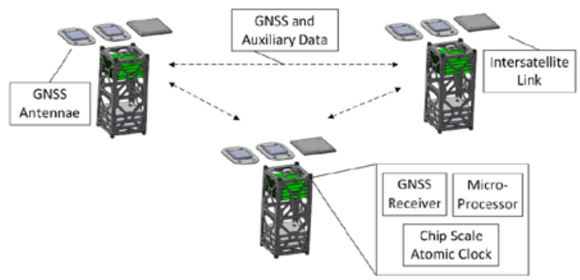
Distributed Timing and Localization (DiGiTaL)

A Precision GNSS-Navigation System for Nanosatellites

NASA facts

The Distributed Timing and Localization (DiGiTaL) system provides nanosatellite formations with unprecedented centimeter-level navigation accuracy in real-time and nanosecond-level time synchronization through the integration of a multi-constellation, multi-frequency Global Navigation Satellite System (GNSS) receiver, a Chip-Scale Atomic Clock (CSAC), and a dedicated Inter-Satellite Link (ISL). In comparison, typical single nanosatellite GNSS navigation solutions are accurate to the meter-level due to the sole usage of single-frequency pseudorange measurements. To meet the strict requirements of future miniaturized distributed space systems, DiGiTaL exploits powerful error-cancelling combinations of synchronous carrier-phase measurements which are exchanged between the swarming nanosatellites through a peer-to-peer decentralized network. A reduced-dynamics estimation architecture on-board each individual nanosatellite processes the resulting millimeter-level noise measurements to reconstruct the full formation state with high accuracy.

Although carrier-phase observables offer millimeter-level noise, they are subject to an offset corresponding to an unknown integer number of cycles, the so-called integer ambiguity. These ambiguities must be resolved in real-time on-board to meet the accurate relative positioning goals of this project. This is a very computationally intensive task, often beyond the capability of spaceborne microprocessors. In contrast to standard offline approaches, DiGiTaL leverages diverse combinations of measurements from new GPS frequencies (L2 and L5), as well as from Galileo and BeiDou, to efficiently resolve integer ambiguities in real time using the Modified Least-Squares Ambiguity Decorrelation Adjustment (mLAMBDA). The estimation architecture is embedded in a



DiGiTaL consists of a plug-in ready multi-GNSS hardware/software 0.5U unit capable of integration with most satellites enabling peer-to-peer decentralized navigation accuracy at the centimeter-level over separations up to hundreds of kilometers.

distributed network of nanosatellites that is intended to support all operational scenarios, while coping with data handling and communication constraints. To this end, each DiGiTaL instance processes carrier-phase measurements from only a limited number of satellites simultaneously. The resulting state-covariance estimates produced by each nanosatellite are then fused through a dedicated swarm relative orbit determination algorithm to provide full formation orbit knowledge. Contingency scenarios are aided by a near-omnidirectional antenna system and a CSAC which allows accurate orbit propagation and faster convergence times in GNSS-impaired scenarios.

DiGiTaL is motivated by two key technologies which are revolutionizing the way humans conduct spaceflight: the miniaturization of satellites and the distribution of payload tasks among multiple coordinated units. The combination of these techniques is leading to a new generation of space architectures, so-called distributed space systems, which promise breakthroughs in space, planetary, and earth science, as well as on-orbit servicing and space situational awareness. However, current technologies for satellite navigation and timekeeping are insufficient to support NASA's future mission concepts. DiGiTaL responds to this need by providing the navigation and timing accuracy required for multiple nanosatellites to act in unison as a large aperture spacecraft. Some specific mission applications include but are not limited to synthetic aperture radar interferometers, differential gravimeters, starshade/telescope systems for the direct imaging of the star vicinity, and autonomous assembly of larger structures in space.

DiGiTaL is developed by the Space Rendezvous Laboratory (SLAB) at Stanford University's Department of Aeronautics and Astronautics in partnership with NASA Goddard Space Flight Center and Tyvak Nano-Satellite Systems, LLC. The project leverages algorithms, software, and hardware developed by the proposing team and demonstrated on formation-flying missions such as PRISMA (SSC, DLR, CNES), MMS (NASA), and CPOD (NASA).

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

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

Publications on DiGiTaL and related work:

Giralo V., D'Amico S.; "Development of the Stanford GNSS Navigation Testbed for Distributed Space Systems"; *Institute of Navigation International Technical Meeting*, Reston, Virginia, January 29- February 1, 2018.

Giralo V., D'Amico S.; "Distributed Multi-GNSS Timing and Localization System for Nanosatellites"; *Institute of Navigation GNSS+* 2018, Miami, Florida, September 24-28, 2018.

D'Amico S., Carpenter R.; "Satellite Formation Flying and Rendezvous"; In Parkinson, et al.: *Global Positioning System: Theory and Applications* - Chap. 50 (2018). *Submitted*.

Giralo V., D'Amico S.; "Distributed Multi-GNSS Timing and Localization System for Nanosatellites"; *Navigation*; *Submitted*

For more information on DiGiTaL contact:

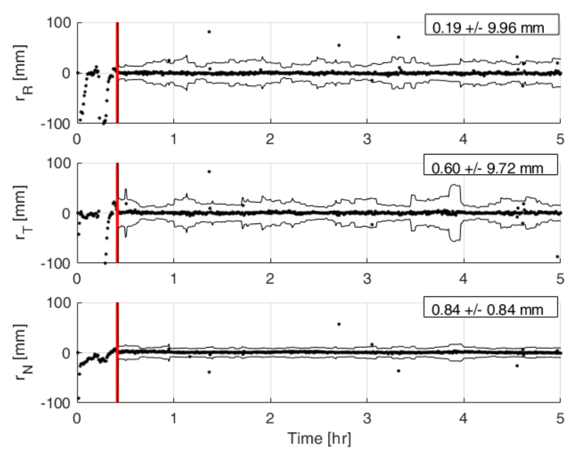
Professor Simone D'Amico
Department of Aeronautics and Astronautics
Stanford University
damicos@stanford.edu

Roger C. Hunter
Small Spacecraft Technology Program Manager
Space Technology Mission Directorate
NASA Ames Research Center
Roger.C.Hunter@nasa.gov

Christopher Baker
Small Spacecraft Technology Program Executive
Space Technology Mission Directorate
NASA Headquarters
Christopher.E.Baker@nasa.gov

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, CA 94035
www.nasa.gov
FS #2013-04-07-ARC

DiGiTaL is validated on two Tyvak flatsat development boards (top), each consisting of a Novatel OEM628 Multi-GNSS receiver, an Endeavour flight computer (800 MHz), and a UHF intersatellite radio. GNSS signals are generated using an IFEN GNSS Signal Simulator (bottom), allowing for GPS L1 and L2, Galileo E1, and BeiDou B1.



DiGiTaL's relative position navigation errors and 3σ covariance bounds for two spacecraft in the frame aligned with (R)adial, (T)angential, and (N)ormal directions. Results show sub-centimeter level accuracy obtained in real-time on-board CubeSat avionics. Red line indicates initialization of carrier-phase integer ambiguity resolution.