P01

Direct Bayesian Admissible Region 手法による軌道物体追跡の改良

Improvements to Resident Space Object Tracking with the Direct Bayesian Admissible Region Approach

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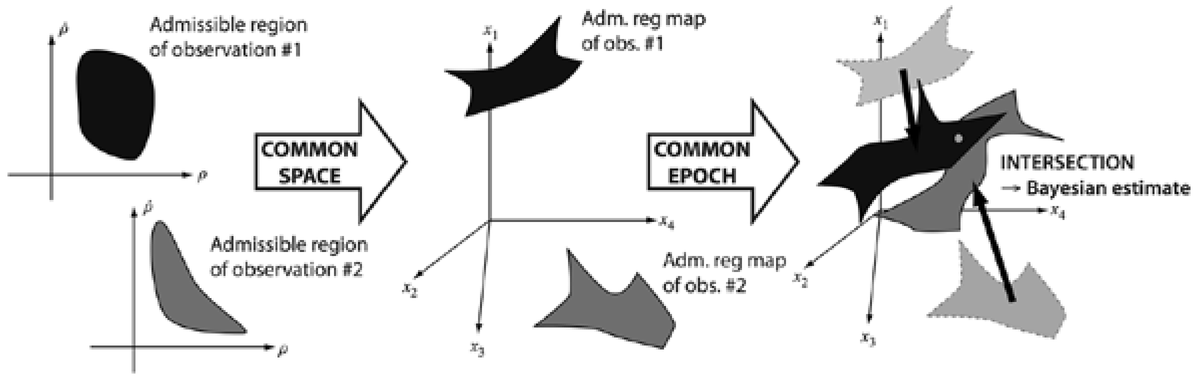
地球周辺の宇宙空間がより過密化し、多国間の競争が激化する中、宇宙状況認識 (SSA) は宇宙を利用するすべての国にとって重要な技能であり続けると考えられる。しかし、観測が希薄であるがゆえ、同定仮定を初期軌道決定の的確さによって判定する従来の方法は、しばしば失敗することが確認されてきた。Direct Bayesian admissible region 手法は、先験的な状態を必要としない、観測同定・初期軌道決定の方法である。経過時間の短い光学観測の弧を元に、観測された物体までの、もっとも可能性の高い距離・距離の変化率の値を含んだ、コンパクト空間を定義することが可能である。Admissible region とは、このコンパクト空間上に定義された連続一様分布である。本研究では、上の手法をベルン大学から提供された実データを元に検証し、新たに 2 つの物体を検出することに成功した。

As space becomes ever more congested, contested, and competitive, space situational awareness (SSA) capabilities will continue to be important for all spacefaring nations. In almost all SSA related tasks, the first step is to track, detect, and identify active satellites, space debris, and other resident space objects (RSOs). Conventional approaches of testing association hypotheses based upon IOD quality, however, can often fail since sparse measurements lead to poor, if not divergent, estimates. The direct Bayesian admissible region approach is an a priori state free measurement association and IOD technique. Given a short-arc series of optical data, or a tracklet, a compact region in the range / range-rate space is defined based on a set of physical constraints such that all likely and relevant orbits are contained within it. The admissible region (AR) is a uniform probability density function (pdf) whose support is this compact region. Multiple ARs may be propagated to a common epoch and an a posteriori pdf directly computed based on Bayes' rule. The proposed approach has been applied to tracklets from a survey of geostationary (GEO) objects taken at the Zimmerwald Observatory of the Astronomical Institute of the University of Bern. Processing a set of 212 tracklets resulted in 20 objects detected; 2 of which are newly detected by the proposed method. Furthermore, it was noted that the direct Bayesian approach would allow one to reevaluate future observational strategies in order to minimize false positive / negative association solutions. As such, this work ultimately aims to “close the loop” on the short-arc optical track association problem by enhancing the survey strategy based on the association results and vice versa.



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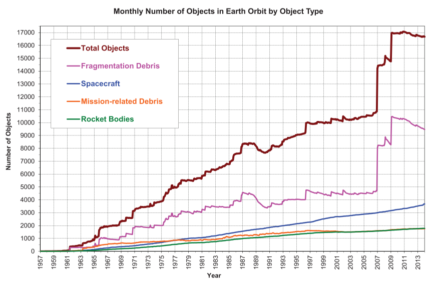
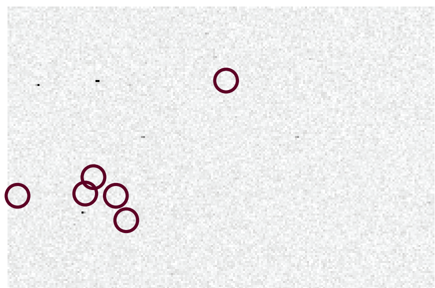
Space Situational Awareness



Number of tracked objects in the Joint Space Operations Center (JSpOC) public catalog of Earth-orbiting objects [NASA, 2014].

