Accuracy Assessment of Two GPS Fidelity Prediction Services in Urban Terrain

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D6: Aerial Vehicle Navigation

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Outline

- GPS Fidelity Prediction Services
- Methodology
- Agreement between prediction and measurements
- Correlation of SV count
- Prediction of visible SV IDs
- Limitations

Conclusions

- The prediction services validated in this study run fast enough for preflight safety planning
- Incidence of false positive predictions is negligible but incidence of false negative predictions is too high
- Better modeling of stray signals is needed to improve prediction

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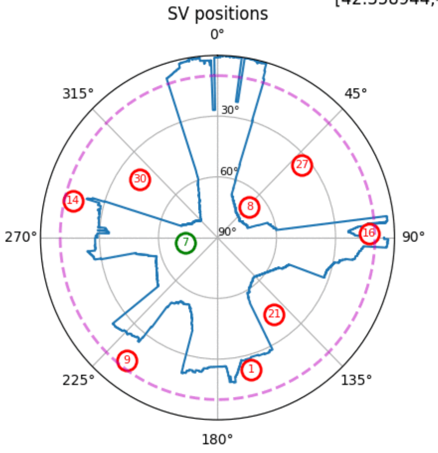
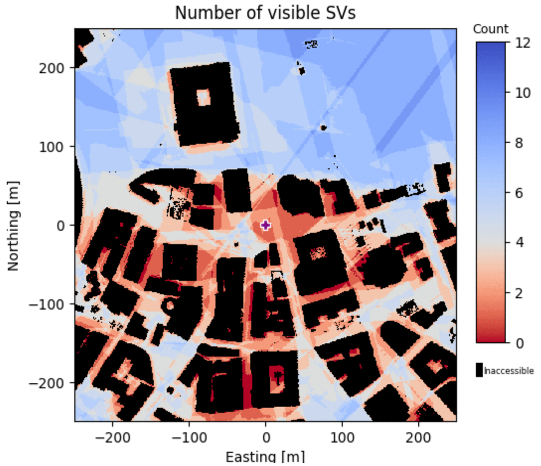
GPS Prediction Service: Geometric Assessment of Positioning Systems (GAPS)

- GAPS projects from the satellite position to all locations within a volume and computes the shadows cast by 3D terrain features interposed between each satellite and each location

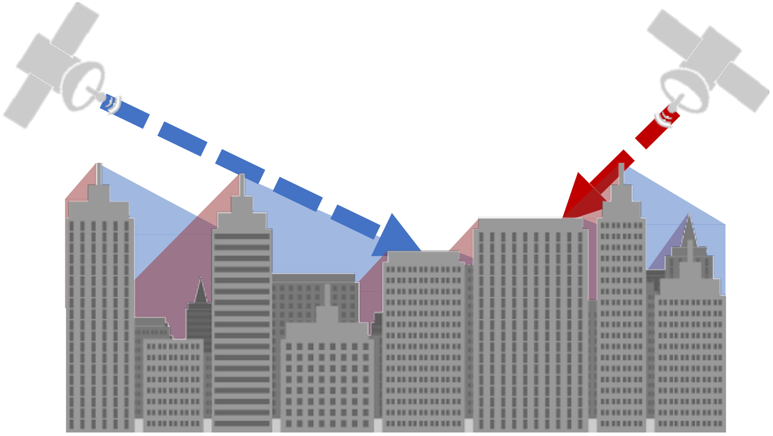
2021-07-25 06:00:00 EDT
[42.358944,-71.057019] Alt: 30.0 [m]



