GSAW 2018 Tutorial B:

Developing Machine Learning Solutions for Space Missions

Length: Half day

Overview:
This tutorial presents the detailed discussions of the recent developed machine learning framework for creating the operational situational awareness (OSA) capabilities for satellite operations. The operational situational awareness is defined as the ability of a system to perceive, analyze and predict its own behavior, and it is essential for an autonomous system that could regulate itself based on the high level management objectives. The OSA capability in spacecraft operations brings fundamental changes to how the health and safety data for a space mission with both space and ground assets are monitored and analyzed, which leads to automated operations for engineering analysis that has traditionally been manual and offline. OSA has been crucial to meet the growing challenges in the latest missions with the order of magnitude increases in the data volume from the spacecraft and its payload.

A space mission with both space and ground assets is a dynamic system, in which its state variables have the following common characteristics:

- The variables describing the operational states are time dependent.
- The datasets for the continuous state variables, such as those in spacecraft telemetry, are measurements with noise and/or variability that satisfy the Gaussian probability distribution.

The datasets with Gaussian probability distributions are characterized by the **time dependent trends**, which include the time dependent function and the standard deviation representing the noise level of these datasets. The time dependent trends for space missions are categorized into two groups; the derivable group that its time dependent function can be derived by the first principle, such as orbital behaviors of a spacecraft, and the phenomenological group, such as the temperature profile, that its time dependent function is very difficult if not impossible to derive.

Machine Learning establishes the data model for the time dependent trend of the phenomenological group through the data training of the existing datasets. It captures the data patterns of a satellite mission in its optimum states so that any deviation from its optimum can be detected. The time dependent trend can be used to predict the expected behavior of a dataset, thus, leads to the OSA capability of a dynamic system. The process of obtaining a time dependent trend is called the time dependent trending, which is a natural extension of the statistical trending in the current spacecraft operations. The time dependent trending is also the well defined **regression** task in the machine learning algorithms.

The OSA capability provides the actionable information in improving the system autonomy and resiliency, and the examples of potential applications leveraging the OSA capability are the dynamic data monitoring, data filtering, and self-optimizing in a dynamic system. The data monitoring for a system with OSA compares the predicted values from the time dependent trend with its actual values instead of the static limit monitoring in the current operations. It is highly sensitive to deviations from predicted values above its noise level that are defined as outliers. The deviations of a dataset from predicted values could potentially lead to system anomalies, can be detected early in real-time or near real time. The system anomalies are characterized with outlier cluster functions in this approach, which provide the direct insights into the root-cause of system anomalies.

A machine learning system consists of data models representing the time dependent function of datasets that are capable of predicting its future behaviors and the data training algorithm. There are many different data models such as using the Fourier expansion as the data model (see Ref. 3), the support vector machines (SVM), and neural networks. The neural network implementation is particularly powerful for regression tasks due to the universal approximation theorem, which states that all possible data patterns can be reproduced by a neural network with sufficient complexity. The challenges for developing machine learning solutions for space missions are to develop a mathematical representation for the data models and an effective data training approach in an operational environment. The mathematical representation for a machine learning system allows a machine learning system to be archieved, retrieved, and reconstructed. An effective data training approach should be both efficient and adaptive so that it can be used in a real time or near real time environment while capturing the long term changes in a dynamic system.

This tutorial consists of the following 4 sections:

- The first section discusses the general framework of developing the machine learning solutions for a dynamic system. How the machine learning solution for a dynamic system enables the OSA capability for dynamic monitoring and automated engineering analytics in flight operations.
- The second session address the development of machine learning solutions for datasets in satellite missions. The tradeoff for selecting different data models with different data training algorithms depends on the complexity of data patterns and the efficiency requirements for data training algorithms. The neural network implementation of machine learning and the issues in data training, such as the selection of the training samples, the training algorithms, and the data training in the presence of outliers, are presented.
- The third section presents the general requirements for software implementation of the machine learning systems in ground system and the operational concepts, and the development of mathematical representation for data models, and the data training approaches in an operational environment. The software implementation of the machine learning system in creating the OSA for dynamic monitoring is discussed.
- The final section presents an use case of machine learning in satellite operations; the deployment of the machine learning system in NOAA GOES-R ground system to automate the engineering analysis and monitoring of the Advanced Baseline Imager (ABI) radiometric operations. How the outputs of machine learning system are used to monitor and evaluate the performance of overall systems is also presented.

The development of the machine learning solutions for space missions is still in early stage, and hopefully this tutorial session will facilitate more interests and collaborations in developing the machine learning solutions to space missions.

Reference:

[1] Zhenping Li, J.P. Douglas, and Ken Mitchell, “Creating Situational Awareness in Satellite Data Trending and Monitoring”, 32nd Space Symposium, April 11-12, 2016, Colorado Springs, Colorado. http://www.spacesymposium.org/tracks/technical-track/papers

[2] Zhenping Li, “Creating Situational Awareness in Spacecraft Operations with the Machine Learning Approach”, 2016 AMOS Conference, September 20-23, Maui, Hawaii. http://www.amostech.com/TechnicalPapers/2016/Poster/Li.pdf.

[3] Zhenping Li, David Pogorzala, Ken Mitchell, J.P. Douglas, “Adaptive trending and limit monitoring algorithm for GOES-R ABI radiometric parameters” GSICS Quarterly Newsletter, Summer 2015 Issue, http://dx.doi.org/10.7289/V5XK8CHN#page9.

[4] Zhenping Li, “Machine Learning in Spacecraft Ground Systems”, Proceedings of 6th IEEE International Conference on Space Mission Challenges for Information Technology, 2017, to be published.

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Biographies:
BZhenping Li: Received Ph.D in Physics from The University of Tennessee in 1992, the Master degree in computer science from Johns Hopkins University in 2003, joined ASTS in 2013. His main focus areas are the algorithms development of satellite instrument data processing and the application of machine learning algorithms in satellite operations.

Biruh Tesfaye: Received a Masters in Electrical and Computer Engineering from Johns Hopkins University in 2015. He Joined AFSS in 2015. His main focus areas are satellite ground system application development, cloud computing and machine learning.

Description of Intended Students and Prerequisites:
The target audiences are systems engineers and software developers who are interested in machine learning and satellite data analytics, and the satellite engineers who manage and monitor the health and safety of satellite and its instruments. The knowledge of satellite operations and basic knowledge of the machine learning are very helpful.

What can Attendees Expect to Learn:
The attendees will learn the recent developed framework for developing machine-learning solutions, understand the issues to be addressed for machine solutions for satellite operations, and how the machine learning solutions can be integrated into ground systems to improve the operation efficiency and system resilience.