Asynchronous Multi-Sensor Fusion for 3D Mapping and Localization

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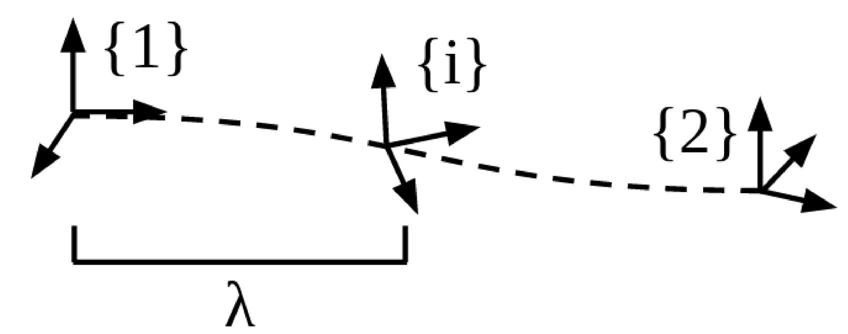
Motivation

- Leverage cheap asynchronous sensors in a modular system for localization
- Use pose graph-based optimization and directly incorporate delayed measurements
- Reduce the overall graph complexity by not creating new nodes

Factor Interpolation

- *Assumptions*: Constant angular and linear velocities
- Linearly interpolate in $SE(3)$ 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
- Derived *analytically* covariance propagation Jacobians in technical report [1]

Unary Factor Interpolation

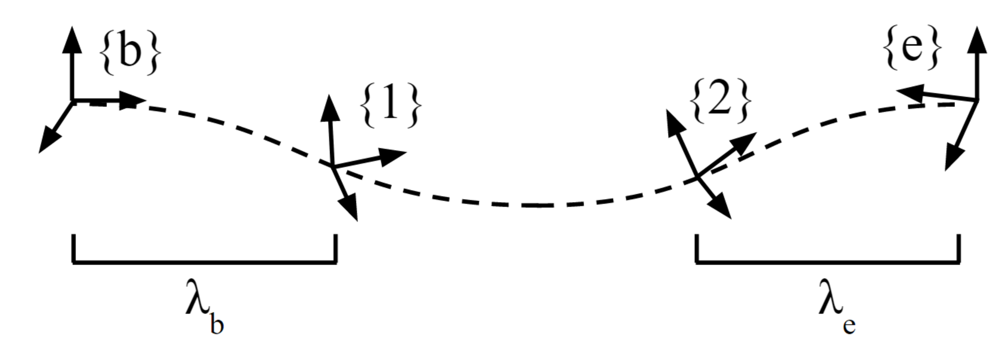


$$\lambda = \frac{(t_i - t_1)}{(t_2 - t_1)}$$

$$^i_G\mathbf{R} = \text{Expv}\left(\lambda\ \text{Logv}({}^2_G\mathbf{R}\,{}^1_G\mathbf{R}^\top)\right){}^1_G\mathbf{R}$$

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

Binary Factor Interpolation

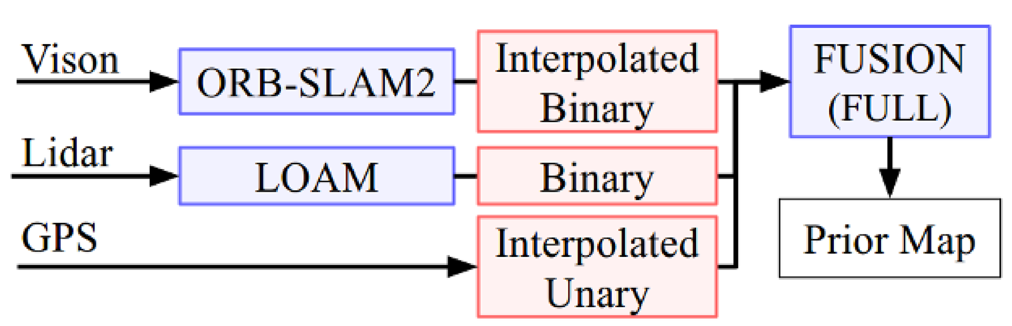


$$\lambda_b = \frac{t_1 - t_b}{t_2 - t_1} \qquad \lambda_e = \frac{t_e - t_2}{t_2 - t_1}$$

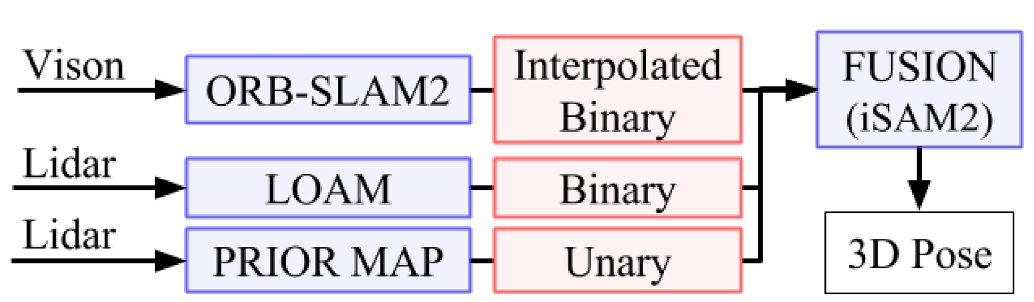
$$^e_b\boldsymbol{R} = \text{Expv}\left[(1+\lambda_b+\lambda_e)\text{Logv}\left({}^2_1\boldsymbol{R}\right)\right]$$

$$^b\boldsymbol{p}_e = (1+\lambda_b+\lambda_e)\text{Expv}\left[-\lambda_b\text{Logv}\left({}^2_1\boldsymbol{R}\right)\right]{}^1\boldsymbol{p}_2$$