Blue: Skyline
Green: Visible satellite
Red: Blocked satellite

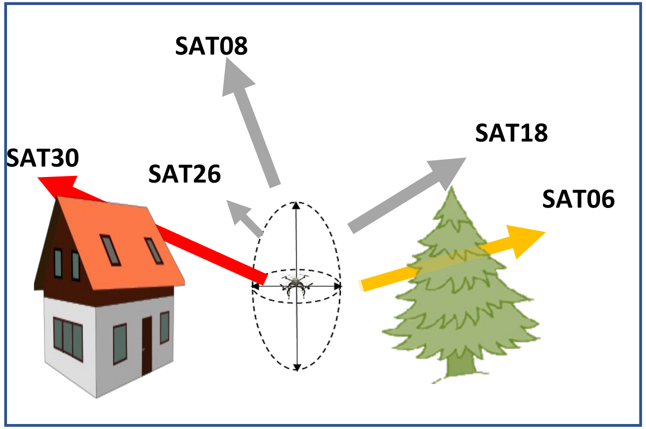


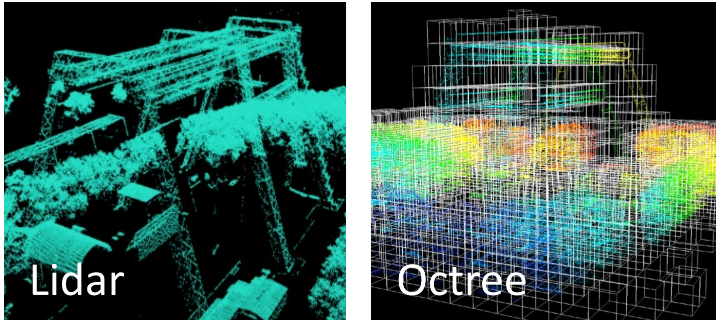
Downtown Boston navigation at 30m altitude, GPS constellation



GPS Prediction Service: Corridor Assessment of Positioning Systems (CAPS)

- Organizes 3D lidar data of a flight range into a spatial octree, computes rays from a receiver location to each satellite position, and finds intersections of each ray with voxels of the octree



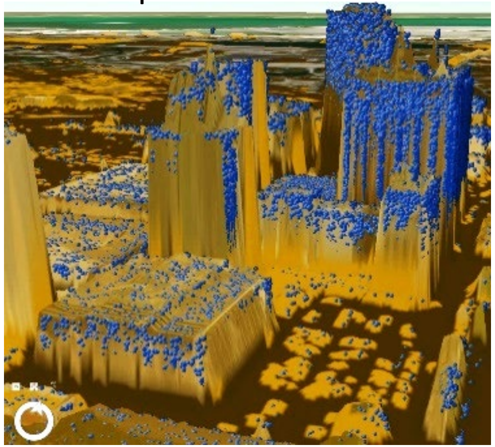


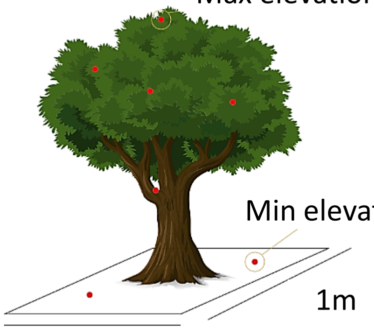
Rays to GPS + Glonass SVs at NASA Lunar Landing Facility

Methodology

- Terrain data
  - The two prediction services used a common terrain survey
    - Aerial lidar scan conducted for the United States Geological Survey (USGS) in 2018
  - To improve point cloud sampling for CAPS:
    - Additional points were added to the raw point cloud at 0.5m intervals between ground and the maximum survey altitude at each side of buildings
  - The GAPS engine operates on Digital Surface Models (DSMs) representing the maximum elevation captured by the LIDAR survey for each 1x1 m^2 tile

Lidar (blue) and TIF (brown) for Corpus Christi terrain





@Map data: Esri/ArcGIS

Methodology

- Data Collection
  - Real-time geolocation measurements across:
    - 3 days in 2022: June 6, July 28, August 27
    - Different start time, ~5 miles across ~1 hour, each day
    - Through unobstructed areas as well as dense urban canyons of Corpus Christi
- Sensors
  - u-Blox Zed-F9P receiver configured to receive L1 and L2 band signals from GPS and Glonass
  - Ruggedized VN-200 antenna configured to receive L1 signals from GPS constellation and produce a tightly integrated GPS/IMU solution
  - CORS station TXPO (for kinematic RTK)

