite of today has a mass of 50 kg, accommodating a space of 0.6 x 0.4 x 0.3 m producing only 30 W of power by batteries.

Nevertheless it can perform well for specific purposes as small satellites integrated by Surrey University in the UK have proven (UoSAT 2 launched 1984). Surrey's marketing claims that 95 % of performance of large satellites can be reached with small satellites at 5 % of the cost or 70 % performance at 1 % of the

cost (Wei Sun, IAA Symposium on Small Satellites for Earth Observation, Berlin, April 2-6, 2001).

The classification of satellites according to mass is usually as follows:

- large satellites: mass > 1000 kg
- medium satellites: mass 500 to 1000 kg
- mini satellites: mass 100 to 500 kg
- micro satellites: mass 10 to 100 kg
- nano satellites: mass 1 to 10 kg
- pico satellites: mas 0.1 – 1 kg
- fenito satellites: mass < 100 g.

It is obvious that the performance of the satellites will depend on the necessary auxiliary devices, which lead to additional mass requirements. The usability of small satellites is therefore generally restricted to micro, mini, and medium satellites.

2. SATELLITE USES

The website <http://centaur.sstl.co.uk> lists the uses of small satellite customers in the 1980's and 1990's as

commercial	37.1 %
military	35.1 %
government	17.3 %
University	5,4 %
amateur	5.1 %.

The application of these satellites in that period is:

communications	69.2 %
science	14.4 %
technology demonstration	11.0 %
military	2.3 %
education	1.7 %
earth observation	1.4 %.

3. REQUIRED COMPONENTS FOR OPERATION OF A SMALL SATELLITE FOR EARTH OBSERVATION

3.1 Launch

For satellite launches several competitive possibilities exist. They can be launched by a separate mission or in piggyback. Recently retrievable launch vehicles, such as the German Phoenix are under development. Traditionally, launchers have been used in the Russian Federation, in India, from ESA, and in the United States. A launch cost estimate is about 10 000 \$ per 1 kg of mass. A retrievable launcher would cut this cost to about half.

3.2 Choice of Orbit

The choice of the orbit is crucial for the performance of an earth observation satellite.

Geostationary orbits at 36 000 km are preferred for communication satellites. Earth observation satellites prefer sunsynchronous polar orbits at orbital heights between 400 and 1000 km. If the observations are aimed at specific areas of the globe, then lower inclinations combined with elliptical orbits (150 to 500 km) can be chosen. Such orbits do not provide ideal illumination conditions, however. The choice of the orbit determines repeatability of sensing.

3.3 Attitude and Orbit Controls

The orbit can best be monitored by an on-board GPS satellite receiver. The positions of the satellite are downlinked and monitored in the ground facilities. Orbit corrections are possible by hydrocne propulsion systems with the need to carry this fuel on board.

The attitude of the satellite is warranted first by 3 axes gyros. For higher precisions a sun sensor is required. After monitoring the attitude on the ground the propulsion systems can carry out the attitude corrections for pointing of sensors. For smaller corrections the sensor may be reoriented.

3.4 Sensors

For earth observations sensors are required, which sense reflections of the earth within the range of the electromagnetic spectrum. Optical and thermal (passive) sensors require sensitive elements, which need to be read out and transmitted to earth. Onboard processing by microprocessors is possible.

Active sensors (such as radar) require antennas for transmission of electromagnetic pulses and for reception of the backscattered reflections from the ground. Obviously passive sensors require less mass.

The sensor limitations for use in small satellites have been discussed in detail in the paper "High resolution mapping with small satellites" by Rainer Sandau, presented to the ISPRS 2004 Congress (1). They refer mainly to optical and thermal sensors. They are:

- Spatial resolution by the optical system, which is governed by the diffraction limitation;
- sensitivity of the detector elements requiring a minimum exposure time of about 1 msec;
- image motion, due to the forward motion of the satellite movement in the order of 7.4 km/sec or 7.4 m/msec.

