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MARKET FOR HIGH PRECISION DEBRIS DATA

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Commercial and civil satellite operators need high precision debris data to accurately assess conjunctions and ensure safety of their assets, but this data is not readily available from the military space surveillance networks. Small low-cost telescopes have proven to be a valuable tool for obtaining such data. Industry and academia have moved to explore this option and start deploying their own sensor networks. Each network will have a subset of the full desired dataset. A free market for high precision debris data will provide satellite operators with comprehensive and highly accurate datasets they need.

I. THE RATIONALE

Debris objects in Earth orbits constitute 95% of the published catalog and are responsible for most conjunctions with operational satellites. It is generally recognized that the accuracy of published two-line element (TLE) data is not sufficient for conjunction analysis, and that much more precise data is needed to ensure the safety of commercial and civil spacecraft. National surveillance networks have more precise data on certain objects, but it is typically restricted and not readily available. It is also limited in scope because of limited coverage of particular networks. Sharing of precise data between national catalogs is not easily achieved because it could reveal capabilities of military sensors. Besides tracked debris objects, there are many times more debris fragments that are not tracked by national surveillance networks, but can disable spacecraft. They need to be discovered and tracked. This, however, will overburden the existing military space surveillance sensors.

A number of new tracking methods, technologies, and systems have been developed recently and more are in development by the industry. It has been shown that impressive accuracies can be achieved even with small telescopes, resulting in state vector estimations up to two orders of magnitude more accurate than derived from TLE data. Traditionally, commercial players will be attempting to sell these technologies and systems to their governments. Some of them will be absorbed by national surveillance networks, and data produced by the new instruments will become restricted, as dictated by the defense functions of these networks.

Debris data, however, has a much wider market. This market was essentially created when NORAD started publishing TLE data, but it is still overlooked. Cued by TLE data, commercial entities can produce very precise orbital data on debris, which dominates the published catalog. There is no inherent reason why debris data obtained by commercial instruments outside surveillance networks may need to be restricted, and all national space agencies will benefit greatly from having such data, because they do not have comprehensive sets of high precision debris data at this time.

Thus, we have potential interested buyers and potential capable sellers. What is missing is a legitimate trading floor for high precision debris data. The debris threat is indiscriminate, and spacefaring nations can recognize neutrality and utility of this solution and find a suitable form of its implementation. This will be a potent measure for debris threat mitigation. IADC could lead the way, or the industry could create this market on its own.

II. NEW INITIATIVES

One of the most notable new initiatives is the creation of the Commercial Space Operations Center (ComSpOC) by AGI[1]. It aims to provide commercial and civil satellite operators with a variety of space situational awareness services, including conjunction analysis. ComSpOC has essentially jump-started the market for observation data by creating a commercial demand for it. The data supplier chain is still emerging, and it will be interesting to see how this market will be taking shape.

AGI, however, does not have a monopoly on commercial SSA services. ExoAnalytic Solutions offers now a software suite called ExoAnalytic Space Operations Center (ESpOC)[2]. It can process and interpret optical data from small telescopes in real time[3] and will allow any company or organization to build their own data processing pipeline. The package features dim and closely spaced object detection, orbit determination, light curve analysis, maneuver detection, and conjunction alerts, among other functions.

The USAF Academy Center for Space Situational Awareness is deploying its Falcon Telescope Network that will involve twelve universities around the world[4]. It is stated that besides university students, K-12 educators will be able to submit observational requests to the network, and there will be a database of publicly available images.

International Scientific Optical Network (ISON) started by Russian astronomers in 2005 has been adding new telescopes at a brisk pace. It currently joins 35 observation facilities of various affiliations with 80 telescopes in 15 countries[5]. The network is open for new members and collaboration. The primary focus is on GEO, but LEO observations are also planned. Recently, ISON has started deploying specially designed mini-observatories. Each carries three telescopes with apertures ranging from 19 to 40 cm.

A consortium of Lawrence Livermore National Laboratory, Naval Postgraduate School, and Texas A&M University started deploying its Space-based Telescopes for the Actionable Refinement of Ephemeris (STARE)[6]. The goal is to have a constellation of 18 3U Cubesats in low Earth orbits observing objects that are predicted to have close conjunctions with valuable assets. Each of the Cubesats will carry a small telescope. The data will allow more accurate assessment of those conjunctions. Two pathfinder Cubesats are already in orbit.

Last year, Canadian Space Agency launched its Near Earth Object Surveillance Satellite (NEOSSat)[7]. The satellite weighs 74 kg and carries a 6" telescope. It was inserted into a sun-sync orbit. One of the mission goals is to observe and track debris objects in high orbits.

