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Embedded PNT Module For Distributed Radar Sensing

A Self-contained Positioning, Navigation, and Timing (PNT) Solution that Enables
High-Resolution and Low-Latency Multi-Baseline Observations

A NASA ESTO Decadal Survey Incubation (DSI) 2022-2025 Project

2023 Earth Science Technology Forum

21 June 2023

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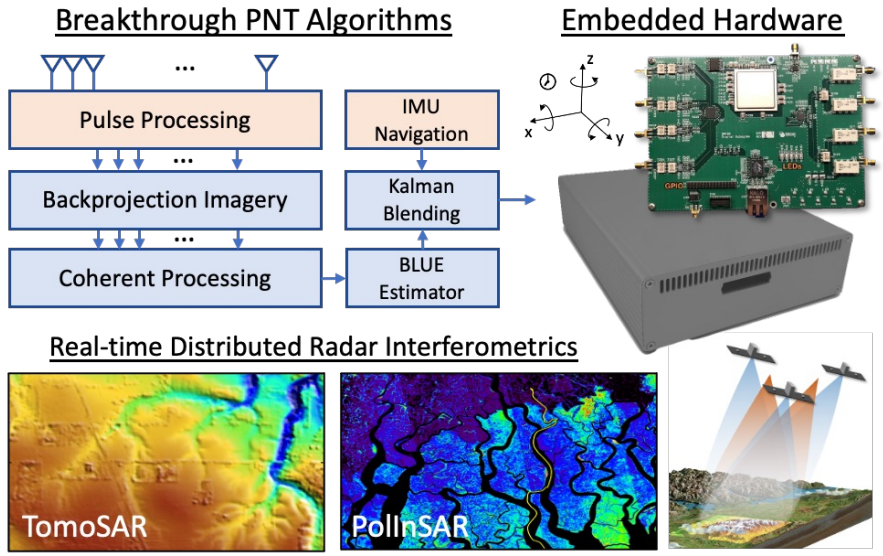
Aloft DSI Project Overview

- Aloft's patent-pending radar-based PNT (Positioning, Navigation, and Timing) technique provides **micron-level positioning, milli-degree orientation, picosecond timing** ("AloftPNT").
- This high level of precision is required for **coherent alignment of complex radar imagery** across distributed sensors to realize emerging techniques like multi-baseline polarimetric InSAR (PolInSAR) and tomographic SAR (TomoSAR) and achieve accurate 3-D volumetric reconstructions of surface vegetation and other structures.
- Under our DSI program, Aloft is developing, implementing, and testing a **prototype PNT module** that delivers high-precision PNT solutions in real-time.
- The resulting custom-built digital hardware, combined with efficiently embedded innovative algorithms, enables distributed interferometric radar formations to support new STV science investigations and provide **low-latency, high-resolution, high-accuracy** products.



***Objective**: Create a portable hardware module with embedded software/firmware to enable distributed radar STV measurements via AloftPNT.*

