Latest Developments in Small Satellite Design

SSTL
February 2010
Small Satellite Constellations

Using multiple satellites in a constellation allows much more frequent access to locations around the globe.

With 5 satellites we can offer an imaging opportunity, anywhere on the globe, at least once per day.
DMC – 2nd generation launched

29 July 2009 — Successful launch of UK-DMC2 and Deimos-1
EO surveillance missions

Very timely, wide-area surveillance from lower resolution imagers, cueing……

… close-up look from hi-resolution satellites
Low-light Imaging

The agility of small satellites allows them to collect more light from a scene and hence produce a higher quality image.

Images can be collected at different local times of day.

Ability to image can be maintained if sun-synchronous condition degrades.

Crucially, the ability to launch into lower inclination orbits and cope with variable lighting conditions.
Constellation-level procurement - RapidEye

- Commercial contract for RapidEye AG
- Launched 29th August
- 5 enhanced micro-satellites
- 6.5m metre spatial resolution
- 5-band multispectral sensor
- Daily revisit
- 80 km swath

World’s First Commercial EO Constellation
Increasing capability

Wide Area Capacity + Accuracy
DMC+4 (2005)

Rapid Revisit
5 x RAPIDEYE (2008)

Agility + High Resolution
TOPSAT (2005)

Agility, High Resolution + Wide Area Coverage, Accuracy + Rapid Revisit
SSTL 300 (2010)
Increasing Resolution

- 1990, >1km
- 1992, 200m
- 1998, 100m
- 2000, 30m
- 2003, 12m
- 2005, 4m & 2.5m
- 2009, 1.2-2.5m
- 2010, <1m

Below 1m Ground Sample Distance
SSTL 300 Optical Imager

• 3 Imagers (assuming operation at 500 km altitude)
  - Panchromatic 1.2 m resolution; 15 km swath
  - 4 Band Multi-Spectral 2.4 m resolution; 20 km swath
  - 4 Band Multi-Spectral 15 m resolution; ~200 km swath

• Multiple Operational Modes
  - Spot, Strip, Fast-response, Area, Stereo
  - Possible additional modes include: Low-elevation, Line of communication, Super-resolution, Change Detection, In-theatre Control

• High accuracy pointing (better than 15 m geolocation)

• 2 Day Revisit to Anywhere on Earth (from single satellite)

• Fast slewing in roll and pitch

• 7 Year Life

• 150-400 images per day

• Mass - 300 kg
Novel Collection Modes

High small satellite agility allows a range of responsive modes of operation.

- Highly Agile Single Scene Imaging
- Extended Strip Imaging
- Area Mode Imaging
- In-pass Stereo Mode Imaging
- Super-Resolution Mode Imaging
- Low-Elevation Mode Imaging
- Change Detection Mode Imaging
- In-theatre Control Mode Imaging
Resolution will continue to improve

Ideal for security applications, the agile SSTL 300 S1 Earth imaging system offers 0.75m GSD imagery with high speed downlink and 45deg fast slew off-pointing.

On-chip Time-Delay Integration (TDI) and a novel camera configuration will be used to provide even greater resolution than the baseline SSTL 300

<table>
<thead>
<tr>
<th>Mission and System</th>
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<td>Reference Orbit</td>
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<td>Design Lifetime</td>
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<th>Space segment</th>
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<tr>
<td>Mass</td>
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<td>GSD</td>
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<td>Swath</td>
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<tr>
<td>SNR</td>
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<td>MTF at Nyquist</td>
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<td>Digitisation</td>
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<td>Compression</td>
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<td>Data products</td>
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<tr>
<td>Off-pointing</td>
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<td>Flexibility</td>
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<td>Safety &amp; security</td>
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The next generation of small satellite surveillance will be capable of providing images of 95% of the Earth’s land-area in 2.5 years.

Applications include mapping and web-based GIS.

