ACCURACy: Adaptive Calibration of CubeSat Radiometer Constellations

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***Abstract*—Constellations of CubeSat radiometers are increasingly used in scientific applications due to their low cost and power requirements as well as their ease of deployment relative to conventional radiometer systems. However, using constellations of small CubeSats rather than conventional radiometer systems comes with additional challenges, particularly in instrument calibration, due to the sensitivity of the instrument to ambient conditions and the use of vicarious earth calibration measurements. To address these problems, we developed a novel, constellation-level calibration framework called "Adaptive Calibration of CubeSat Radiometer Constellations (ACCURACy)." ACCURACy uses machine learning algorithms to cluster CubeSat radiometers in a constellation using telemetry data. These calibration measurements and times are managed in cluster-level calibration data pools to share calibration data among other cluster members and enable frequent calibration. This paper discusses the development of the ACCURACy framework in MATLAB, along with analyses of simulations of CubeSat radiometer constellations. The performance of ACCURACy is compared to conventional intercalibration algorithms.**

I. Introduction

Technological advancements in recent years have enabled the wide-spread use of constellations of CubeSat radiometers for scientific missions including weather tracking, atmospheric science, and other remote sensing applications. The primary drawbacks are the sensitivity of CubeSat radiometers to ambient conditions, and the infrequent collection of vicarious Earth calibration measurements, determined by radiative transfer models and Earth surface conditions. This sensitivity to change in payload temperature results in significant changes in the radiometer gain and offset over short time periods. Radiometer gain and offset is typically determined by the payload temperature and age of the instrument, and so ACCURACy uses this relationship to cluster radiometers in similar states based on telemetry data collected by onboard thermistors. These clusters are used to pool calibration measurements between radiometers by identifying when calibration measurements are made while in similar states. Then, these calibration measurements and times are managed by the framework and saved in calibration pools and are used to calibrate radiometers in similar states in the future. By characterizing the relationship between the radiometer gain and payload temperature as well, the propagation of errors and uncertainties in the estimated antenna temperature can also be quantified [1, 2]. The current best methodology for calibrating constellations of radiometers is to determine when two instruments make a calibration measurement at nearly the same location and at nearly the same time and relate the calibration measurements to the rest of the constellation through the use of a radiometer making absolute calibration measurements as a transfer standard. This paper will present how ACCURACy performs against an implementation of this methodology operating on a simulated constellation of CubeSat radiometers.

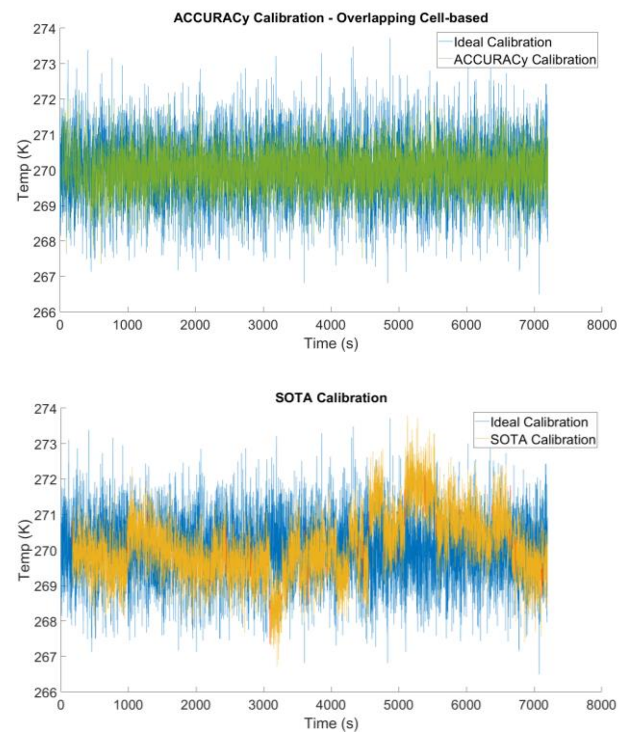

Fig. 1: (**Top**) Green trace is the ACCURACy calibration, the blue trace is the baseline calibration, and the yellow trace (**Bottom**) is the calibration using the SOTA method, where the red marks indicate times when the SOTA algorithm identifies overlapping calibration measurements, and there is sufficient calibration data to update the calibration.