Ground truth (green) and computed position from receiver data (cyan) on June 6

Measurement rig

@Map data: Google, SIO, US Navy, NGA, GEBCO, Landsat/Copernicus

Methodology

- Reference position
  - The ground truth measurement location is inherently uncertain at times– some hand-editing required
  - Several seconds of temporal smoothing of receiver 1 output via the u-Blox u-Center utility most closely tracked the actual lateral position
  - Vertical position error in this derived track was severe at some locations, and so the reference altitude was set to 2 meters above ground
- Receiver 1 output was post-processed with RTKLIB to provide, at each one second measurement time
  - The subset of SVs used in the position determination
  - Receiver geolocation estimated from the instantaneous signals

Ground truth (green) and computed position from receiver data (cyan) on June 6

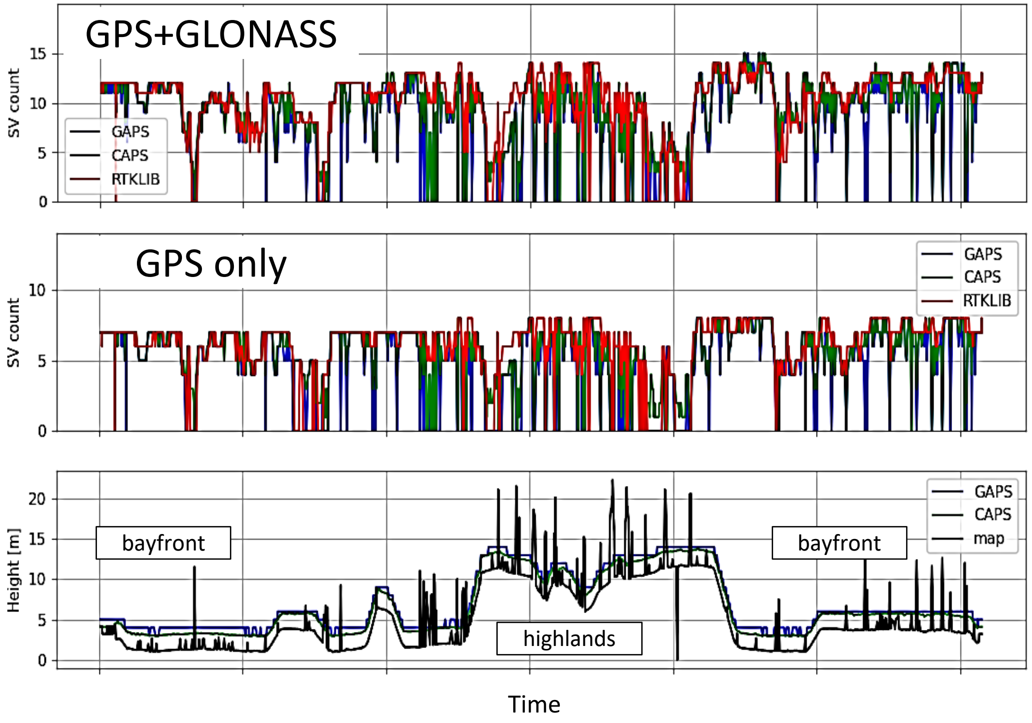
Measurement rig

@Map data: Google, SIO, US Navy, NGA, GEBCO, Landsat/Copernicus

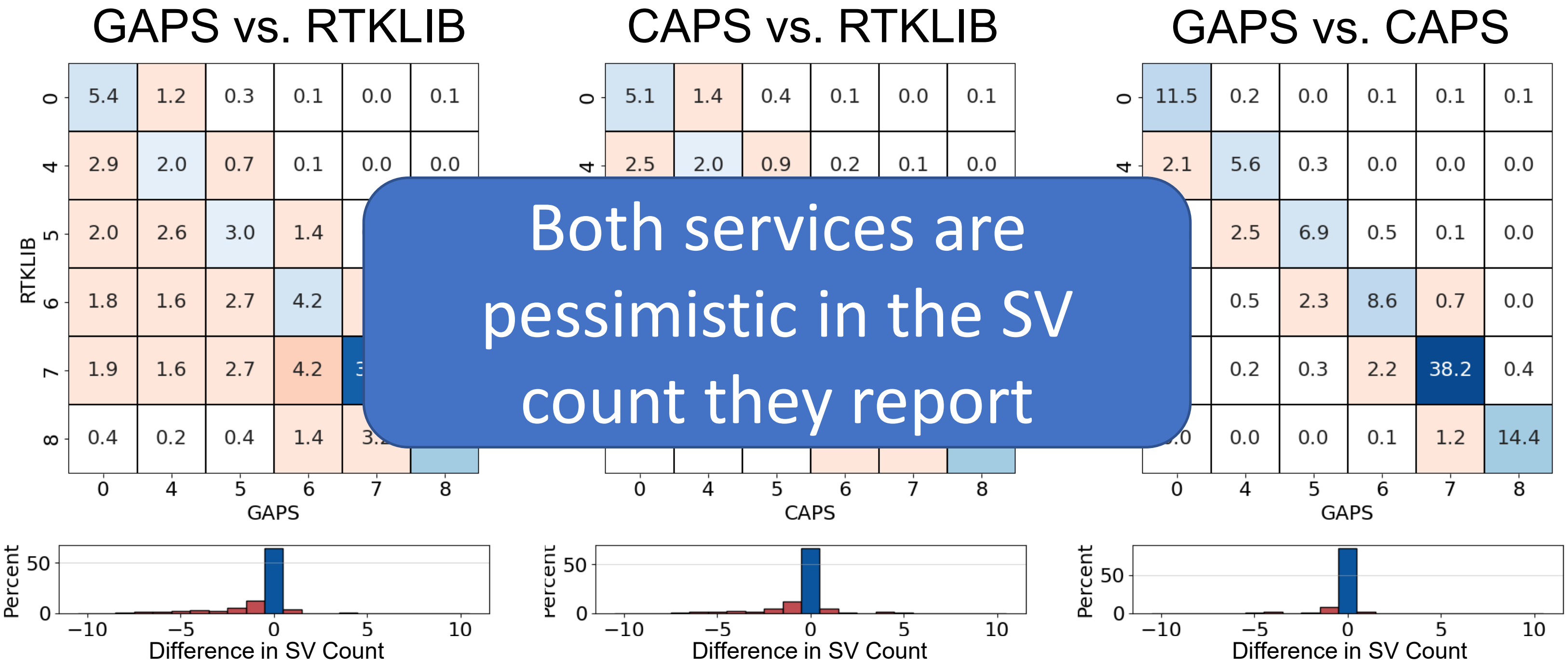
Agreement between prediction and measurements

- Broad SV count agreement for both GPS+GLONASS and GPS-only
- Degraded navigation is severe in the urban canyons of the highlands, traversed in the middle portion of this series
- Lower graph shows topographic elevation and ground truth elevation used by the two prediction services