If higher resolutions than 7 m are desired, then image motion compensation must be applied. This is possible by time delay

integration sensors (TDI), in which instead of a single array of detector elements across the platform motion a number of arrays in direction of the platform motion are utilized, over which the detector signals are averaged before readout. High resolution sensors with ground resolutions better than 7 m therefore not only need smaller resolution elements, e.g. by staggered arrays, but also means of image motion compensation, either by TDI arrays or by rotation of the satellite sensor during the exposure time.

3.5 Power

For the requirements of on-board sensing, processing and the reception and transmission of sensing and auxiliary data, as well as for the control options of the satellite power systems must be provided. The principal source are batteries (NiCd, NiH or Li-Ion). For longer duration missions they need to be charged by solar energy, which has to be collected by solar panels.

3.6 Data Readout

The charges received at the sensor elements of the arrays need to be transmitted at appropriate readout rates to the ground stations during a ground station contact time of about 10 minutes. At a rate of 100 Mb/s up to 60 GB of data can be transmitted. If higher data rates are required data compression must be utilized for transmission.

3.7 Ground Station Processing

The received signals at a ground antenna must be stored and processed at the ground station facility.

4. CONCLUSIONS

Simple imaging of the ground requires a linear array sensor perpendicular to satellite motion. Images of such a sensor system require geocoding. This is possible using the transmitted GPS and attitude orbital data within accuracy limitations. Ground control points can increase the accuracy of geocoding. However, the images cannot be orthorectified onto a cartographic projection unless a digital elevation model of the terrain is known from other sources, and used in the ground processing chain.

To be independent of the knowledge of the digital elevation model stereo sensing can be utilized, using at least two sensor systems operating with a forward and a backward inclination along the orbital path against the nadir. Rainer Sandau describes the possible stereo sensing configurations in his paper, which have been utilized in satellite systems (1).

As the swath widths for small satellite sensors are usually small due to the use of narrow angle optical systems optimal base/height ratios of 1:1 permitting to acquire digital elevation models with sufficient accuracy are difficult to achieve.

5. LAUNCHED SMALL SATELLITES

The first micro satellites launched during the period 1957 to 1969 were:

(2) IAA, Study Group on Cost Effective Earth Observation Missions, IAA Position Paper on Cost Effective Earth Observation Missions, 2004.

Sputnik 1	1957	USSR	83 kg	for gravity field measurement
Explorer 1	1958	USA	13 kg	radiation measurements

The first amateur satellite launched in piggy back with a military satellite was

Oscar 1	1961	USA	4.5 kg	with radio
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The first University of Surrey micro satellite

UoSAT	1981	UK	52 kg	experimental satellite
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Micro satellites were used extensively in the USSR for the Kosmos satellite series in the 1980's (61 kg), and by the US Military in the 1990's.

In the time period 1980-1999 altogether 238 mini satellites and 249 micro satellites have been launched from countries all over the globe including India, Germany, Japan, Korea, Saudi Arabia, China, Algeria, and Malaysia.

Of special interest are those small satellites which were used for remote sensing, a selection of these is listed here:

Satellite	Year	Sensor	Ground pixel
UoSAT	1981	CCD array	2 km
KitSat 1	1992	CCD array	400 m pan
2	1993	CCD array	200 m RGB
Techsat 1B	1998	linear CCD	12 m MS
Thai-Phutt	1998	CCD array	80 m MS
UoSAT	1999	CCD array	8 m pan
Tubsat (DLR)	1999		6 m
Kitsat 3	1999		15 m
Tsinghua 1	2000		39 m MS
Bird	2001		thermal
Proba	2001		8 m pan

6. THE FUTURE

The International Academy of Astronautics has conducted four symposia on small satellites organized by the DLR Berlin-Adlershof in Berlin (1997, 1999, 2001, 2003). The international community of small satellite users of up to 300 participants gathered for a week in Berlin to discuss progress, and to encourage the use of small satellites.

At the last symposium in 2003 an initiative was launched to compile a 100 page report propagating the benefits of small satellite uses, which will be submitted to the Space Agencies and to users of satellites, confirming that with the current state of miniaturization of electronics a new cost-saving era of satellites has come about (2).

7. REFERENCES

(1) Sandau, R., High Resolution Mapping With Small Satellites, Presented Paper, ISPRS 2004, Commission IV.