System Design



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



- *GPS-Denied*: Perform ICP matching between LIDAR clouds and prior map
- 3D pose estimated in the global GPS frame

GPS-Denied Results

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

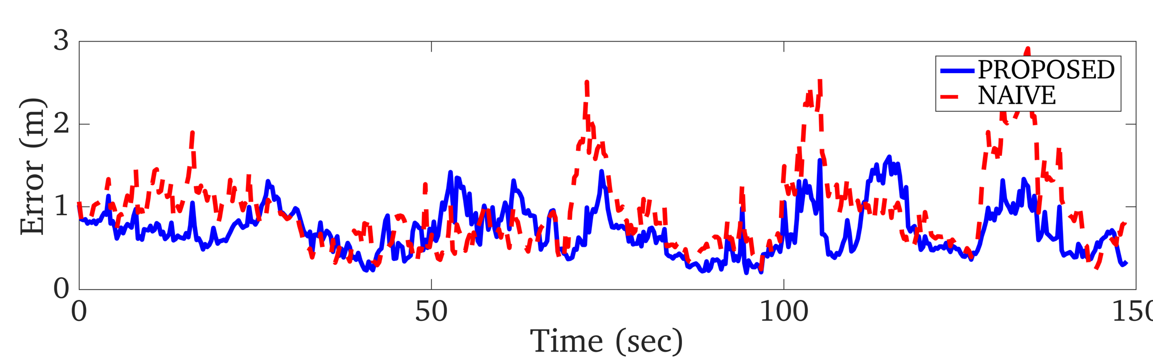


Figure: Position error over 10 runs. Total run length of 500 meters. Average vehicle speed of 6mph. Average RMSE of 0.71 meters for proposed method and 0.93 meters for the naive approach (**overall 23.6% decrease**).

Impact of Interpolation

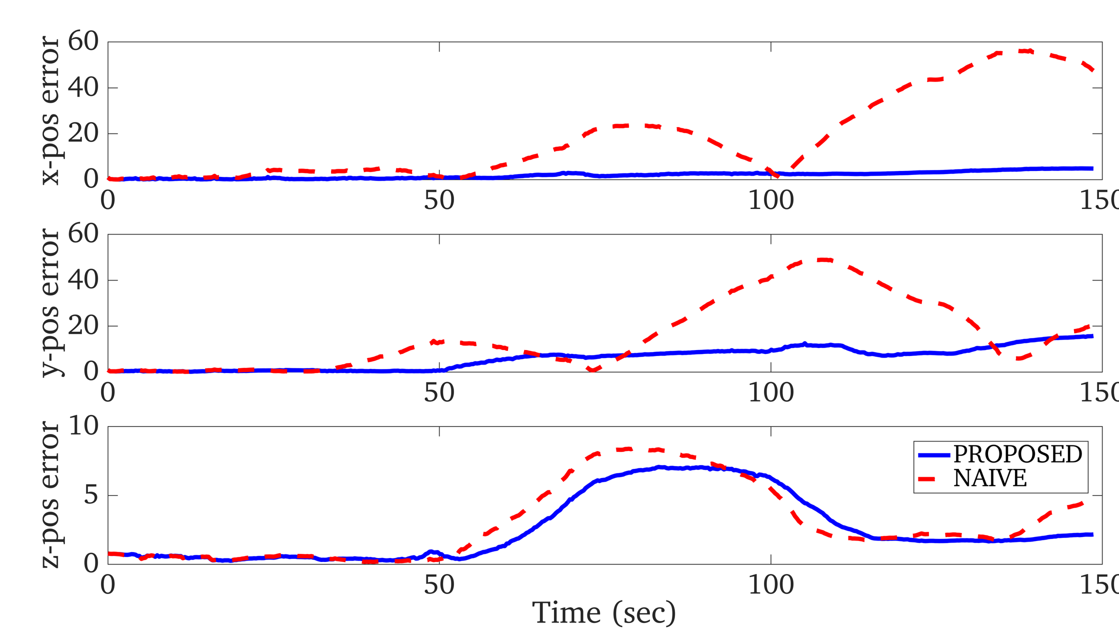


Figure: Comparison of the proposed method and naive approach position over 10 runs, using pure odometry measurements. RMSE of the naive approach was 26.74 meters and the proposed method's average error was 7.026 meters (**overall 73.7% decrease**).

Conclusion

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

References

[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.