Planned Outcome and Contribution to STV Architecture

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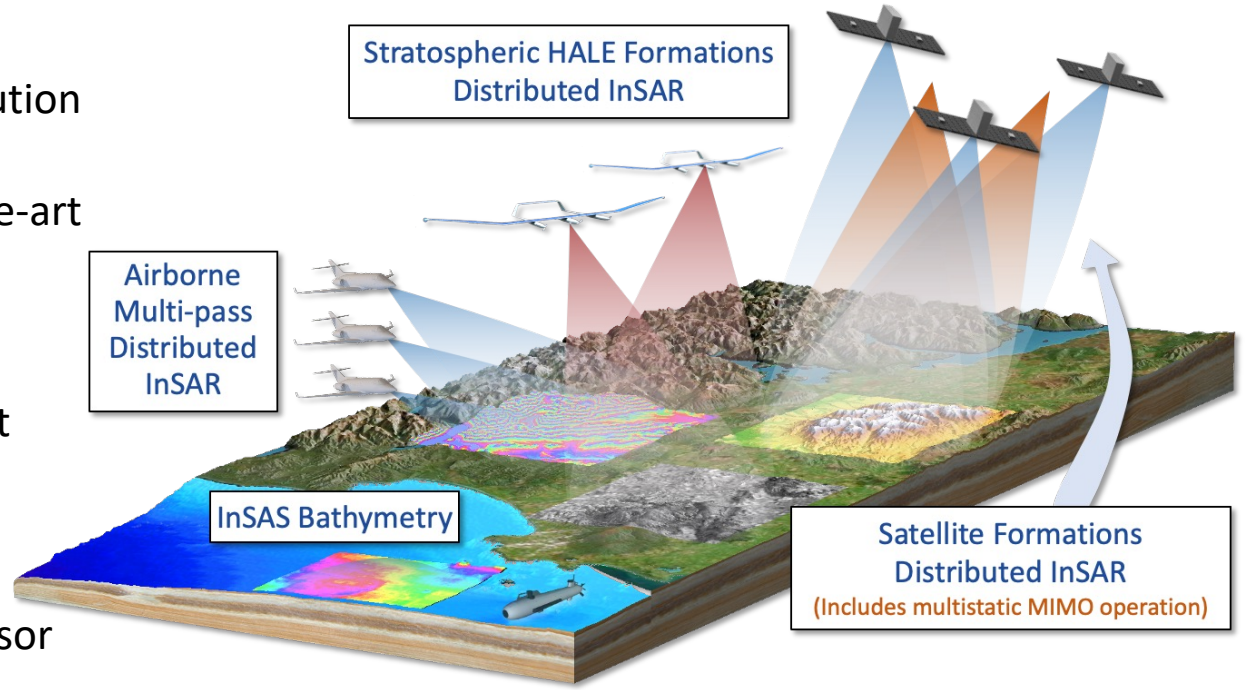
- A portable module to improve surface topography & vegetation (STV) observations by enabling distributed interferometric radar measurements
  - Embedded AloftPNT algorithms support STV observational requirements for enhanced vertical accuracy (3 cm), resolution (0.5 m vertical, 1 m horizontal), and latency (0.5 day)
  - 10 to 100x improved accuracy over the current state-of-the-art
- Flexible Implementation:
  - AloftPNT can be implemented as a stand-alone hardware module or integrated into existing/future InSAR sensors (at either the HW or SW level)
- Broad Applicability:
  - An AloftPNT module can serve as the core of an InSAR sensor or function as a strictly navigational device
  - AloftPNT module is small & modular and can remove the need for a high-grade GNSS/IMU system
    - Offers reduction in cost and size of STV science instruments



AloftPNT enables measurements across multiple domains

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Aloft's Core Algorithms provide exquisite PNT precision

Supports autonomous navigation and enhanced coherent sensing

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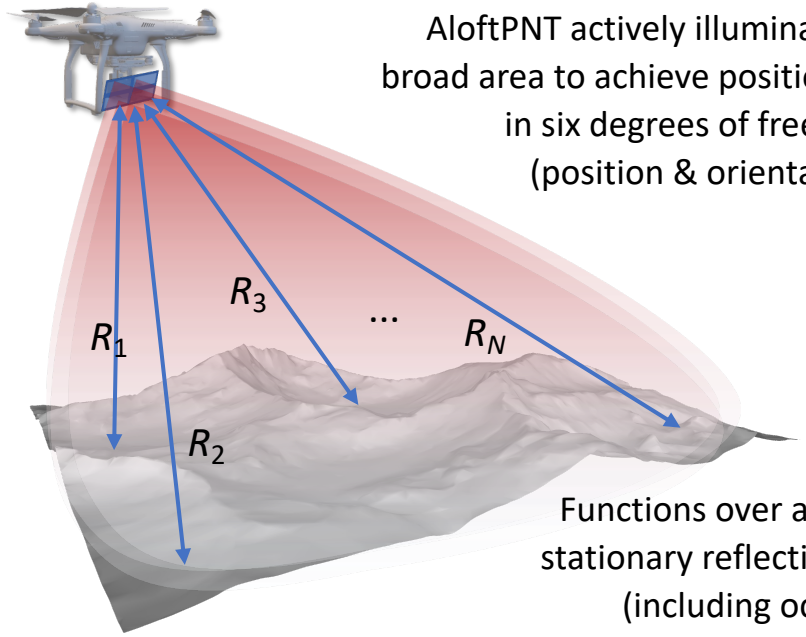
AloftPNT