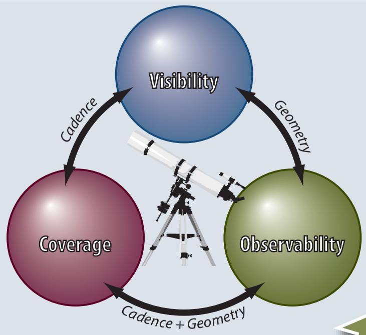
As the Earth-orbiting environment becomes ever more **congested, contested, and competitive**, capabilities to characterize resident space objects (RSOs), or space situational awareness (SSA), is now crucial for all space-faring nations in order to secure reliable access to space.



Typical telescopic negative image of geostationary objects (circled dots) [IHI Corp., Hamane, and Fujimoto, 2012].

Beyond several thousand km in altitude, optical sensors are the workhorse of SSA. Consistent tracking is difficult, however, due to short, sparse measurements and an interdependency between track association and state estimation quality.

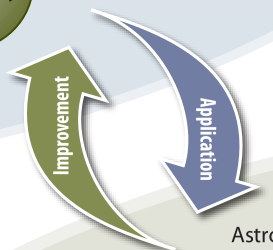
To enable the next-generation of RSO surveys, we have been pursuing an integrative approach encompassing both hardware and software research



Current high-altitude RSO surveys are influenced heavily by observer experience and *ad hoc* rules.

E.g. a survey targeted at objects near opposition will have excellent ***visibility*** *and* ***coverage****... but poor* ***observability*** *due to repetitive geometry*

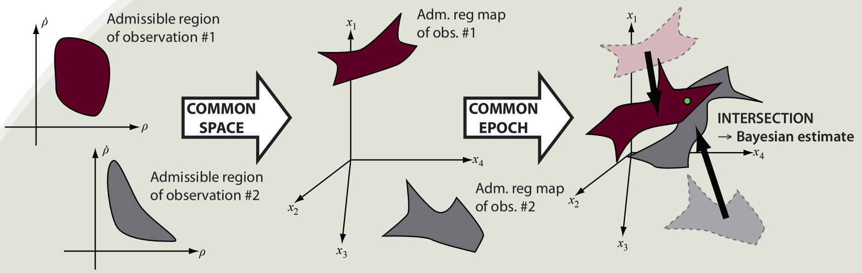
A systematic and analytic approach of optimizing leak-proofedness, lighting conditions, and orbit determination accuracy will help us better understand the RSO population.



Optical Measurements

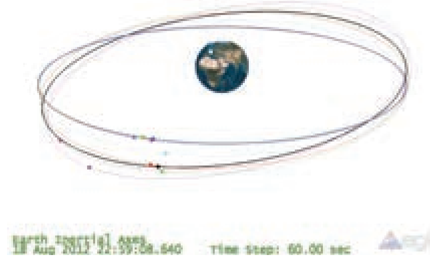
Astrodynamical Tools

Astrodynamical algorithms provide a platform for engineers to make better use of data at hand. As such, advancements in this realm may also be directly fed back into how the measurements are made.



The direct Bayesian admissible region (DBAR) approach, an *a priori* state free measurement association and IOD technique, is one such example. It employs **an exact description of the measurement uncertainty** based on physical constraints, or admissible regions, making it not only computationally efficient but also conducive to topological interpretations of the problem.

Recent Results



3-D representation of geosynchronous objects detected by the DBAR method from two nights of observations (Aug 18-20, 2012) taken at the Zimmerwald Observatory (white dot). Both previously cataloged (dotted line) and uncataloged (bold line) objects are shown.

In collaboration with the Astronomical Institute of the University of Bern (AIUB), the DBAR approach has been used to process 600+ optical tracks, **succeeding in detecting several previously uncataloged objects.** Furthermore, we revealed that their catalog accuracy would be much improved if their survey strategies were designed with explicit consideration of state observability.

Based upon these findings, we recommended a new strategy with enhanced measurement geometry diversity, which AIUB plans to implement in spring 2014.

Selected Publications

Fujimoto, K., Scheeres, D. J., Herzog, J., and Schildknecht, T. "Association of Optical Tracklets From a Geosynchronous Belt Survey via the Direct Bayesian Admissible Region Approach." *Advances in Space Research*, Vol. 53, No. 2, 295 – 398 (2014).

Fujimoto, K., Scheeres, D. J. and Alfriend, K. T. "Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem." *Journal of Guidance, Control, and Dynamics*. Vol. 35, No. 2, 497 – 509 (2012).

Fujimoto, K. and Scheeres, D. J. "Correlation of Optical Observations of Earth-Orbiting Objects and Initial Orbit Determination." *Journal of Guidance, Control, and Dynamics*. Vol. 35, No. 1, 208 – 221 (2012).