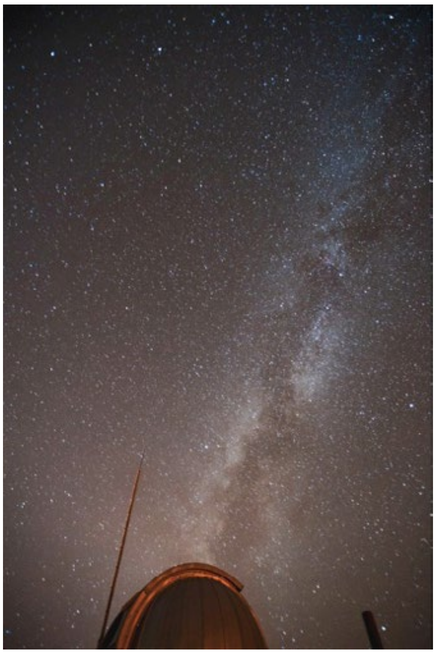
SpaceInsight

An introduction to Space Insight's Starbrook systems for the surveillance of space

Starbrook is a ground-based optical sensor system for the surveillance of space. Designed and implemented in 2006, Starbrook is one of a new class of wide field of view sensors that scan near-Earth space to discover and catalogue objects. The system was conceived by Space Insight as an innovative response to the problem of monitoring the increasing population of man-made objects in the higher Earth orbits.



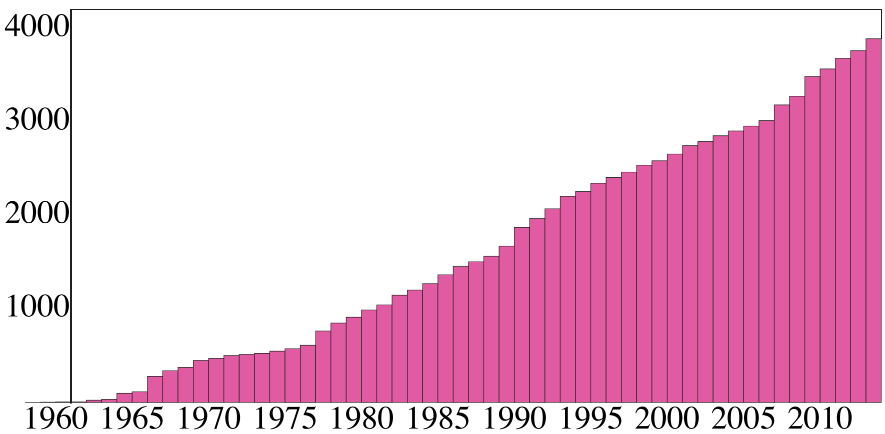
Starbrook dome against Milky Way backdrop

Background: the need to survey near-Earth space

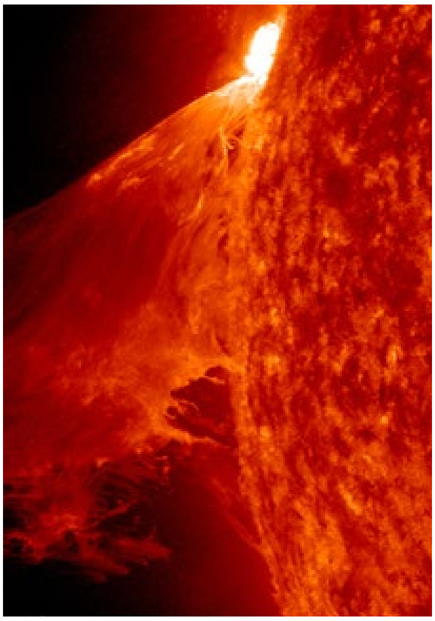
There are many political, scientific, and operational reasons for the surveillance of space.

- The UN Outer Space Treaty vests life-long responsibility and liability for any space object in the state responsible for launching it, so that states have an interest in knowing the whereabouts and condition of objects for which they are liable.
- Debris is a major concern because the high velocity of objects in Earth orbit (typically ~25,000 km per hour) means that even tiny millimetre-sized objects can destroy satellites. The first major debris event was in 1961 when a Thor-Ablestar rocket exploded creating about 300 pieces of debris. International concern has been heightened recently by sudden major increases in the debris population caused by, for example, the Chinese ASAT test (2007), and the Iridium-Cosmos collision (2009).
- Satellite operators rely on information derived from space surveillance to enable them to manoeuvre their satellites out of the path of large debris and also to avoid other operational satellites.