Predicted and measured SV count for June 6



Correlation of SV Counts

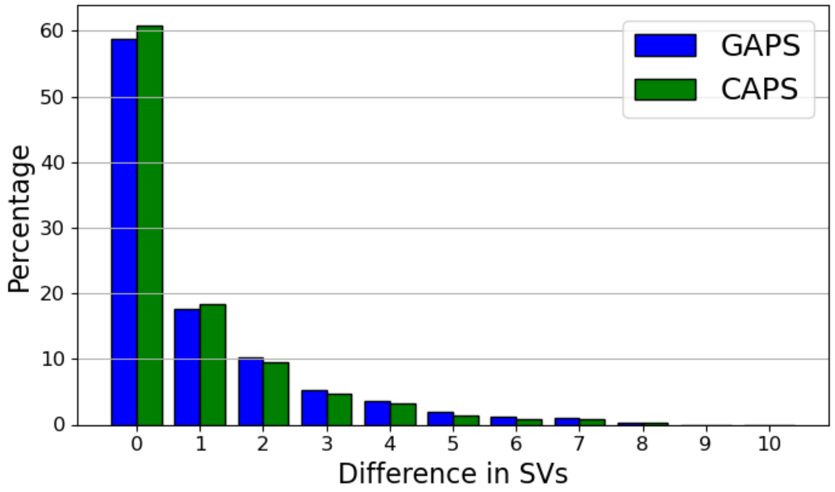


Above diagonal: Predicted but not measured

Below diagonal: Measured but not predicted

Prediction of visible SV IDs

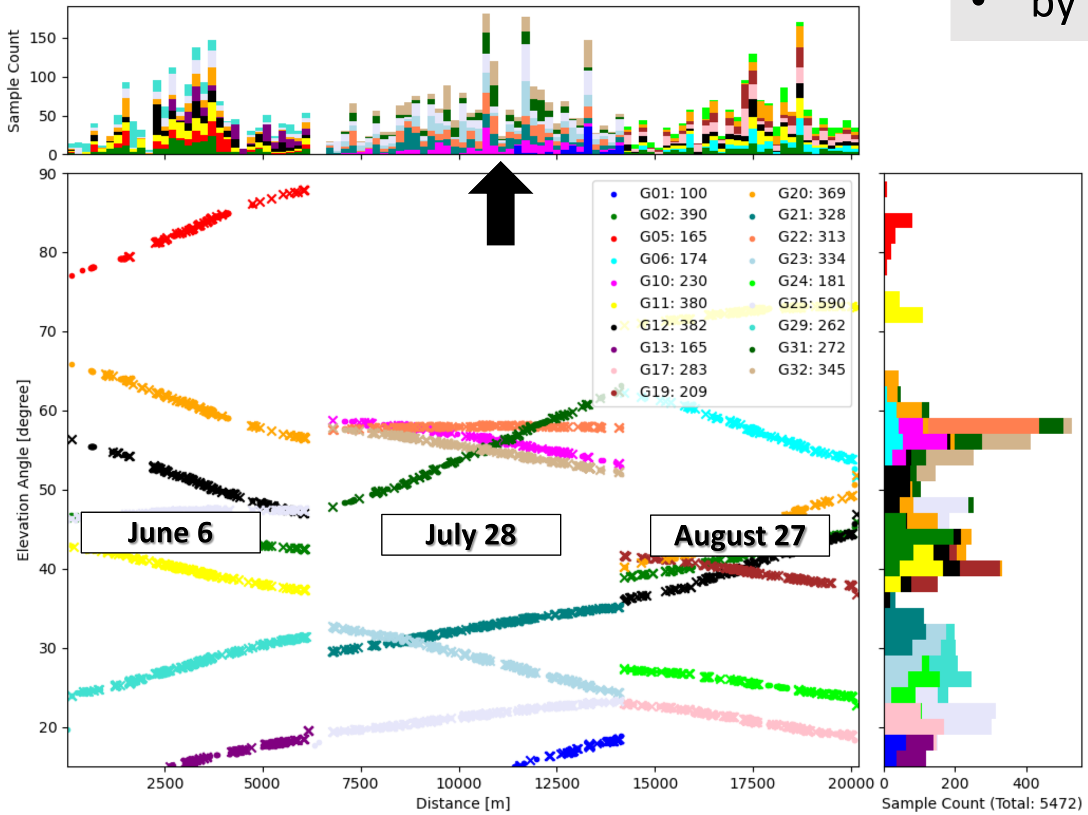
- Both GAPS and CAPS predictions match observations ~60% of the time
- Mismatch by one satellite occurs 18% of the time
- Mismatch by two satellites occurs 10% of the time



Prediction of visible SV IDs

Projection of SV ID mismatch count

- by elevation angle (right)
- by sample sequence (top)