6-DoF Position & Orientation

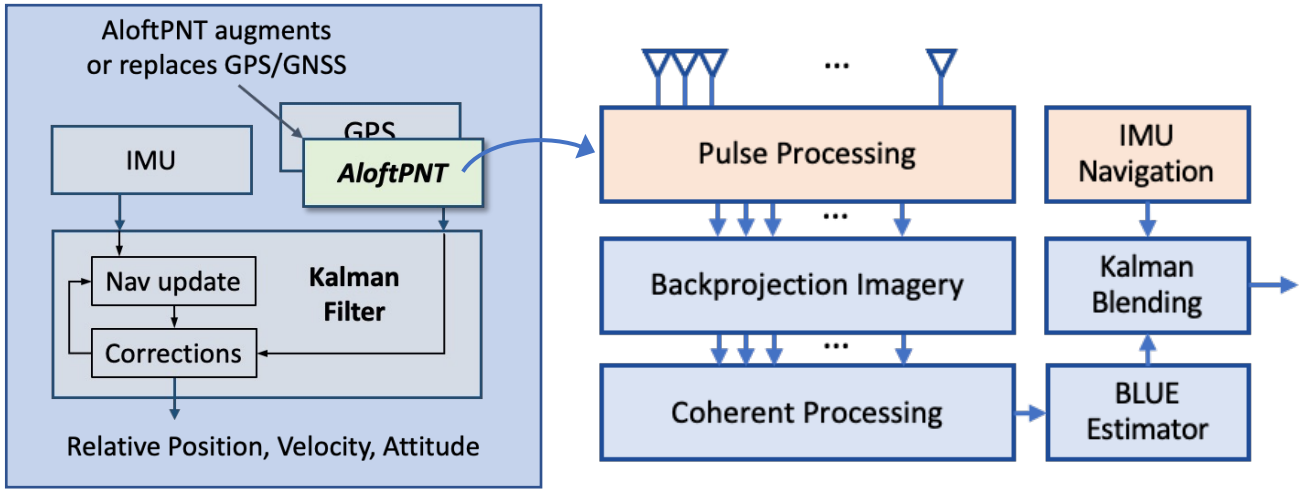


AloftPNT actively illuminates a broad area to achieve positioning in six degrees of freedom (position & orientation)

Functions over any quasi-stationary reflecting surface (including ocean)

AloftPNT trades IMU performance for computational performance

- MEMS IMUs are inexpensive and small, but inaccurate
- Computational radar algorithms recover the needed accuracy, leveraging the coherent response at fractional-wavelength scales



AloftPNT employs algorithms developed for GPS positioning*

1. Best Linear Unbiased Estimate (BLUE) for position/time
2. Carrier frequency "widelaning" for ambiguity resolution

*Misra and Enge, *Global Positioning System: Signals, Measurements, and Performance*, Ganga-Jamuna Press, 2012.

Features of AloftPNT:

- Exceptional precision
- Self-contained
  - Operates with or without GPS
  - Requires no terrain information
- Reliable and robust
  - Not susceptible to lighting/weather/obscurants
  - Rapidly reconfigurable for anti-jam / high interference environments