There are many other developments, both technical and organizational—the area of space situational awareness is very dynamic and is rapidly transforming.

III. COVERAGE ANALYSIS

There are several publications reporting results of observation coverage analysis for certain sensor network architectures[8,9,10,11,12,13], but a particular comparison of deployment options that we find interesting has not been discussed. We therefore have conducted our own study. Its results are summarized below.

Tracking LEO debris appears most challenging because of its very large populations, high velocities, and limited viewing opportunities. Coverage will depend on the configuration of the sensor networks and sensor capabilities.

We started by analyzing a ground-based optical network. To evaluate the theoretical coverage of LEO debris, simulations were performed with a sample international network of 30 observation sites distributed over all continents except Antarctica. We assumed random site availability, with weather being suitable 40% of the time. It may be optimistic, but lower utilization in a larger network will yield similar results. Reasonable restrictions were placed on light conditions and viewing angles. On average, 96% of the cataloged LEO debris objects were observed by the network daily. The average number of viewable passes per object per day varied from 4.1 in summer to 6 in winter. In many cases, the daily coverage was as high as 98-99%, but in other cases, it dropped below 90%. This variability and the large number of sites motivated us to consider airborne options.

Raising the instruments above the clouds substantially improved viewing. It turned out that as few as 5 properly placed airborne observation platforms can match the coverage of a 30-site ground network subject to weather. An optimally balanced 5-site configuration consists of two sites near 50°N, two sites near 50°S, and one near-equatorial site, all spread longitudinally. They provide 98% daily coverage of the LEO debris, with an average number of viewable passes per object per day varying from 4.5 in summer and winter to 6.5 in spring and fall.

Geographically, the optimal configuration can be approximated by locations in Southern Chile, New Zealand (not much land near 50°S), British Columbia (Canada), U.K., and Southern India (for example), but the carriers do not have to be stationed there. Titan Aerospace in New Mexico has been developing a new UAV perfectly suitable for the task. Their solar plane[14] has a sufficient payload capacity and can cruise at an altitude of 20 km for several years. It can even be dispatched to preferred locations over international waters from any suitable airport.

But the prime locations for debris observations are in orbit. Low altitudes offer better viewing. If the instruments were placed on ISS, they would see 96% of the LEO debris daily, with an average of 5.8 viewable passes per object per day. From a satellite in a high-inclination orbit at 500 km, the instruments will see close to 93% of the LEO debris daily, with an average of 6 viewable passes per object per day.

Fig. 1 illustrates the fact that one spacecraft or five UAVs can provide LEO debris coverage comparable to the coverage provided by a network of 30 ground sites. All configurations can use similar optical instruments and can be deployed in various combinations, complementing each other.

Fig. 1. The coverage pyramid: from 30 ground sites to 5 UAVs or 1 spacecraft

While the primary focus of this analysis has been on debris objects in low Earth orbits, the sensor configurations described above can provide full coverage of debris in high orbits as well.

The bottom line is that full and dense coverage of debris in all orbital regimes is well within reach technologically and can be achieved with modest resources.

IV. OPTICAL INSTRUMENTS AND DATA

Analysis shows that rocket bodies and satellites in LEO can be tracked even with 4" telescopes, while debris fragments larger than roughly 10 cm can be tracked even with 6-8" telescopes. Such telescopes with computerized mounts are available off-the-shelf and are owned by many individuals and organizations. Technically, there is already more than enough "observing power" on the ground for a full and dense coverage of all cataloged debris, if only all these resources can be utilized. New telescopes tasked with tracking are being deployed, and optical observation networks are being formed. An arcsecond level of observation data precision has been demonstrated for small apertures[15].

The architectures described in the previous section require high throughputs and high pointing accuracies in dynamic environments. To capture at least three data points for every viewable pass of every cataloged debris object, the data acquisition rates should be ~1 data point/sec for the ground sites, ~2 data points/sec for the airborne platforms, and ~3 data points/sec for the spacecraft. The minimum data rates will go up with time, as more debris fragments are discovered and cataloged. Besides high throughput, the instruments would need to cover a wide range of viewing angles. This could be achieved by deploying multiple instruments at each location.

