ACCURACy: Adaptive Calibration of CUbesat RAdiometer Constellations

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***Abstract*— Recent advances in sensing technology have enabled the deployment of CubeSats equipped with radiometers for scientific missions. While constellations of CubeSats provide benefits to remote sensing science missions, they also bring with them unique challenges in calibration due to considerable sensitivity to ambient conditions. To address this problem, a constellation-level calibration framework is being developed, called "*Adaptive Calibration of CUbesat RAdiometer Constellations (ACCURACy)*". This framework is in early stages, currently covering the theoretical basis through an initial end-to-end prototype utilizing synthetic data. This framework will use instrument-level telemetry data collected pre-launch and in-orbit to separate constellation members into time-adaptive groups (or clusters) of radiometers in similar states. Within clusters, all radiometers share their absolute calibration measurements to a common calibration data pool. These calibration pools, containing measurements of different calibration targets at different times, facilitate frequent multi-point absolute calibration. This, in turn, serves to reduce and quantify calibration errors and uncertainties.**

Keywords—radiometer, calibration, machine learning, cubesat, smallsat

I. INTRODUCTION

CubeSats provide a low-cost alternative to traditional monolithic systems in passive microwave radiometry and can be launched in constellations. However, due to size limitations, they usually lack thermal mass and radiation shielding which makes them susceptible to ambient conditions. Furthermore, many of them do not carry blackbody targets, and their calibration is performed via infrequent vicarious target measurements. As a result, errors and uncertainties can be high in calibration of individual CubeSat radiometers. To minimize this problem, we propose a framework called "Adaptive Calibration of CUbesat RAdiometer Constellations (ACCURACy)" to calibrate CubeSat radiometer constellations in their entirety as a single system. ACCURACy consists of three modules: the Clustering Module, Calibration Pool Module, and the Calibration Module. First, calibration and telemetry data is received in a stream from the radiometer constellation. Data is processed as it is collected, point by point, or in small, local blocks in time. For each block, the telemetry data first goes through a stage of dimensionality reduction and normalization. Next, similar-state radiometers are grouped into clusters based on their telemetry data and each radiometer is assigned a cluster label. These labels, calibration data, and associated times are fed to the Calibration Pool Module, which updates stored calibration information for each cluster and makes it available for all cluster members. Finally, measurements of each radiometer are calibrated using the most recent calibration pool data in its current cluster. Fig. 1 summarizes this process.

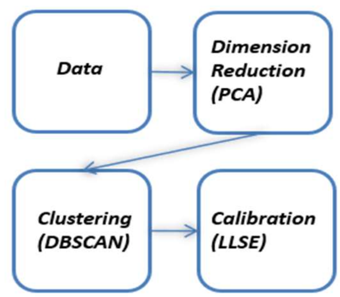

Fig. 1. Outline of the Accuracy Framework. Telemetry and calibration data are provided as a stream. First, the dimensionality of the telemetry data is reduced. Second, radiometers are clustered based on telemetry data and cluster labels for each radiometer are output. Last, these cluster labels and calibration data are sent to the Calibration Pool Module and calibration is performed by the Calibration Module.

II. ACCURACY FRAMEWORK

A. Telemetry Data and Radiometer Characteristics

ACCURACy uses thermistor and time measurements as telemetry data assuming that radiometer gain is typically determined by the physical temperature of the system and the age of the instrument [1]. Currently each radiometer gain is modeled as a weighted sum of thermistor measurements and the age of the instrument as follows:

$$g_i(t) = \sum_{k=1}^{N} W_{ik} T_{ik}(t) + W_{it} t_i \quad (1)$$

This model can be easily modified and, in the future, the relationship between CubeSat telemetry data and radiometer gain characteristics will be studied further utilizing data from

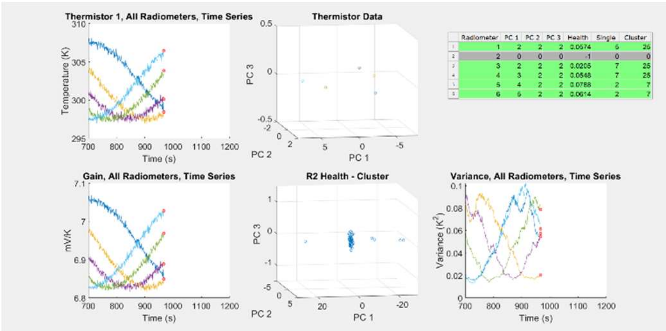

Fig. 2. A panel showing relevant information as a set of synthetic radiometer data is processed using the ACCURACy framework, (top left) measurements of a single thermistor from each radiometer, (top middle) current thermistor data, plotted post-PCA, (top right) a table tracking cluster labels and the number of calibration measurements available for each radiometer, (bottom left) gain plot of each radiometer, (bottom middle) plot showing the health of a single radiometer, defined as a measure of variance, (bottom right) health of all radiometers, measured as variance of thermistors.

real CubeSat radiometer constellations such as "*Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS)*" [2].

B. *Clustering and Calibration Data Pools*

The Cluster Module, seen in part in Fig. 2, is comprised of a dimensionality reduction stage and a clustering algorithm. Incremental principal component analysis (PCA) [3] and density-based spatial clustering of applications with noise (DBSCAN) [4] are used for low-computational-cost dimensionality reduction and clustering, respectively. PCA identifies k principle components from the input n-dimensional telemetry data vector, i.e. thermistor and time measurements, forming a continuously updated k-dimensional principal component vector for each radiometer in the constellation. DBSCAN is then used to perform k-dimensional clustering, grouping radiometers in similar states as well as identifying anomalous sensors. At the end, calibration measurements of radiometers within the same cluster are gathered in a shared data pool by the Calibration Pool Module and used to calibrate radiometers classified in that cluster. Number of principle components, cluster sizes, and cluster update times are adjustable variables in the framework.

C. *Calibration*

When a radiometer is to be calibrated, the Calibration Module takes voltages, temperatures, and observation times from the calibration data pool associated with the current cluster of that radiometer and implements a least squares regression based absolute calibration. The data pool provides an abundance of calibration data from various vicarious targets measured at different times, as seen in Fig. 3, which makes continuous and consistent science measurements with reduced and quantified uncertainties possible [5] and enables the tracking and minimizing of calibration errors [6].

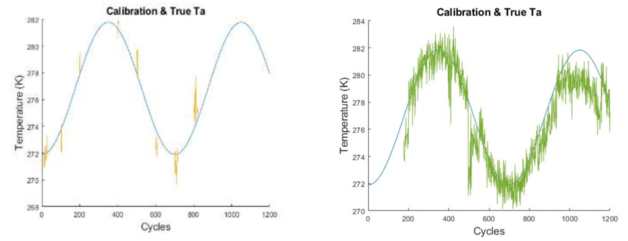

Fig. 3. Calibration of a radiometer out of a six-satellite constellation. One calibration measurement is made every 100 cycles. (left) Calibration using only measurements from a single radiometer. (right) Calibration using pooled calibration measurements. Increase in available calibration data owing to ACCURACy is obvious.

III. Discussion

ACCURACy aims to improve the calibration of CubeSat radiometer constellations by implementing simple machine learning algorithms to identify similar state radiometers, facilitate calibration data sharing, and enable adaptive calibration to minimize calibration errors and uncertainties. The initial analyses are promising; however, data storage and transmission requirements, technologies which allow inter-constellation communication needed to realize ACCURACy, need to be further investigated, especially for large constellations.

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