Huge commercial potential:
Raw imagery costs $0.15/km² (currently sold at $20/km²)

### Mission and System

<table>
<thead>
<tr>
<th>Reference orbit &amp; Launch</th>
<th>400km, SSO, LTAN 10:30am</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>Cloud-free global land coverage within 30 months</td>
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<tr>
<td>Design Lifetime</td>
<td>6 years</td>
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### Space Segment

<table>
<thead>
<tr>
<th>Mass</th>
<th>&lt;500kg</th>
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<tbody>
<tr>
<td>GSD</td>
<td>Pan: 0.6m, R, G, B: 2.4m</td>
</tr>
<tr>
<td>Swath</td>
<td>16km</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>Pan: 450 - 650nm, R: 600 - 670nm, G: 510 - 590nm, B: 440 - 510nm</td>
</tr>
<tr>
<td>SNR</td>
<td>All bands &gt;100:1</td>
</tr>
<tr>
<td>MTF at Nyquist</td>
<td>10%</td>
</tr>
<tr>
<td>Digitisation</td>
<td>10 bits</td>
</tr>
<tr>
<td>Storage</td>
<td>128 Gbytes</td>
</tr>
<tr>
<td>Compression</td>
<td>JPEG-LS configurable</td>
</tr>
<tr>
<td>Downlink rate</td>
<td>300Mbps</td>
</tr>
</tbody>
</table>
And the next generation......Agile ART

- Agility, High Resolution, Wide Area Coverage, Accuracy, Rapid Revisit
  SSTL 300 (2010)

- Very high agility and resolution
  SSTL 300 S1 (2011)

- Very high accuracy mapping
  ART (2011)

- Very high agility and resolution + very high accuracy mapping
  AGILE ART (2012)
Structures

Increasing trend from aluminium honeycomb to carbon fibre composites

Benefits
- Lower mass for equivalent strength

Disbenefits
- Cost
- Reduced shielding

Issues
- Differential thermal expansion
Optical Bench

- Requirement to geo-locate images to better than 15m without ground control points

- All imagers mounted on a thermo-elastically stable optical bench

- Also provides attenuation of microvibration
**Power**

- Move towards Triple Junction GaAs cells
  - Efficiencies of 26-27%

- Trend towards higher voltage devices (e.g. GaN)
  - ~50V rather than 28V

- Improvements in power storage based on Li-ION cells

- Potential for capacitor batteries for some high-power applications such as SAR in the future
AstroSAR-UK

Multi-mode X-band phased-array SAR satellite

- High resolution spotlight mode
  (1m resolution over 5 km region)
- Wide area maritime surveillance modes
  (900 km swath at 20m resolution)
- Multi-polarimetric imagery
- Cost <£50m
- Lifetime - 5 years
Munitions Depot (1m quad polar)
Lower Inclination Orbits

Most imaging systems operate from polar orbits due to lighting constraints.

Small satellites can operate from any orbit and hence provide greatly enhanced revisits to regional users.

Operationally Responsive satellites launched to augment an existing constellation during crisis can use the same design.
Attitude Determination

- Increasing acuity via the use of star cameras
- Reduced size and mass of platform components relative to payload (e.g. sun sensors)
Orbit and Attitude Determination

- Use of GPS for both orbit and attitude control
- Antenna sizes and processor dimensions continue to decrease
- Further enhancements in performance via the use of dual frequency receivers

PCBSat

10x10x2 cm
Using GPS Outside LEO (1)

Å Much historic attention to using GPS at GEO altitude
   • Research interest as technically challenging problem
Å Until now, little pressing need from GEO operators
   • But GEO operators may lose analogue channels and need closer stacking of satellites,
     also GTO transfers, HEO science missions, etc.

Å GPS signal illuminates only a small portion of the orbit.
   • Special tricks to get performance: weak signal, orbit estimator
Using GPS Outside LEO (2)

Å Development of market requires demonstration
  ï But difficult to gain flight experience
Å SSTL flew SGR-GEO on Giove-A
  ï First Galileo satellite launched Dec 2005, altitude 23,260 km
  ï SGR-GEO tracked 5 GPS satellites in short operation
  ï Awaiting further operations at end of Giove-A’s life (2009/10?)
Å GEO operators are conservative
  ï GPS at GEO must be reliable, and needs more proof before adoption
  ï Route in may be via niche missions or small satellites
GNSS For Remote Sensing

Radio Occultation:
- Measure refraction of GPS signals through troposphere (or just ionosphere)
- Can recover temperature, pressure & humidity (alternative to weather balloons)

Technology being demonstrated on Cosmic, Eumetsat, and others
- Service provision now being considered
- What is service worth, technology cost?