All these reasons have become more urgent in recent years as human dependence on information and services enabled by satellites has continued to grow. The population of objects in space — satellites and debris — has increased year on year. Until 1957 there was nothing man-made in space; by the start of 2011, some 7000 satellites had been launched; market analysts in 2010 estimated that a further 1200 satellites will be launched during the next ten years.



Growth of population of high Earth orbit objects (perigee > 2,000 km)



Solar flares affect objects in Earth orbit

Why monitoring of space needs to be continuous

Any object in Earth orbit is acted upon by many forces. The Earth's gravitational field, the braking influence of the Earth's atmosphere, the variable pressure of solar radiation, and the gravitational pulls from the Sun and Moon are amongst a plethora of forces of various magnitudes which act on satellites. Some of these forces are highly predictable; others are not. For example, totally unpredictable flares from the Sun expand the Earth's atmosphere and dramatically increase aerodynamic braking on objects in orbit. A solar flare in July 2000 was widely reported to have caused the International Space Station to drop by ~30km.

Because of these forces, the parameters which describe an object's orbit change continuously, so it is necessary to observe an object at regular intervals to update these parameters. Observations are acquired by radar and optical sensors and used to monitor the evolution of each space object's orbit.

Early approaches to surveillance of space

In the first years of the space age, satellites were launched only into low Earth orbits and were tracked using radars and optical sensors – including binoculars, kinetheodolites, and photographic cameras.

Radars, developed during World War II for aircraft detection, were used for V2 ballistic missile warning. During and after the Cold War radar missile detection abilities were further developed for ICBM warning. Missile warning radars have to catalogue spacecraft to avoid false alarms so space surveillance by radar is a by-product of a radar's primary missile warning mission.

By the early 1960s, satellites were being launched into higher Earth orbits. For example, in 1963, Syncom 1 was launched into a geostationary orbit. Once satellites were placed into GEO there was a need for a means to monitor the higher Earth orbits.

Radars are less efficient at surveillance of the higher orbits because of the large radar-to-target distances (from 10,000 to 45,000 km, typically). For example, to detect objects at a range of 40,000 km a radar will need 2,000 times the signal strength that is needed to detect objects at a range of 6,000 km. As radars often use 10s or 100s of kilowatts of power, obtaining a 2,000-fold increase is non-trivial and can usually only be achieved with a small field of view.

For this reason, optical telescopes were adopted for the surveillance of the higher Earth orbits. Optical sensors can only see sunlit objects against a dark sky, so are normally used only at night on sites which have dark cloudless night-time skies.

In comparison, it is difficult to survey low Earth orbits with optical sensors. For a LEO object, most of its night-time transits over a sensor site occur while the object is in Earth shadow and thus invisible to an optical sensor.

The Earth's shadow is not such a problem for objects in higher orbits so optical sensors can monitor those orbits easily.

With their different capabilities and limitations, radar and optical sensors perform complementary roles in the surveillance of space.

A new strategy for altered circumstances

In the era when there were few satellites in the higher Earth orbits, telescopes could follow an individual object to acquire a long track, necessary for orbit calculations. By the end of the 20th century the continuing growth of the population in higher orbits had reached the point where an unrealistically large number of tracking sensors would be required.

To address this monitoring problem, Space Insight adopted a strategy based on surveying rather than tracking. Enabled by wide field of view electro-optics, the company's Starbrook sensors scan vast areas of sky each hour.

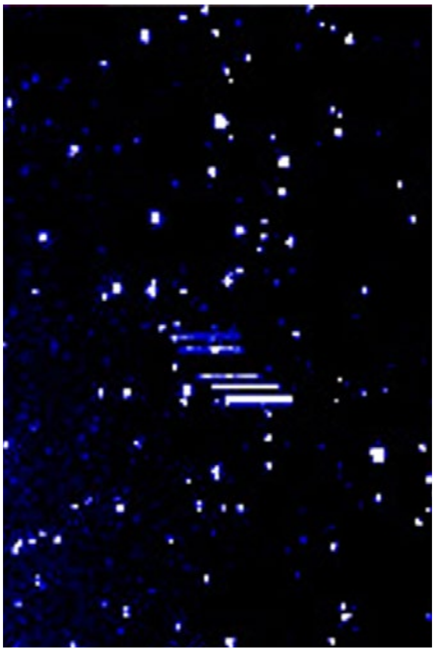
Individual object detections from each survey scan are combined into long tracks by specialised software developed by Space Insight.