TABLE I. SIMULATION PARAMETERS

Simulation Parameters		
Parameter	**Value**	
Orbital Planes	5	
Orbit Period	90 minutes	
Simulation Time	120 minutes	
# of Satellites	35	
# of Thermistors/Satellite	10	
Calibration Parameters		
Parameter	**Value**	
Antenna Temperature	270K	
# of Calibration Targets	4	
Calibration Temperatures (K)	[2.7, 210, 250, 300]	
Receiver Temperature (K)	1400K	
Bandwidth (GHz)	2.031GHz	
Integration Time (s)	4.096 ms	
Orbital Planes		
Angle of Inclination	**Number of Planes**	**Satellites Per Plane**
98	1	7
43	4	7

TABLE 2. CALIBRATION RESULTS

Algorithm	RMSE	σ^2
Baseline	0.93	0.84
ACCURACy	**0.75**	**0.37**
Conventional SOTA	1.03	0.89

II. ACCURACY FRAMEWORK

ACCURACy is divided into three modules. First the Clustering Module processes telemetry data using PCA to reduce the dimensionality of the thermistor data. Then, it clusters radiometer based on the processed telemetry data and assigns cluster labels to each radiometer. The Calibration Pool module uses the cluster labels to sort calibration measurements made by constellation members into data pools. Calibration measurements collected in calibration pools are shared with other radiometers in their respective clusters. Finally, the Calibration Module creates and maintains a cluster-level calibration structure for each cluster and continuously provides calibrated antenna measurements for each radiometer in the constellation.

III. RESULTS

A simulation is created to evaluate ACCURACy against the SOTA implementation described above. This simulated scenario considers a constellation of identical CubeSat radiometers described by Table 1. Figure 1 shows the calibrated antenna measurements calculated using ACCURACy as well as the current State of The Art intercalibration method for constellations of radiometers, compared to a baseline calibration. The baseline calibration is defined by simulating hot and cold absolute calibration references and performing a 2-point calibration every second. The SOTA implementation simulates sharing calibration measurements between two radiometers when they both collect a calibration measurement over nearly the same locations at nearly the same times. Figure 2 shows the uncertainty (standard deviation) and mean for the simulated calibrated antenna measurements using ACCURACy, the SOTA implementation, and the baseline described above. These values are calculated over a one minute moving window. Table 2 shows the RMSE and variance of the calibrated antenna for ACCURACy compared to the SOTA implementation and baseline, and the improvement is substantial.

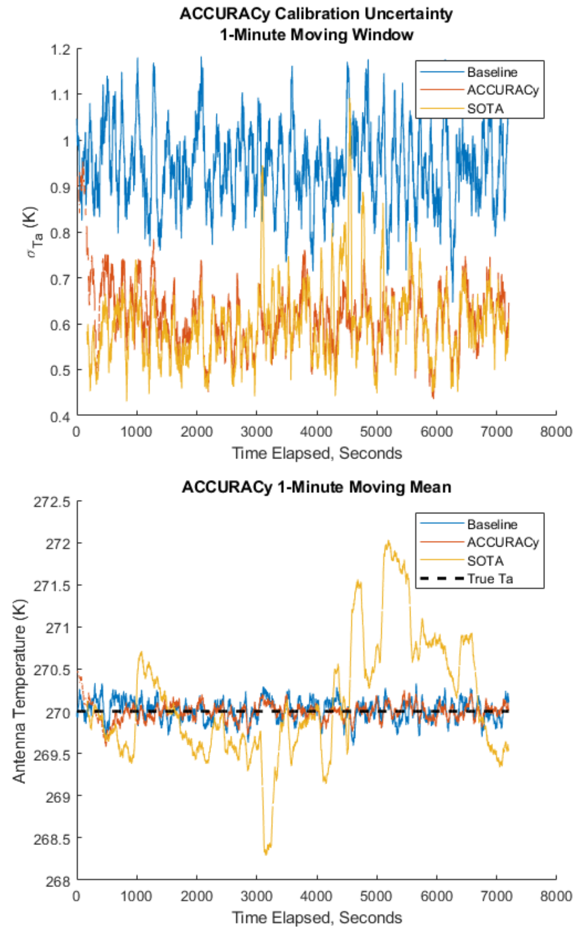

Fig. 2: (**Top**) Standard deviations and (**Bottom**) means of the Baseline, ACCURACy, and SOTA intercalibration methods calculated over a 1-minute moving window.

ACKNOWLEDGEMENT

This work was supported by an Early Career Faculty grant (Grant #: 80NSSC20K0067) from NASA's Space Technology Research Grants Program.

REFERENCES

[1] M. Aksoy, H. Rajabi, P. E. Racette and J. W. Bradburn, "Analysis of Nonstationary Radiometer Gain Using Ensemble Detection," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 13, pp. 2807-2818, 2020, doi: 10.1109/JSTARS.2020.2993765.

[2] M. Aksoy, P. E. Racette and J. W. Bradburn, "Analysis of Non-Stationary Radiometer Gain Via Ensemble Detection," IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium, Yokohama , Japan, 2019, pp. 8893-8896.