Asynchronous Multi-Sensor Fusion for 3D Mapping and Localization

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Motivation

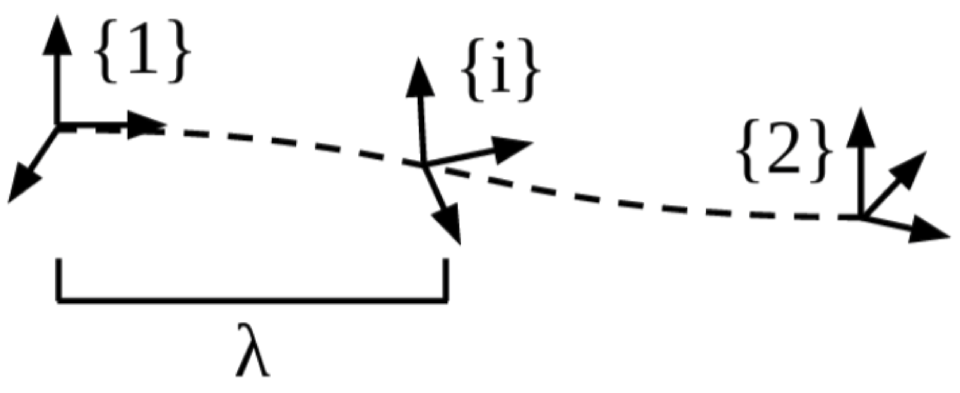
- Leverage cheap asynchronous sensors in a modular system for localization
- Use pose graph-based optimization and directly incorporate delayed measurements
- Reduce the graph complexity by limiting created nodes

Uber autonomous vehicle prototype testing in San Francisco. Credit Wikimedia Commons

Factor Interpolation

- *Assumptions:* Constant angular and linear velocities
- Linearly interpolate in *SO(3)xR³* to correct the incoming unary and binary graph factors
- Time-distance fractions "correct" the factors to corresponding node times
- Allows for direct addition into graph *without* adding new graph nodes
- *Analytically* derived measurement covariance propagation Jacobians [1]

Unary Factor Interpolation

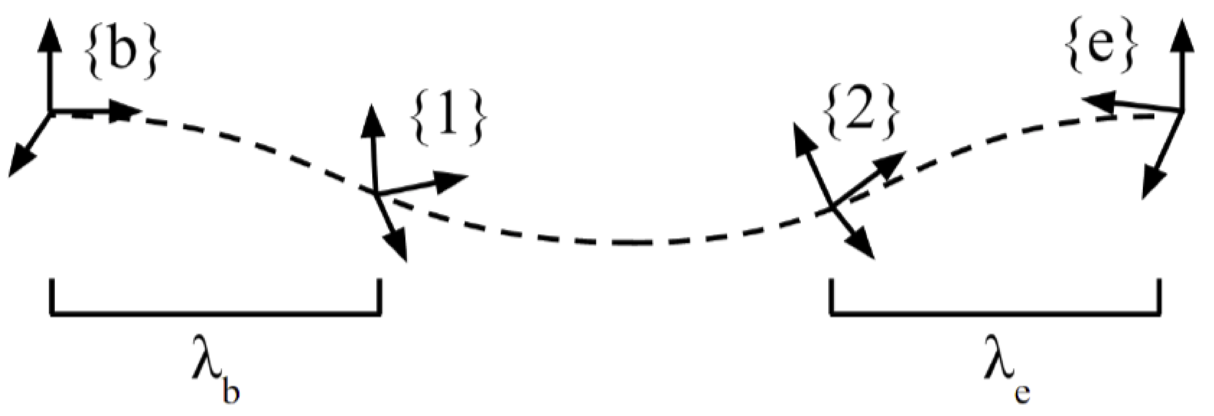


$$\lambda = \frac{(t_i - t_1)}{(t_2 - t_1)}$$

$$ {}^{i}_{G}\mathbf{R} = \mathrm{Exp}\left(\lambda\ \mathrm{Log}({}^{2}_{G}\mathbf{R}\,{}^{1}_{G}\mathbf{R}^{\top})\right){}^{1}_{G}\mathbf{R}$$

$$ {}^{G}\mathbf{p}_i = (1-\lambda){}^{G}\mathbf{p}_1 + \lambda\,{}^{G}\mathbf{p}_2$$