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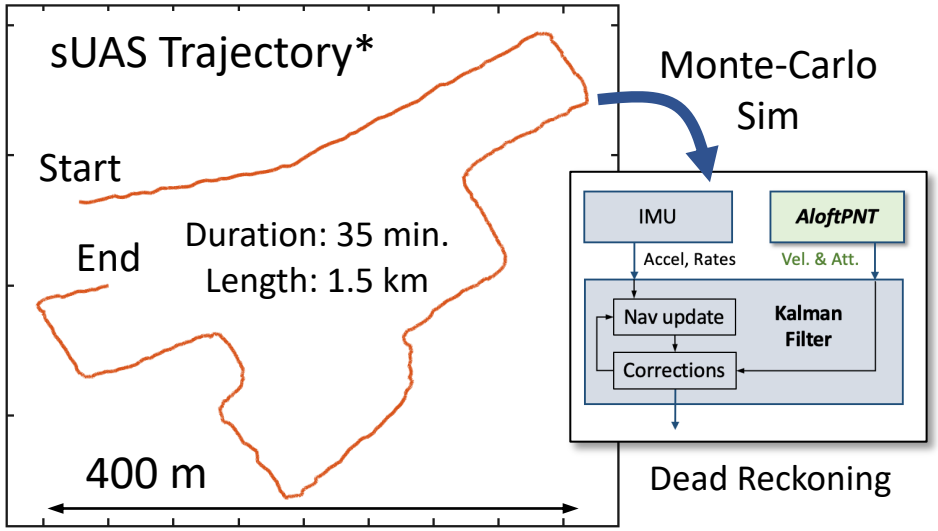
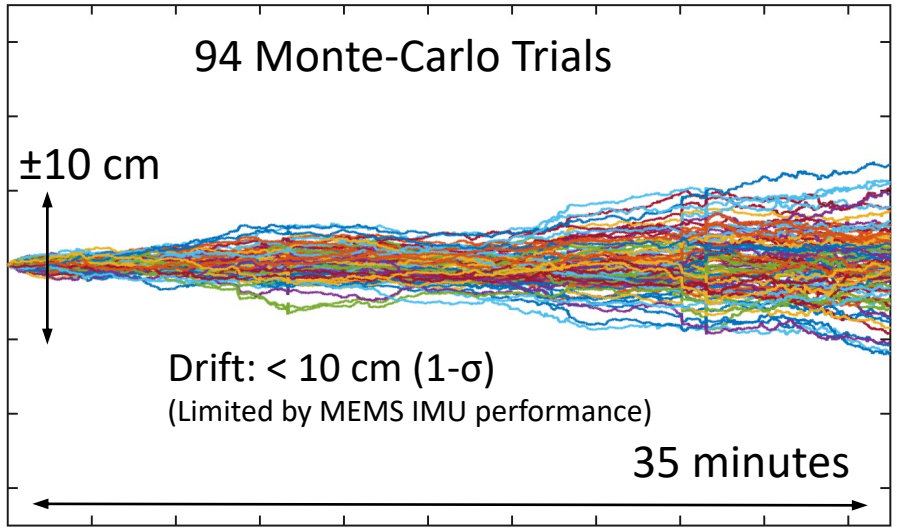
AloftPNT Simulated Performance: MEMS IMU

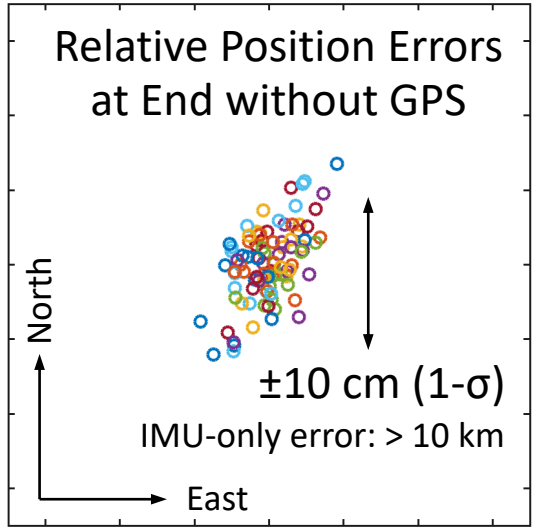
AloftPNT provides precise positioning to constrain IMU drift without the need of GPS

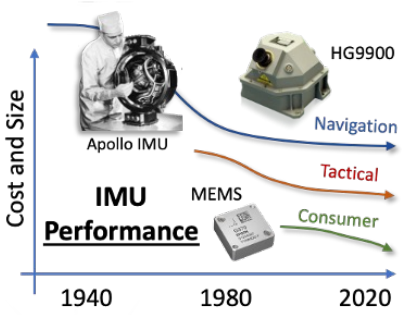
Monte Carlo MEMS IMU Simulation Results



*A.L. Majdik, et al., "The Zurich Urban Micro Aerial Vehicle Dataset," Int. J. of Robotics Research, April 2017





