Tightly-coupled GNSS-aided Visual-Inertial Localization

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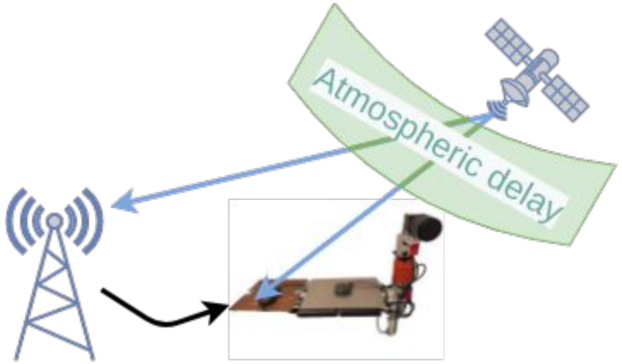
RPNG

Single-Sensor-Based Differential GNSS

- GNSS fusion with VIO: Globally accurate and locally precise localization
- Differential-GNSS: More accurate than single GNSS solution

Conventional DGNSS

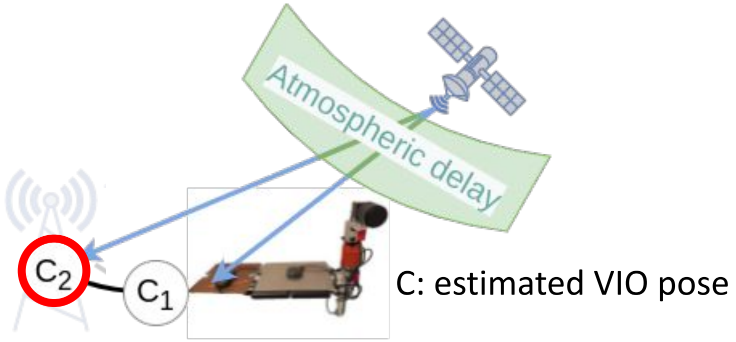


Remove atmospheric error by comparing:
signals from two different GNSS sensors

Drawbacks of conventional:

- Requires 2 or more GNSS sensors
- Requires stable communication
- Limited range from base (< 10km)

Single-sensor-based DGNSS



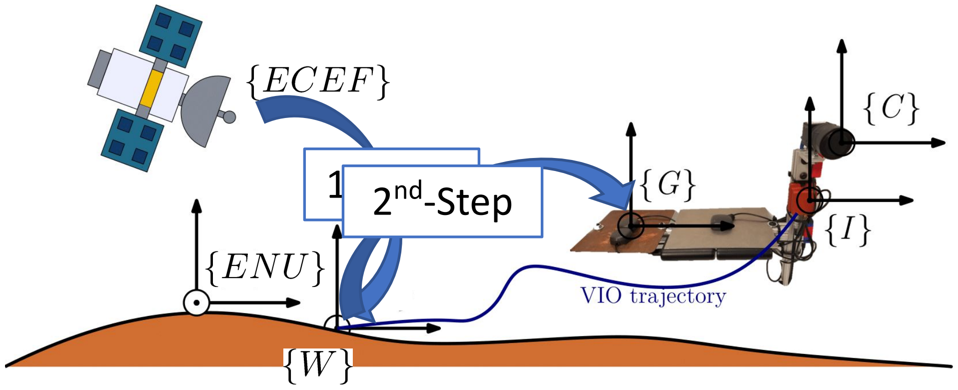
Remove atmospheric error by comparing:
sequential signals of the same GNSS sensor

Advantages of proposed system:

- Single GNSS sensor mounted on robot
- No communication or distance issue
- Equivalent to have base right next to robot
- **Raw GNSS** (pseudorange, carrier, doppler) model
- No need to model atmospheric error

