National Aeronautics and Space Administration

SmallSat Precision Navigation with Low-Cost MEMS IMU Swarms

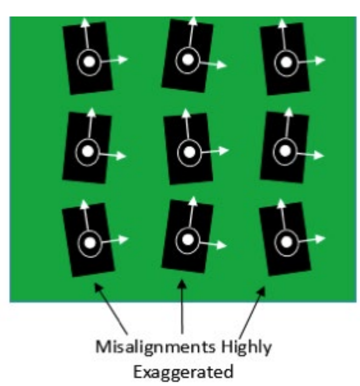
Improving Inertial Sensing Performance for CubeSats

The continued advancement of small satellite-based science missions requires the solution to a number of important technical challenges. Of particular note is that small satellite missions are characterized by tight constraints on cost, mass, power, and volume that make them unable to fly the high-quality Inertial Measurement Units (IMUs) required for orbital missions demanding precise orientation and positioning. Instead, small satellite missions typically fly low-cost Micro-Electro-Mechanical System (MEMS) IMUs. Unfortunately, the performance characteristics of these MEMS IMUs make them ineffectual in many spaceflight applications when employed in a single IMU system configuration.

Therefore, the objective of this project was to employ advanced software algorithms coupled with embedded system architectures to create an effective high-quality IMU from clusters (or swarms) of low-cost MEMS IMUs. Even a large number of MEMS IMUs have a much smaller mass, power, and volume than a traditional high-quality IMU. As a result, a cluster of MEMS IMUs may provide an effective solution to high-quality inertial sensing for small satellite platforms.

Over the course of a two-year SmallSat Technology Partnership, two generations of prototype IMU clusters were built, calibrated, and tested. Each of these IMU clusters contained 16 redundant IMU sensors integrated into a single printed circuit board (PCB) and were designed to fit within the 4 inch x 4 inch (10 centimeter x 10 centimeter) CubeSat footprint. The first generation IMU cluster employed analog sensors and used a field-programmable gate array (FPGA) as a massively parallel input/output processor to simultaneously acquire data from all of the individual sensors. To reduce power demands and simplify the design, the second generation IMU cluster employed digital sensors and a microcontroller for sampling the sensors. There is ongoing work in developing a third generation IMU cluster.

In addition to fabrication of the prototype board, the research team faced new



First generation of the IMU cluster based on analog devices and FPGA (left). Notional illustration of how each individual IMU sensor may be misaligned and motivating the special importance of alignment and calibration for IMU clusters (right).

technical challenges in the areas of precise and low-cost IMU calibration and alignment. This led to the development of novel alignment techniques that make use of only a single axis rate table. Finally, new software algorithms were developed for data processing and for autonomously detecting the failure of individual sensors in the cluster.

The most recent version of the IMU cluster prototype is presently scheduled to fly on a sounding rocket from NASA Wallops Flight Facility in Virginia in 2015. Based on the results from this initial flight test, the team will prepare to fly a final version as part of the Simulation-to-Flight (STF-1) CubeSat mission being led by the NASA Independent Verification and Validation (IV&V) Facility in Fairmont, West Virginia.

The technology developed under this project will help enable a new class of precision inertial sensing for small satellites, and for CubeSats in particular. As other spacecraft components become miniaturized, small satellite are now capable of performing more substantial science missions. The objectives of some of these new science missions result in strict pointing and navigation requirements, and meeting these requirements require high-quality inertial sensing. The MEMS IMU clusters described here may play a critical role in bringing the necessary inertial sensing performance to small satellites in a small and cost-effective package.

This work is being performed by a team of researchers from West Virginia University, Marquette University, and University of South Florida, in collaboration with NASA Johnson Space Center.

This project is funded through the SmallSat Technology Partnerships, a program within the Small Spacecraft Technology Program (SSTP). The SSTP is chartered to develop and mature technologies to enhance and expand the capabilities of small spacecraft with a particular focus on communications, propulsion, pointing, power, and autonomous operations. The SSTP is one of nine programs within NASA's Space Technology Mission Directorate.

For more information about the SSTP, visit:
http://www.nasa.gov/smallsats

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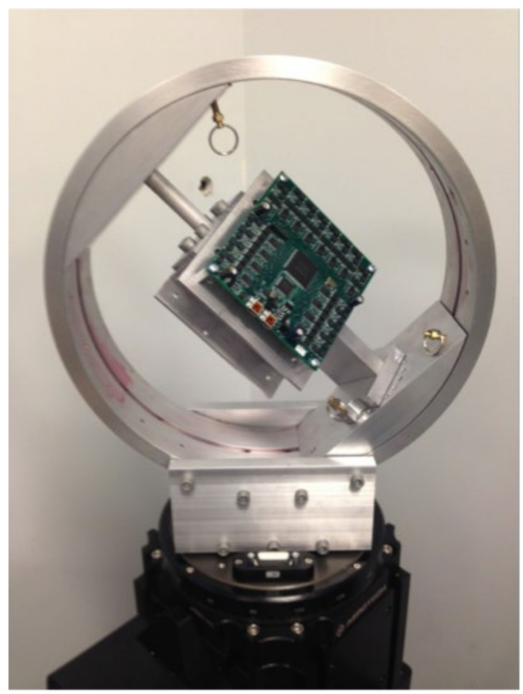

The IMU swarm research team developed a new system (patent pending) for calibrating and aligning MEMS IMU clusters on a single-axis rate table.

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