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Message from the Guest Editors of the Special Issue on Astrodynamics for Space Situational Awareness

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The term space situational awareness (SSA), in a broad sense, refers to the comprehensive knowledge of the near-Earth space environment. It has gained increasing attention as the number of space objects, including the natural and artificial, continues to grow rapidly in recent years and several collisions between them have occurred. One of the main objectives of SSA is to maintain awareness of potentially adversarial space events, in particular collisions, and avoid them. This typically involves tracking and identification of orbiting space objects, predicting their future locations, assessing the collision risk, and removing harmful objects such as debris to improve safety.

This special issue of *Astrodynamics* aims to collect recent progress of scientific research and engineering technology on space situational awareness. Specific topics range from space object collision probability computation to orbit estimation and propagation, space object tracking, and space debris removal. Techniques and methods including analytic, numerical, and machine learning-based are presented. Following an open call for paper, seven papers that comprise the special issue were selected and are briefly introduced in the following.

The special issue starts with the survey "A review of space-object collision probability computation methods" by Jia-Sheng Li, Zhen Yang, and Ya-Zhong Luo. The paper provides a comprehensive review on the state of the art algorithms for computing the collision probability of space objects. Such algorithms are of high relevance in SSA, particularly in spacecraft conjunction assessment and collision avoidance. The survey includes detailed descriptions of those collision probability computation methods for three different cases: instantaneous collisions, short-term encounters, and long-term encounters. The advantages and limitations of different methods are compared and discussed. In addition, applications in SSA of these methods are presented, and recommendations for future research are provided.

The paper "Spacecraft collision avoidance challenge: Design and results of a machine learning competition" by Thomas Uriot *et al.* reports the results of the spacecraft collision avoidance challenge, a machine learning competition hosted by the European Space Agency in 2019. The competition motivated participants to build models to predict the final collision risk between orbiting objects based on a real-world dataset containing information about the close approach events related to actively monitored satellites. The paper describes details of acquiring the dataset, outlines the competition design process, shows the final competition results of selected top teams, and discusses the learned lessons from the competition in using machine learning in spacecraft collision avoidance systems.

Authors Changxuan Wen and Dong Qiao study the problem of calculating the long-term collision probability for satellite close operations in their paper "Calculating collision probability for long-term satellite encounters through the reachable domain methods". The authors propose a parametric method based on the concept of random variable (RV) space, which is defined as the transformed state space of the spacecraft at the fixed initial time considering initial state uncertainty. Transforming the spherical spacecraft hard body to the RV space results in an ellipsoid, which sweeps out a derived collision volume in the RV space during the encounter. This volume is specified by the reachable domain method and the collision probability for long-term encounter is finally computed by integrating a probability density function over the collision volume.

The topic of angles-only orbit estimation is explored in the paper "Analytic continuation extended Kalman filter framework for perturbed orbit estimation using

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a network of space-based observers with angles-only measurements" by Tahsinul Haque Tasif, James E. Hippelheuser, and Tarek A. Elgohary. To achieve accurate orbit estimation, the authors develop a new measurement model in which a constellation of low-cost observers with monocular cameras is used to produce angles-only measurements, and integrate the model in an extended Kalman filter (EKF) framework with the analytic continuation (AC) technique. Specifically, AC is a semi-analytic integration method that is used to propagate the perturbed orbit dynamics and compute the perturbed state transition matrix in the EKF framework to improve orbit estimation accuracy without sacrificing much computational efficiency.

The paper "PHiFA—A tool for numerical propagation of high-fidelity astrodynamics" by Yang Yang *et al.* presents a numerical tool named PHiFA for propagating the 6-DOF coupled orbit-attitude dynamics of a space object. Various perturbative forces and torques are considered to achieve high-fidelity propagation. In particular, the surface forces of the space object, such as aerodynamic drag and solar radiation pressure, are attitude-dependent and hard to model. The paper implements and compares two methods, i.e. the area matrix method and the beam method, to calculate the surface forces, and shows that the beam method can achieve high modeling accuracy.

The paper "Real-time space object tracklet extraction from telescope survey images with machine learning" by Andrea De Vittori *et al.* presents a machine learning-based approach for real-time extraction of space object tracklets from optical images. The dataset for training, which consists of dual-tone pictures with black backgrounds and white tracklets, is generated using a software simulator that can produce synthetic night sky shots of transiting objects over a specified location. Then, a convolutional neural network (CNN) based model is designed and trained with the dataset. The performance of the trained model is evaluated using both synthetic and real images, which shows fast processing capabilities with acceptable accuracy.

The final paper in the special issue is "Timeline Club: An optimization algorithm for solving multiple debris removal missions of the time-dependent traveling salesman problem model" by Nan Zhang, Zhong Zhang, and Hexi Baoyin. The authors propose a novel intelligent global optimization algorithm, namely Timeline Club Optimization (TCO), to solve the multiple debris removal trajectory optimization problem. The problem is formulated as a time-dependent traveling salesman problem (TDTSP) with both the vertex sequence and the transfer time to be optimized, which is hard to solve due to the time dimension. To address the challenge, the paper builds upon the ant colony optimization framework and develops a novel technique named Timeline Club to represent the time dimension. The proposed TCO algorithm is evaluated in the Iridium-33 mission and the GTOC-9 mission, both showing state-of-the-art performance.

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Sincerely,
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