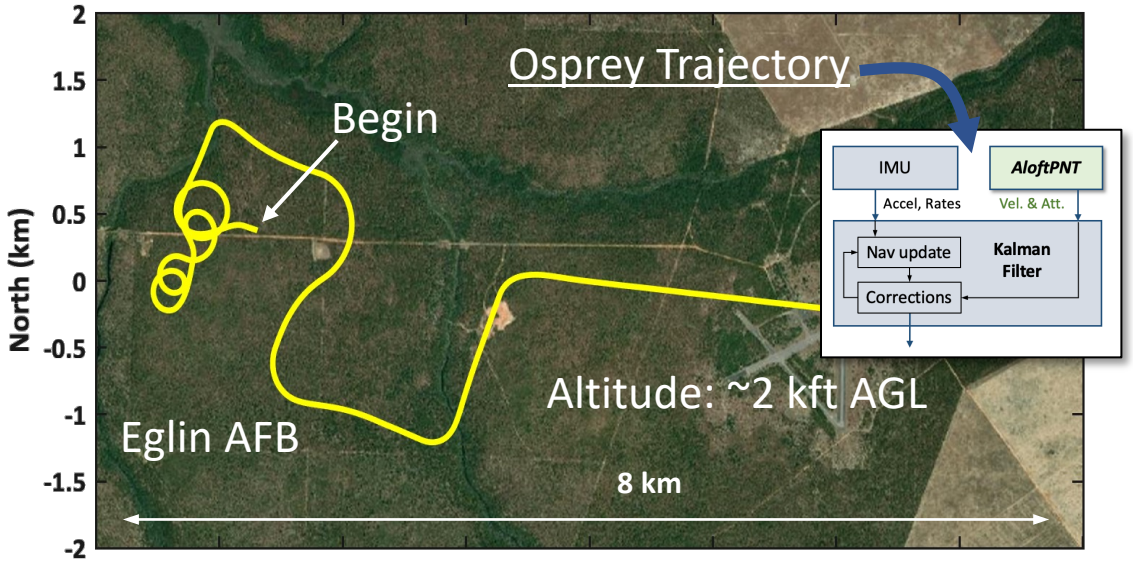


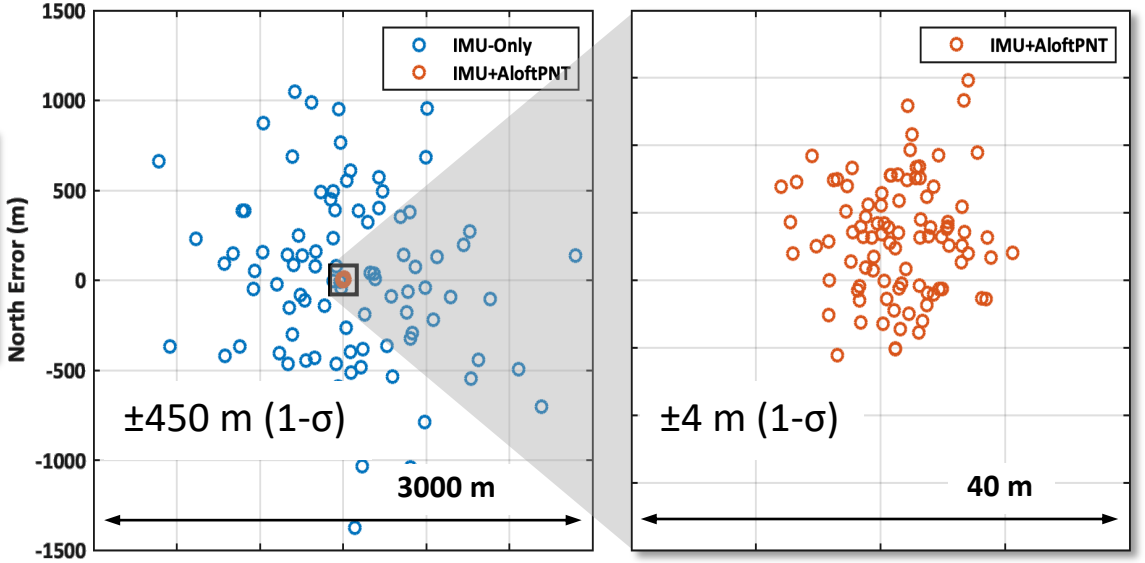
Simulations and data analysis show that AloftPNT provides a **10^5 improvement over low SWAP-C MEMS IMUs**