Binary Factor Interpolation

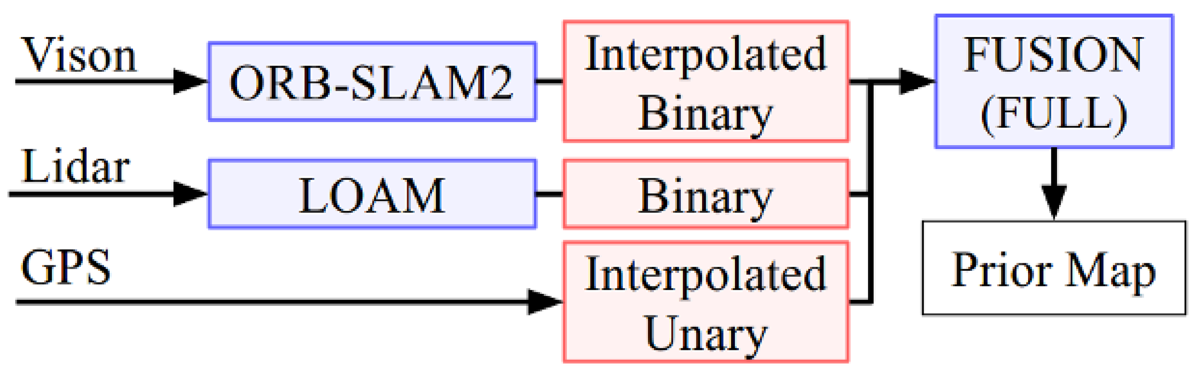


$$\lambda_b = \frac{t_1 - t_b}{t_2 - t_1} \qquad \lambda_e = \frac{t_e - t_2}{t_2 - t_1}$$

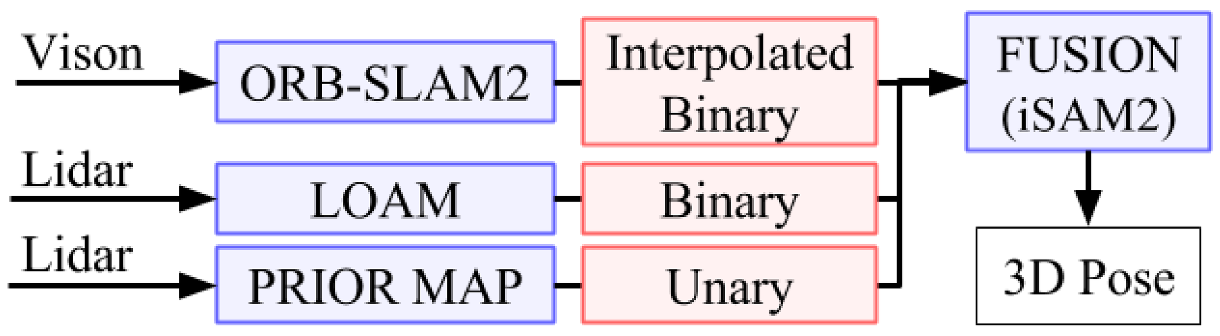
$$ {}^{e}_{b}\boldsymbol{R} = \mathrm{Exp}\left[(1+\lambda_b+\lambda_e)\mathrm{Log}\left({}^{2}_{1}\boldsymbol{R}\right)\right]$$

$$ {}^{b}\boldsymbol{p}_e = (1+\lambda_b+\lambda_e)\mathrm{Exp}\left[-\lambda_b \mathrm{Log}\left({}^{2}_{1}\boldsymbol{R}\right)\right]{}^{1}\boldsymbol{p}_2$$

System Design



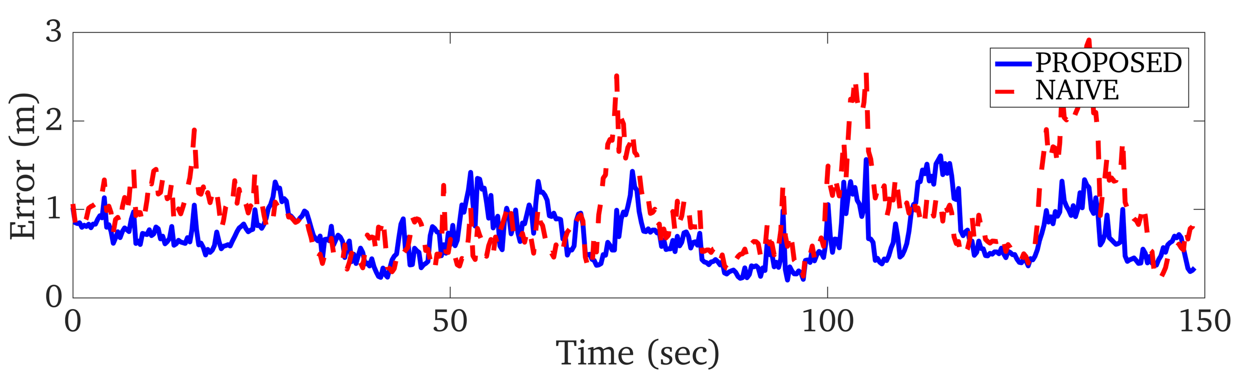
- *Prior Map:* ORB-SLAM2 [2] and LOAM [3] odometry fused with RTK GPS
- Interpolated relative vision and GPS factors