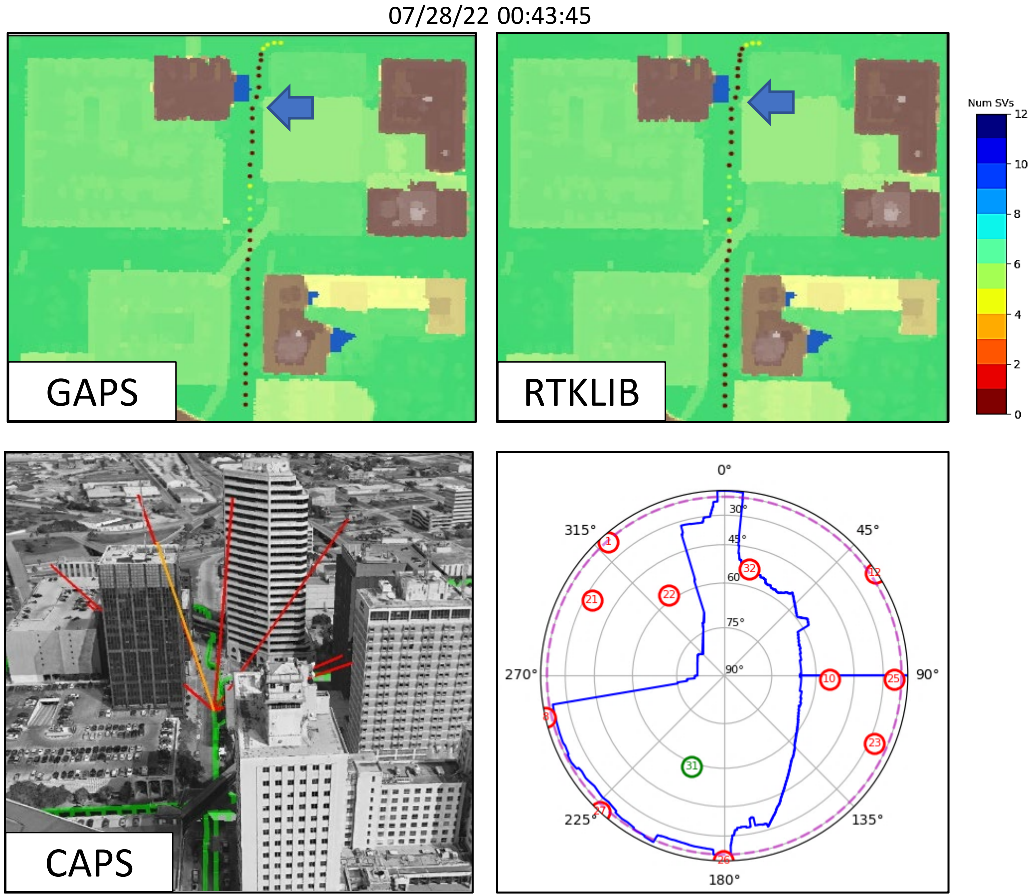
Achieved diversity of SV IDs and elevations across dates

Mismatch magnitude is skewed toward low-elevation SVs

- Signals from SVs directly overhead would not be obstructed by terrain
- Signals from SVs at high elevation are less likely to be obstructed but may be diffracted and reflected from the sides of buildings
- Signals from SVs at low elevation are most likely to be obstructed, diffracted, and reflected