AloftPNT Simulated Performance: Tactical IMU

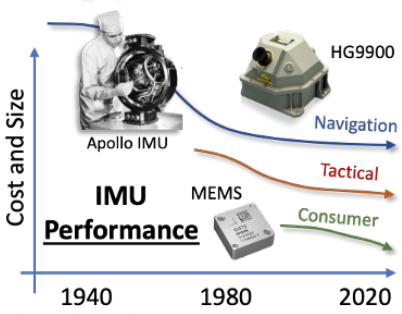
AloftPNT provides precise positioning to constrain IMU drift without the need of GPS

Monte Carlo Tactical-grade IMU Simulation Results





Tactical IMU



Simulations and data analysis show that AloftPNT provides **50-100× improvement over tactical-grade IMU** (above) and 10^5 improvement over lowest-SWaP-C MEMS IMU (previous slide).

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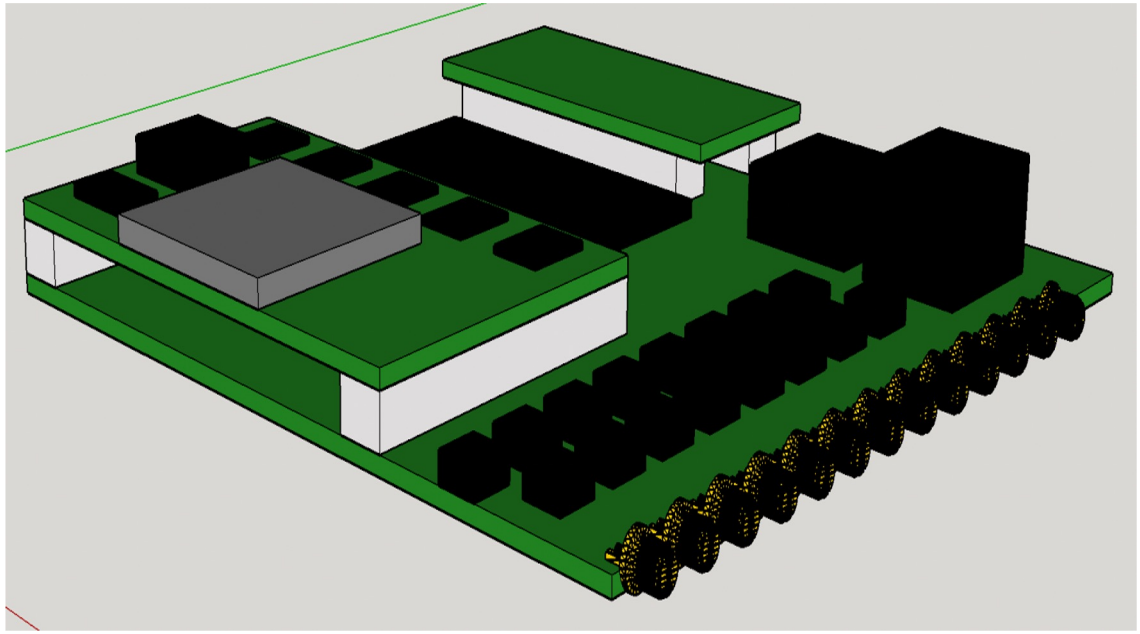
AloftPNT Module Overview

Hardware module and embedded firmware / software development in progress, culminating with first airborne tests in late CY2023 & final form factor demonstrations in early CY2024.



AloftPNT module follows a modular approach to allow for updates to individual key areas (FPGA, GPU, IMU, oscillator, additional interfaces) while preserving the other elements of the design.