GPS reflections off sea surface
- Ocean roughness can be obtained
  - Demonstration on UK-DMC
- Altimetry from space still to be proven
  - ESA’s PARIS programme & others
- New technology developments still emerging
  - Hype peak not yet reached?

Prototype service will establish needs
Attitude Control

- Wheels and gyros now implemented as standard approach to 3-axis attitude control

- Impact of micro-vibration on imaging sensors addressed via damping of wheels

- Magnetic levitation under investigation to permit increased wheel speeds. Potential for greater stability and possibly also energy storage
Propulsion

Increasing interest in:-

- High accuracy micro-propulsion (0.1-100 µN) for formation flying applications
- Electric propulsion technologies, as more power-efficient options become available, (e.g. hollow cathode thrusters)
  - Potentially opens up lower-altitude orbits, (300-500 km altitude), for commercially viable exploitation
  - Lower-power terminals become increasingly feasible, improving LPI/LPE characteristics
Hyperspectral imaging has a number of potentially significant applications including:

- Terrestrial material discrimination
- Wake detection
- Camouflage detection
- Plume characterisation
- Etc.
Basic System Parameters

- Image area: 13 km square
- Spatial sampling interval: 17 m
- Spectral range (nominal): 400nm to 1050nm
- Spectral resolution: 1.25 to 11nm
- Digitisation: 12 bits
- Signal-to-noise ratio: 200 (@ 0.2 albedo, 17m, 10nm)
- Programmable spectral & spatial dimensions
Multiple Angle Imaging

Nominal view angles: +/- 55°, +/- 36°, 0°

Allows sampling of the Bi-directional Reflectance Distribution Function

Permits reliable determination of surface material types
Hyperspectral Imaging

CHRIS INSTRUMENT

Mass: 14kg
Power: 8W
Volume: 790x260x200mm
## CHRIS Imaging Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>No. of bands</th>
<th>GSD (m)</th>
<th>Swath Width</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>34</td>
<td>Full</td>
<td>Aerosols</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>17</td>
<td>Full</td>
<td>Water</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>17</td>
<td>Full</td>
<td>Land</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>17</td>
<td>Full</td>
<td>Chlorophyll</td>
</tr>
<tr>
<td>5</td>
<td>37</td>
<td>17</td>
<td>Half</td>
<td>Land</td>
</tr>
</tbody>
</table>
Communications Platforms

Low Earth Orbit and Geostationary Orbit satellite platforms for communications
Our Largest Small Satellite

Giove A Navigation Satellite
GIOVE-A: The First Galileo Satellite

- Mission Objectives
  - Secure frequency filing
  - Measure MEO environment
  - Demonstrate key payload technologies
  - Provide Signal-in-Space for Experimentation

- Contract signed in July 2003
- Launched: 28 December 2005
- Signals Generated: 12 January 2006
- Availability 99.5%
Latest Contract - Galileo

- Galileo FOC contract for 14 navigation satellite payloads
- Value ~£200M

FOC is 30 satellites 27 plus 3 on-orbit spares
SSTL 900 - Geostationary modular platform

“Beyond LEO” - designed for MEO, GEO, HEO, Interplanetary Orbits

Two variants:
- GMP-D, Direct Injection
- GMP-T, GTO Injection

Key parameters:
- 12+ year design life
- Station keeping through hydrazine or bi-prop propulsion system
- Modular & flexible design
- Payload accommodation (GMP-T)
  - 200kg, 2.5kW (Typical comms)
  - 260kg, 1.0kW (Other apps)

Flight heritage:
- ESA GIOVE-A (2005-)
- Development through ESA ARTES-4
Future Terminals

Will need to rely on leading commercial technologies:

- Small
- Mobile
- Low power
- Omni-directional
- Higher data rates
- GPS/Galileo enabled
- Real time communications
- Stored communications
- Enables IFF
- Enables Blue Force Tracking
- Low cost (through mass production)

Satellite links will support the individual user
Constellation Design

- Constellation design is critical
- LEO comms case study considered here

ORBCOMM

IRIDIUM

GLOBALSTAR
Communications Coverage Requirement

- Where exactly is the requirement?
- Can this be delivered by a satellite constellation?