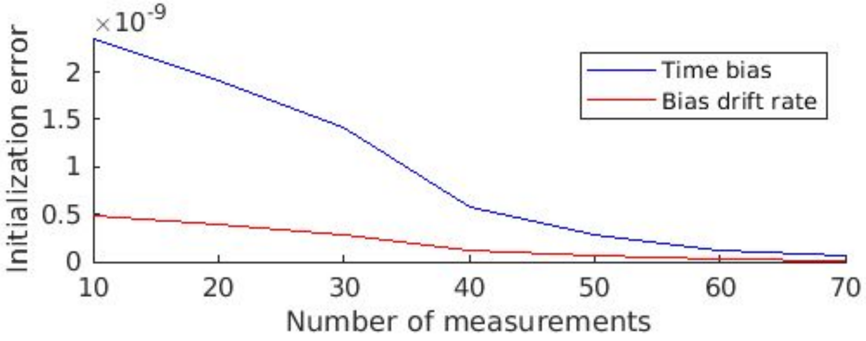
2-Step GNSS Initialization

- 0^{th}-Step: Information Collection
  - GNSS measurements
  - VIO poses
- 1^{st}-Step: ECEF-to-World frame
  - Linear least-squares with quadratic constraint problem
  - Better with longer trajectory
  - Better with smaller GNSS noise
- 2^{nd}-Step: GNSS sensor parameters
  - Sensor time bias, time bias drift rate
  - Linear least-squares problem
  - Better with larger # of measurements



dist\\σ	0.1m	0.5m	1m	2m	5m
5m	1.57 / 0.58	6.25 / 2.91	14.52 / 6.79	30.66 / 71.75	69.26 / 88.42
10m	1.31 / 0.52	5.54 / 2.19	9.45 / 4.17	20.41 / 44.94	47.45 / 94.93
20m	0.79 / 0.27	2.47 / 0.99	4.84 / 2.01	10.24 / 4.10	26.96 / 51.54
50m	0.53 / 0.07	0.80 / 0.16	0.97 / 0.27	1.79 / 0.62	4.86 / 1.48
100m	0.45 / 0.09	0.49 / 0.06	0.50 / 0.12	0.78 / 0.24	2.11 / 0.65

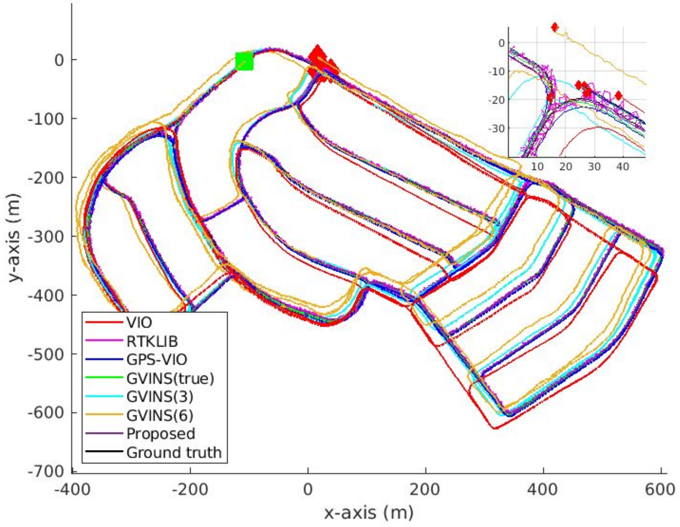
Table: Initialization error (deg/m)

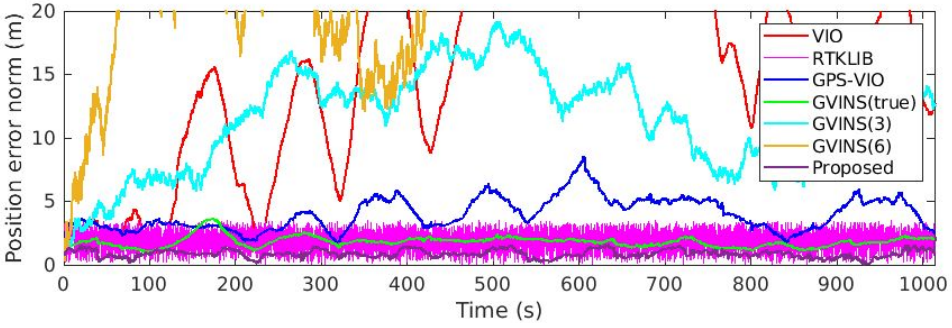


Simulation Results: Localization & Calibration

Localization

- Robust to GNSS atmospheric errors
- Accurate GNSS measurement model
- Accurate Localization





Algorithms	8m	16m	24m	40m
VIO	0.04 / 0.11	0.05 / 0.16	0.07 / 0.19	0.08 / 0.26
GPS-VIO	0.03 / 0.09	0.05 / 0.13	0.06 / 0.16	0.07 / 0.21
RTKLIB	0.44 / 2.55	0.51 / 2.56	0.63 / 2.55	0.53 / 2.59
GVINS(true)	0.03 / 0.08	0.05 / 0.11	0.06 / 0.14	0.07 / 0.18
GVINS(3)	0.23 / 0.52	0.34 / 0.74	0.74 / 0.90	0.46 / 1.21
GVINS(6)	0.63 / 1.46	0.86 / 2.04	1.02 / 2.35	1.18 / 3.09
Proposed	**0.03 / 0.08**	**0.04 / 0.11**	**0.05 / 0.14**	**0.07 / 0.18**