As a more efficient alternative to conventional telescopes designed for astronomy, we have considered specially designed optical instruments that are optimized to perform the task of debris tracking with arcsecond precision and achieve high throughputs in all configurations described in the previous section. The candidate layouts are compact—the assemblies can be less than 1 m long. Each instrument can cover up to a 60° cone. It will take on the order of 1-2 seconds to produce a data point for a debris object. The new design substantially relaxes restrictions on the attitude motion of the airborne platforms or spacecraft carrying the instruments. There is no need to maintain their orientation with high precision. Instead, precise knowledge of the carrier rotation is used to drive the instruments in such a way as to compensate for that motion and produce steady images.

A set of six instruments mounted on a common platform could satisfy the coverage requirements for ground sites and airborne platforms. Each instrument will be assigned its observation sector. The instruments can be placed in the horizontal plane and arranged to form radial, triangular, or other configurations.

A candidate layout of a space-based debris tracking system contains twelve instruments. Each instrument has its own CPU(s) to capture and process images. Once the astrometric data is extracted, the images are discarded. The data points are sent to the ground frequently to calculate state vectors for the observed debris objects by fitting the orbits to several days of data. Observation scheduling instructions are received from the ground. The mass of the spacecraft is estimated to be on the order of 150 kg, and the size around 1 m. Its imaging subsystem is highly redundant and can survive multiple failures of the components. It is also scalable, as the number of instruments can be increased or reduced if desired. Eventually, there could be two or three such spacecraft placed in different orbital planes in LEO for overall system survivability and better coverage of debris. A constellation of three spacecraft could produce over half a million observation data points every day, densely covering debris in the current catalog.

Numeric experiments with simulated dense data show that for debris in the most populated regions of LEO state vector estimations at the time of the last measurement could be accurate to a few meters in position and a few mm/s in velocity—incomparably better than from the published TLEs. This illustrates how high precision debris data can be acquired and maintained.

V. DISCOVERING UNTRACKED DEBRIS

Radars miss a substantial fraction of debris objects in the 10-15 cm range and a much larger fraction of objects smaller than 10 cm[16], but even sub-centimeter fragments can seriously damage spacecraft[17]. We estimate that in LEO there are tens of thousands of untracked debris fragments in the 5-15 cm range detectable by small telescopes, see Fig. 2. They are big enough to disable even large spacecraft in hypervelocity impacts, and the knowledge of their orbital motion is essential for the safety of space operations.