Iridium Usage Plot
Borealis

The Borealis elliptical orbit constellation is designed to provide coverage of the northern temperate latitudes. This constellation is based on the use of 10 satellites in two elliptic orbital planes. Borealis orbits are inclined at 116.6 degrees. They have apogees of 7,605 kilometers, perigees of 633 kilometers, and a three-hour orbital period. The apogees are near the northern extremity of the orbits.

Concordia

The Concordia constellation provides coverage from 50 degrees south latitude to 50 degrees north latitude, with a focus on tropical and southern areas that the Borealis satellites do not reach. The initial complement of seven Concordia satellites was to be deployed in an circular equatorial orbit at an altitude of 8,050 kilometers with a launch of 4 satellites and a subsequent launch of the remaining three.
Matching Coverage to the Requirement

• The Ellipso coverage is tailored to match the capacity requirements over the globe.

• 17 satellites are required.

• The orbits are "quite hot" from a radiation point of view!
Communications

- Downlink data rates of up to 300 Mbps feasible from steerable X-band satellite antenna

- Use of two antennas operating at different polarisations gives a total rate of 600 Mbps

- 400 images per day can be down-linked to a network of ground sites
Inter-Satellite Link (ISL) Networks

- The power and value of PC computers was massively enhanced when they were networked in the World Wide Web

- Similarly, the true value of satellites, (especially small satellites, the PC's of space), will be realised when they are fully networked via inter-satellite links into a space wide web

- To date, inter-satellite links have principally been utilised a). between some low Earth orbit (LEO) surveillance assets and geostationary (GEO) satellites for rapid data return, and b). for the Iridium LEO satellite communications network.

- In the future, it will be conventional to provide intersatellite links for all satellites
The optical intersatellite link system SILEX has been demonstrated between the Artemis satellite in GEO and the Spot satellite in LEO.

- SSTL developed some of the SILEX hardware

Future RF intersatellite links may be possible using INMARSAT BGAN terminals.

Neither LEO-GEO system currently offers global coverage, but either would offer significantly higher data rates than the existing LEO communications networks.
Communications

- Inter-satellite links for command-file transfer via GEO would allow satellites to be pre-configured for all relevant imaging passes.
- Downlink data rates of up to 600 Mbps feasible from steerable X-band satellite antennas to a network of ground sites.
- In-theatre downlink to deliver data immediately to users.
- Possibility of joystick control mode from theatre.

Access to LEO satellite on every orbit from a single GEO satellite.
On-board Processing

- Significantly enhanced processing capacities potentially offered by the advanced parallel processors now being developed for the games console market.

- Provides the opportunity to implement significant on-board processing with consequent advantages in:
  - Speed of delivery
  - Data rates/downlink bandwidth required
  - Power required

- Significant implications for:
  - High resolution imaging systems
  - Hyperspectral sensors
  - Radar sensors
  - Future communications systems

IBM BladeCenter H Form Factor
- 2 Cell Processors
- 3.2 GHz Cell Processor
- 408 GFlops (SP)/42 GFlops (DP)

Soma QS21 Blade
Mass Memory

Å Development of magnetic storage units

- 60GByte storage per unit (typically flown dual redundant)
  - SEU tolerant
  - Non-volatile storage
- 20-40Mbps access
- Pressurised sealed unit (1.2bar, 0.8bar EOL)
- Two units in flight since 2005 on Beijing-1

Å Non-Volatile storage
Å Storage of experimental data
Tech Demo Sat

• A demonstration mission, allowing the UK Space industry and academia to provide affordable, timely on-orbit flight experience for next-generation technologies

• Baseline Platform - Enhanced micro-satellite
  - Payload Mass: 50kg
  - Power: 50 W
  - Data Rate: 40 Mbit/s
  - Volume: 770 x 500 x 900 mm

• Potential Sources of funding:
  - TSB, SEEDA, BNSC, other 3rd party organisations

• Expected launch date:
  - 2011

• Principal Application:
  - Wide area maritime surveillance
    • SAR
    • AIS
    • SIGINT
    • GPS Reflectometry
Conclusions

• Small satellites have huge potential

• Constellations are the key
Thank You