Key components of the physical module include:

- RFSoC/FPGA: 8 channels TX + RX
- NVIDIA GPU SoM
- Embedded Epson IMU

Estimated resources:

- Size: ~18cm x 18cm x 4cm
- Mass: ~1.5kg

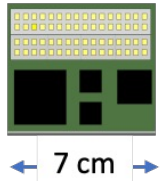
Embedded algorithms include:

- FPGA-based pulse processing
- FPGA->GPU high speed throughput
- GPU-based real-time backprojection image formation processing
- GPU-based coherent processing with BLUE 6-DoF estimation
- Kalman-blending & final product delivery

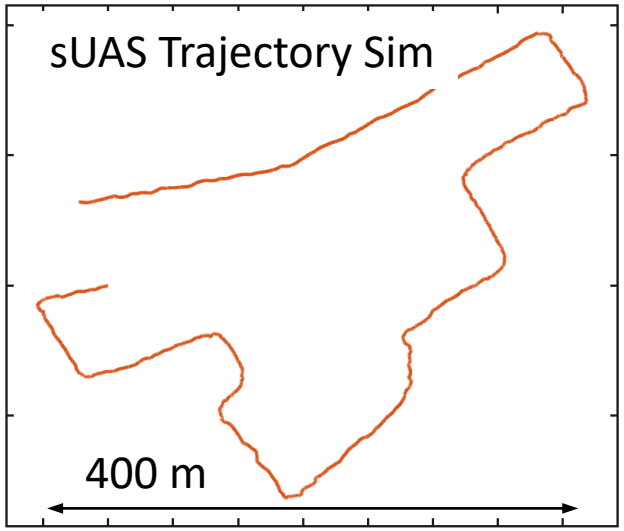
An aside for micro-vehicles…

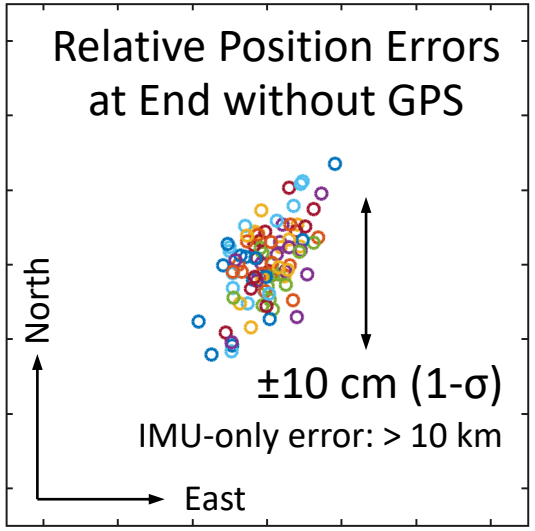
- Aloft's Embedded PNT module is geared toward full radar systems in a few-kg class form-factor.
  - For example, see Aloft's presentation on our stratospheric radar system
- For small vehicles (μUAVs, for example), Aloft is also developing* a PNT-enabled class of systems based around automotive millimeter-wave radar-on-a-chip parts
  - Allows for ~8x scaling for comparable accuracy, e.g., a 25cm diameter system becomes 3cm

iPhone 13

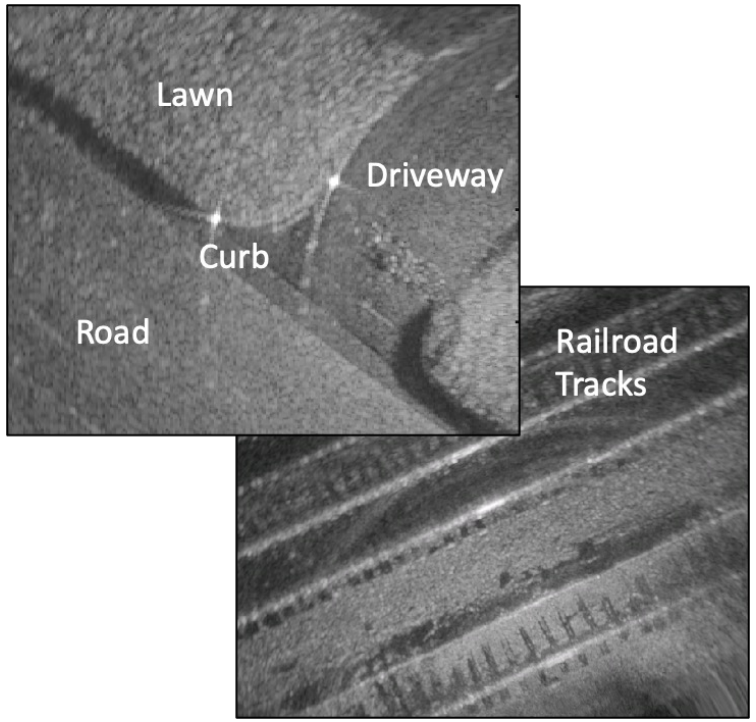


Aloft's in-development micro-Radar Vision System is AloftPNT enabled. The design fits in a 7cm x 5cm form factor.