- *GPS-Denied:* Perform ICP matching between LIDAR scans and prior map
- Interpolated relative vision factors
- 3D pose estimate in the prior map frame (i.e., the global GPS frame)

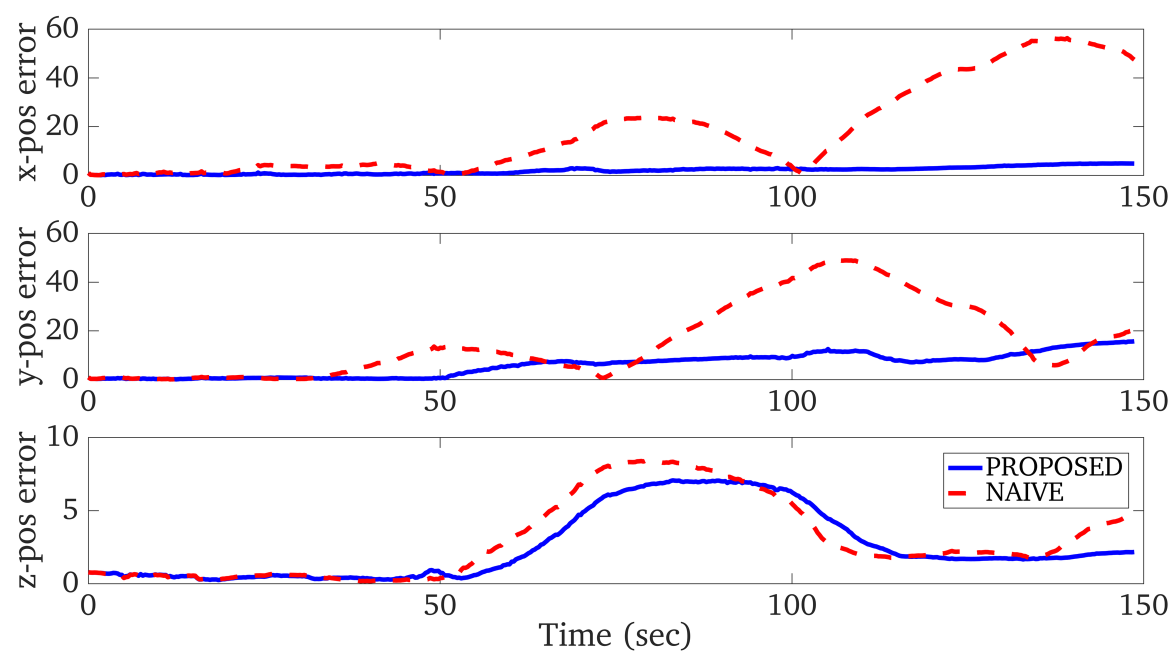
GPS-Denied Localization

Quanergy M8 LIDAR, ZED stereo camera, and RTK enabled NovAtel Propak6 GPS sensors used in the collected datasets



- Position RMSE over 10 runs
- 0.71 for proposed alignment with 0.93 for naive approach
- 23.6% overall error decrease
- Run length of 500 meters, 6mph average vehicle speed

Impact of Interpolation



- Pure *odometry* comparison
- Position RMSE over 10 runs
- 7.03 for proposed alignment with 26.74 for naive approach
- 73.7% overall error decrease

[1] Patrick Geneva, Kevin Eckenhoff, and Guoquan Huang. *Asynchronous Multi-Sensor Fusion for 3D Mapping and Localization*. Tech. Rep. RPNG-2017-002. Available: http://udel.edu/~ghuang/papers/tr_async.pdf. University of Delaware, 2017.

[2] Raul Mur-Artal and Juan D Tardos. "*ORB-SLAM2: an Open-Source SLAM System for Monocular, Stereo and RGB-D Cameras*". In: arXiv preprint arXiv:1610.06475(2016).

[3] Ji Zhang and Sanjiv Singh. "*LOAM: Lidar Odometry and Mapping in Real-time.*". In: Robotics: Science and Systems. Vol. 2. 2014.

Conclusion

- General approach for **asynchronous** measurement alignment
- **GPS-denied** and modular system that allows for any sensor six d.o.f odometry incorporation
- Tested on an experimental dataset, shown to have **<2 meter accuracy**
- Asynchronous measurement alignment shows **accuracy improvement** compared to naive approach