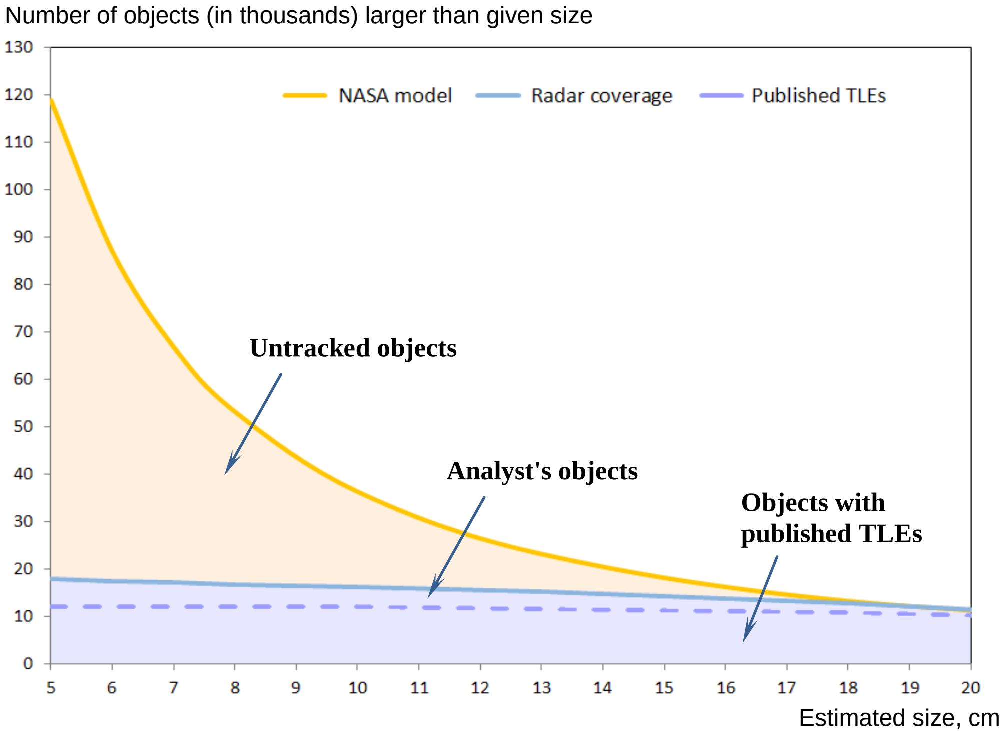

Fig. 2. Distribution of LEO debris objects by size

Fragmentation and collision events in LEO create very distinct streams of debris fragments[18]. They are very narrow in terms of inclination, but with time, spread out in nodes. Probable distributions of untracked fragments from known events can be represented by a large number of virtual fragments based on the known statistics of tracked fragments. The instruments can be tasked to track these virtual fragments in exact same way they track cataloged fragments. If a real fragment with a closely matching orbit happens to be in the field of view, it will produce a somewhat blurred but familiar signal in the image. The closer the actual new object's motion is to that of the virtual object, the smaller the blur and the brighter the image. Once the signal is detected, the instrument can iteratively improve its tracking and continue imaging the new object throughout the pass to accumulate data points and refine the orbit. If the object is reacquired on subsequent passes, the virtual fragment becomes a real object in the catalog. Due to a very large number of detectable, but untracked fragments in the known streams, such as left by Cosmos 2251, Iridium 33, and Fengyun-1C, the probabilities of detection are non-trivial, and a practical discovery process can be built around this concept.

In addition, this capability will allow prompt detection of new fragments after collision and fragmentation events, especially in the first few weeks or months while the streams of fragments remain tightly clustered.

The point is that even without new collisions the existing catalog is set for an explosive growth due to the discovery of many thousands of currently untracked debris fragments.

VI. THE MARKET

The markets for SSA products and services already exist, but they are in most cases restricted to national marketplaces because of national security concerns. However, it is time to recognize that the debris threat is indiscriminate, and that high precision debris data obtained by commercial sensors outside of the military surveillance networks can be traded globally to the benefit of all spacefaring nations. The value of global access to accurate current data is already recognized for commercial air and sea traffic. Why not treat debris objects similarly?

Historically, one of the primary concerns has been that high precision data on operational military satellites could also be acquired and distributed. To address this concern, we will refer to a stock exchange as a legalized and regulated trading model. Let us say we have a hypothetical Debris Data Exchange that operates like a stock exchange, where all cataloged debris objects are listed for data trading, but operational satellites are not listed. In this environment, you can buy and sell only debris data, but cannot buy or sell data on operational military or other satellites simply because these objects are not listed on the Exchange. When new objects are discovered and characterized as debris, there will be new listings—"debris IPOs," so to say. One could imagine even finder's fees for bringing new objects to the market, but this can be settled between the finder and a licensed data trader outside the Exchange.

Furthermore, satellite operators who want to have better orbital data for their assets and do not object to have it openly traded can list their satellites on the Exchange.

Another common concern is the quality of the data. This concern can be addressed by cross-verification of data from different providers and by a due process of certification of the providers when they acquire licenses to trade on the Exchange.

Data pricing on the Exchange can be dynamic and reflect the need for specific data from particular buyers.

We have referred to the stock exchange model primarily to illustrate that debris and satellite data trading can be organized to the advantage of all interested parties, but we do not insist that this is the only possible mechanism.

Let us now look at the demand side of the market. It is natural that all spacefaring nations want to have their own catalogs to support their missions. Therefore, their space agencies should be very interested in acquiring accurate debris data. Note that currently, debris constitutes 95% of the catalog, and its share will increase even further with the discovery of thousands more fragments that are currently untracked.

Large commercial operators, such as Intelsat, Iridium, GlobalStar, Orbcomm, and others, may become indirect buyers through organizations like Space Data Association or ComSpOC providing conjunction analysis for them. Small and single-satellite operators may just buy data for their satellites. Universities may obtain data for research purposes.

The members of the Inter-Agency Space Debris Coordination Committee (IADC) publically stated their concern about the debris problem and could therefore be expected to at least support the development of a global market for debris data, or preferably lead the way in its creation. If this leadership does not materialize, there are all indications that the global market for debris data will shape itself, as it did in many other areas.

VII. CONCLUSIONS

There is a need and opportunity to create a free global market for high precision debris data. Small low-cost telescopes have proven to be a valuable tool for obtaining such data. Specially designed optical instruments will be even more effective in ground, airborne, or space-based configurations. Industry and academia are beginning to deploy their own sensor networks. Each network will have only a subset of the full desired dataset, but if the spacefaring nations agree on a mechanism to freely buy and sell debris data, the market can provide satellite operators with comprehensive and highly accurate datasets they need to accurately assess conjunctions and ensure safety of their assets.

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