Table: Localization error (RPE, deg/m)

Calibration

- Spatiotemporal calibration
- Initial error converge to 0
- Consistent calibration

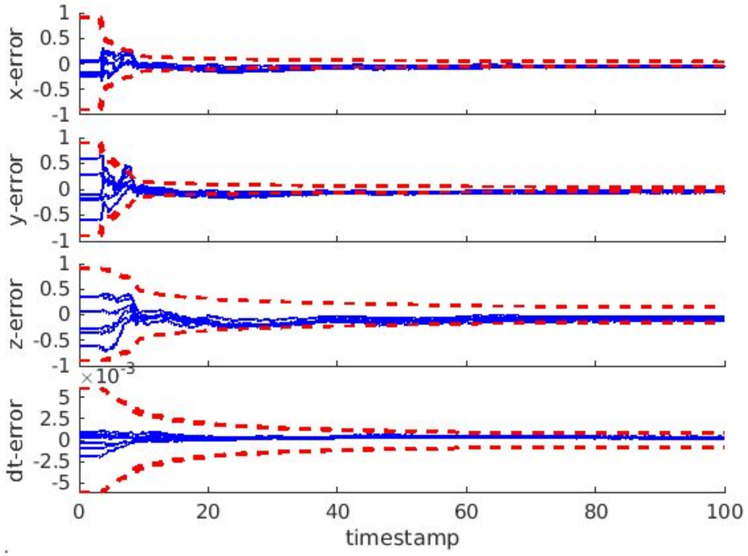
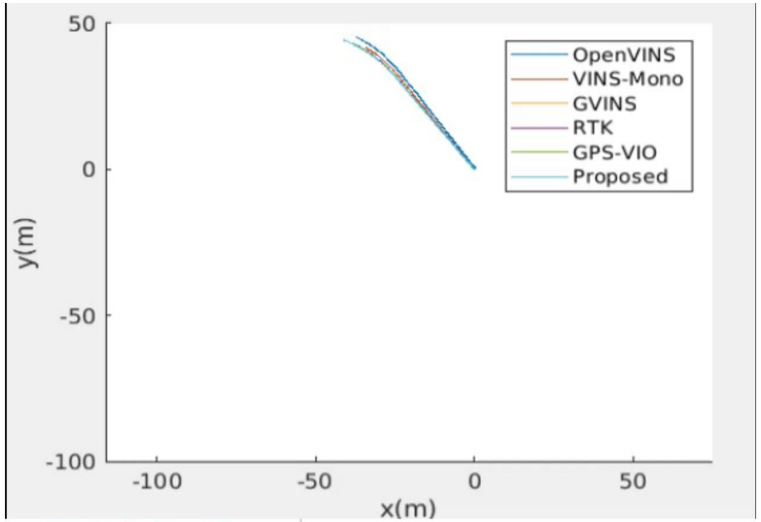


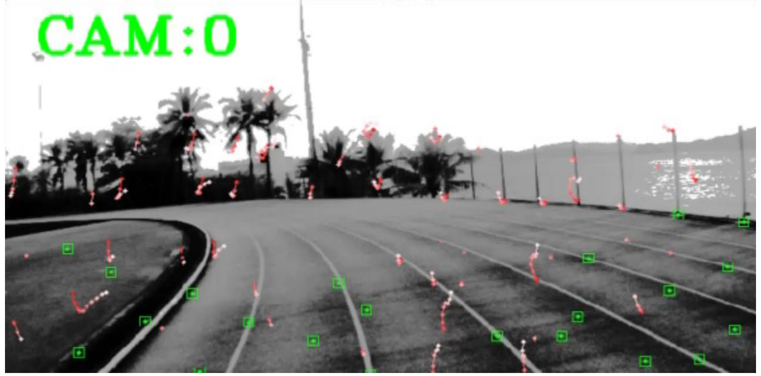
Fig: Calibration error

Conclusion

Real-World

- Proposed Work
  - Raw GNSS measurement fusion with VIO
  - Single-sensor-based DGNSS modeling
  - Robust and efficient GNSS initialization
  - GNSS atmospheric error-robust global localization





Root Mean Squared Error (RMSE)

Proposed	GVINS	GPS-VIO
0.319	0.327	0.374

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