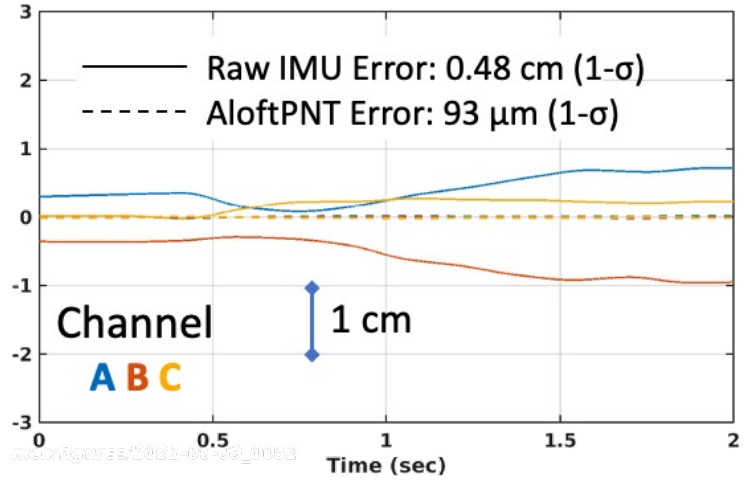
Aloft's millimeter-wave systems can generate quality navigation data (left) and exquisite imagery (right) from a tiny package (upper right)



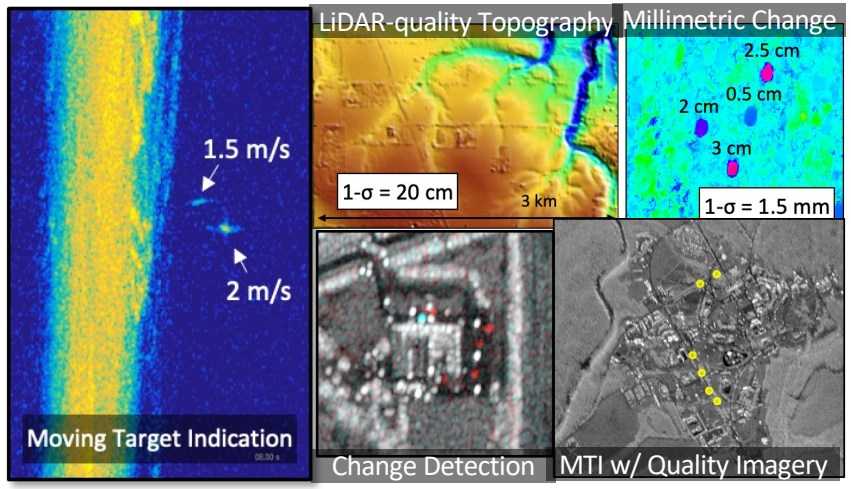
*Under IR&D as well as separate NASA and U.S. Army SBIR programs

Summary

- Aloft is developing, implementing, and testing a **prototype PNT module** that delivers ultra-high-precision PNT solutions in real-time.
- The Aloft PNT Module enables key STV observations, such as distributed interferometric radar for 4-D structural measurements.
- The Aloft PNT module is suitable to serve as a full digital software-defined back-end to new/existing radar systems, or as an add-on module to fully developed systems.
- The Aloft PNT Module provides a path for SWaP reduction on non-radar sensors.
- Key developments to date:
  - Hardware preliminary design is complete, with detailed design in progress.
  - Key algorithms have been prototyped and meet expected performance needs.
  - Key embedded algorithm implementation activities to date include firmware range processing, real-time GPU backprojection implementation, and throughput demonstrations.
- Complementary Aloft programs will leverage the Aloft PNT Module developments (i.e., NASA SBIR for robotic mobility on small solar system bodies).



Example advanced products generated with the AloftPNT module include navigation solutions (above) and/or advance SAR products (below).



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