Example 1 – Exact match

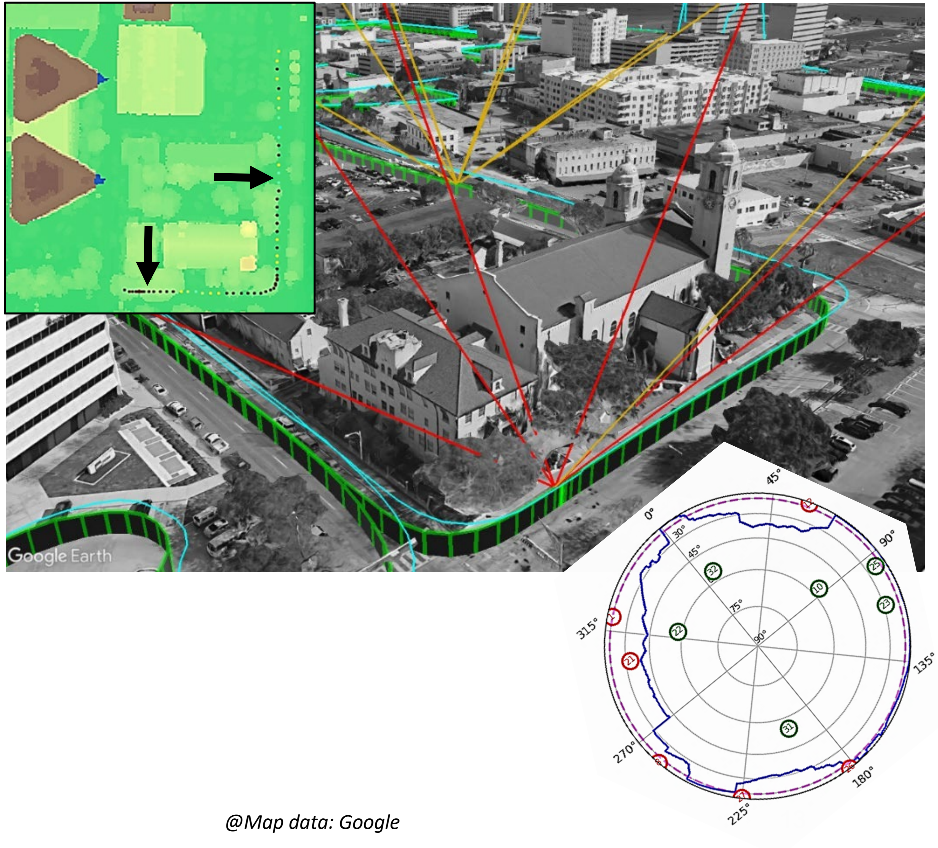
- Prediction of navigation loss in urban canyon
- Few satellites are available to the sensor at this location
- GAPS and CAPS correctly report the set of visible and blocked satellites



@Map data: Google

Example 2 – Perfect match and false negative

- Exact match (background) from the July 28 recording
  - The set of predicted and measured SV IDs match exactly
- False negative (foreground)
  - CAPS and GAPS show visibility from only one SV (gold ray) with the rest blocked by terrain (red rays)
  - This false negative arises from the tree canopy in the foreground location which is regarded as opaque



@Map data: Google

Limitations

- Ground truth reference (spatial)
  - The ground truth measurement location is inherently uncertain in highly degraded areas – some hand-editing required
- Ground truth reference (satellite count)
  - The subset of valid satellites was obtained using the default validity tests of the post-processing tool (RTKLIB)
- Foliage transparency
- Major technology gaps
  - Better terrain map currency
  - Multipath modeling

Ground truth (green) and computed position from receiver data (cyan) on June 6.

@Map data: Google, SIO, US Navy, NGA, GEBCO, Landsat/Copernicus

Summary

1. Two navigation fidelity prediction services were validated by comparison with over 6000 GNSS readings collected along a five-mile path through urban areas of Corpus Christi on three dates in 2022
2. Predicting performance using full 3D geometric methods can aid in planning and support in-flight risk mitigation
3. Comparing SV count as well as SV ID can provide a reasonable validation methodology

Conclusions

- The prediction services validated in this study run fast enough for preflight safety planning
- Incidence of false positive predictions is negligible (< 5%)
- Incidence of false negative predictions is too high (mismatch = four or less 95% of the time)
- Better modeling of stray signals is needed to improve predictions

Goal: **For low altitude navigation, predictions computed in three seconds or less with an accuracy of two SVs or less 95% of the time are desirable.**

BACKUP

Methodology

- GAPS was executed on a machine with two Intel Xeon Silver 4216 CPUs, each with 16 cores/32 threads (hyperthreading enabled), 128 GB of RAM and an A6000 NVIDIA[TM,1] GPU
- CAPS was executed on a machine with two 8-core 2.6 GHz Xeon E5-2670 CPUs (32 total threads) and 128GB of RAM.
- Python code performed high-level setup and some low-intensity calculations (e.g. satellite propagation) for both services
- GAPS' geometry calculations were computed with a combination of C++ and CUDA code
- CAPS' geometry calculations were accomplished with custom C++ raycasting code and octree functions from Point Cloud Library [4] (version 1.7.2)