Track synthesis is a common strategy for radars: a constantly-scanning radar is used to survey huge areas of sky to generate an air traffic picture rather than an individual dish radar being used to track each aircraft. It is an unusual, but highly productive, strategy for optical sensors.

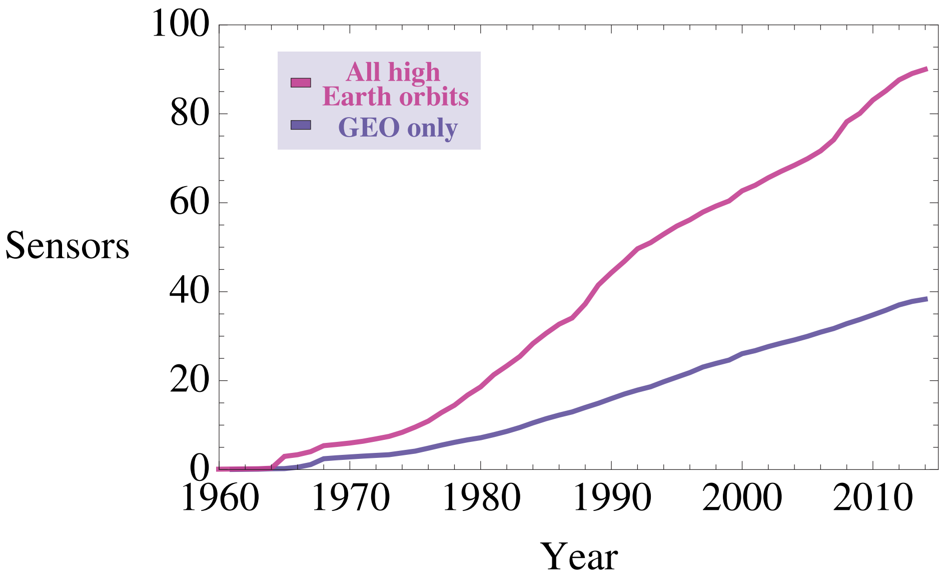
The combination of wide field of view sensors, such as Starbrook, and the surveying method enables coverage of the growing population to be maintained.

Surveying has many advantages:

- The sensor workload is invariant with the number of objects in the space population
- Data collection is anonymous because no target list is required
- Post-hoc questions can be answered by mining the data archive
- New objects are found *en passant* as the survey progresses.



Starbrook image of cluster of satellites against background of stars



An estimate of the number of sensors required for surveillance of higher Earth orbits by tracking

Starbrook: a surveying sensor system

Space Insight combined commercial off-the-shelf (COTS) hardware with its own bespoke hardware and software with the aim of bringing technology-enabled practicality, low cost, and appropriate performance to optical-sensor-based surveillance of space operations.

The key technology enablers of Starbrook are large-format mega-pixel CCD detectors and high performance computing. Both of these are needed for a system to be able to capture and analyse images of large areas of sky.

The original Starbrook design had a 10°x6° field of view, equivalent to the area of 240 full Moons, and was one of the largest field of view sensors in space surveillance, worldwide. Each hour, 1200 sq° of sky were surveyed by this Starbrook. Subsequently, other configurations have been operated with fields of view from 10 sq° to 250 sq°.

The computational performance to handle the 10 GB of image data generated by a typical night's observing is provided by multi-core Apple Mac computers. Their Unix-based operating system provides high reliability. Bespoke hardware interfaces enable the Macs to control sensor hardware and ancillary equipment. For example, Space Insight developed its own triple-processor mount control hardware and firmware to provide functionality tailored to Starbrook's space surveillance role.

Working without staff supervision, Starbrook sensors operate fully robotically. Each has autonomy to dynamically schedule its own workload within each night, to maximise observing efficiency.

Starbrook electro-optics

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