G-SOLVER: Gaussian Belief Propagation and Gaussian Processes for Continuous-Time SLAM

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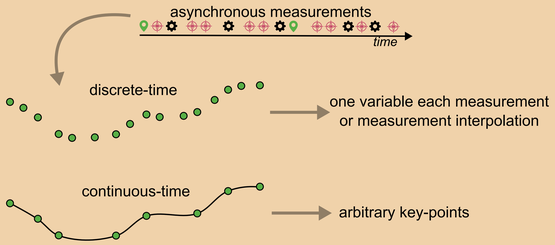
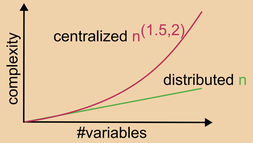
ICCV 2025 Workshop on Large Scale Cross Device Localization

HONOLULU HAWAII OCT 19-23, 2025

WHY CONTINUOUS?

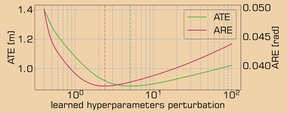


WHY DISTRIBUTED (GBP)?



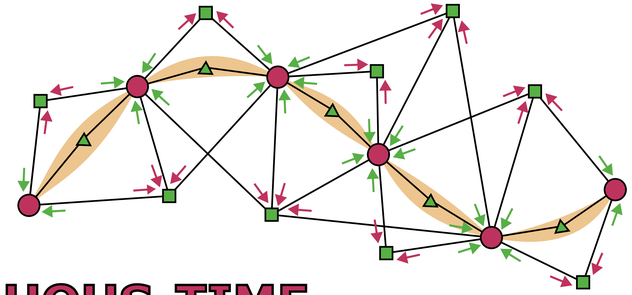
WHY GAUSSIAN PROCESSES?

- continuous estimate distribution → interpolated covariance
- dynamic motion constraint → $E_{cot} = \sum_{j \in meas} \frac{1}{2}\|e_j\|^2_{\Omega_j} + \sum_{i \in GP\ priors} \frac{1}{2}\|e_i\|^2_{Q_i^{-1}}$
- learnable hyperparameters →

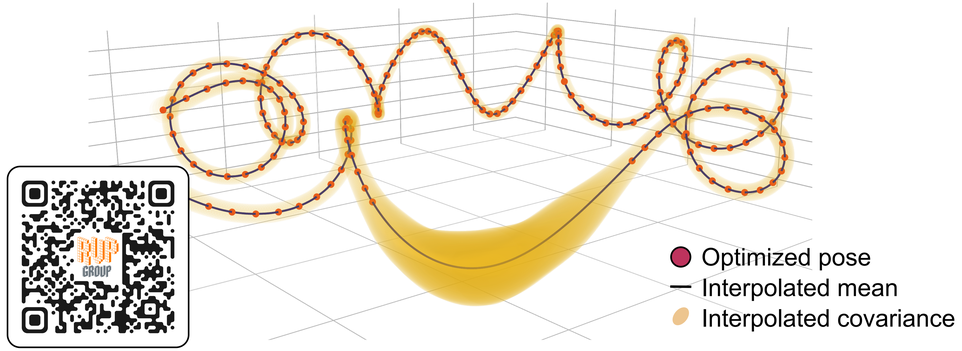


A FULLY PROBABILISTC FRAMEWORK

- Variable
- Factor
- GP prior
- Variable to Factor
- Factor to Variable



FOR CONTINUOUS-TIME TRAJECTORY ESTIMATION



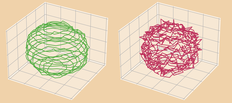
ACCURACY EVALUATION

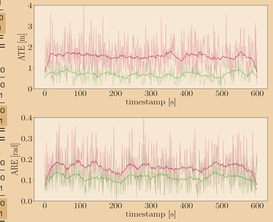
Under high measurement noise (σ=1), **G-solver** estimates a smoother trajectory than **Hyperion**

Helix		Factor noise σ					
		1.00e-04	1.00e-03	1.00e-02	1.00e-01	1.00e+00	1.50e+00
Hyperion	ATE [m]	1.69e-04	1.69e-03	1.69e-02	1.69e-01	1.69e+00	2.53e+00
	ARE [rad]	1.77e-05	1.77e-04	1.77e-03	1.77e-02	1.77e-01	2.66e-01
Ours	ATE [m]	1.69e-04	1.69e-03	1.67e-02	1.19e-01	7.02e-01	1.02e+00
	ARE [rad]	1.78e-05	1.77e-04	1.77e-03	1.75e-02	1.23e-01	1.69e-01

Sphere		Factor noise σ					
		1.00e-04	1.00e-03	1.00e-02	1.00e-01	1.00e+00	1.50e+00
Hyperion	ATE [m]	1.69e-04	1.69e-03	1.69e-02	1.69e-01	1.69e+00	2.53e+00
	ARE [rad]	1.78e-05	1.77e-04	1.77e-03	1.77e-02	1.77e-01	2.66e-01
Ours	ATE [m]	1.69e-04	1.69e-03	1.69e-02	1.30e-01	7.65e-01	1.15e+00
	ARE [rad]	1.78e-05	1.77e-04	1.77e-03	1.75e-02	1.24e-01	1.70e-01

Torus		Factor noise σ					
		1.00e-04	1.00e-03	1.00e-02	1.00e-01	1.00e+00	1.50e+00
Hyperion	ATE [m]	1.78e-04	1.75e-03	1.75e-02	1.75e-01	1.75e+00	2.62e+00
	ARE [rad]	1.82e-05	1.82e-04	1.82e-03	1.82e-02	1.82e-01	2.74e-01
Ours	ATE [m]	1.78e-04	1.75e-03	1.74e-02	1.37e-01	9.93e-01	1.69e+00
	ARE [rad]	1.83e-05	1.82e-04	1.82e-03	1.80e-02	1.30e-01	1.81e-01



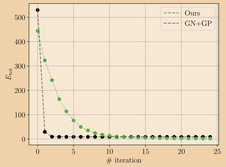


RUNTIMES EVALUATION

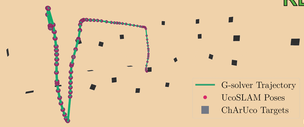
The **G-solver** implementation exhibits runtimes comparable to **Hyperion**. For interpolation tasks, our implementation is faster, despite splines being computationally more efficient than Gaussian Processes

CONVERGENCE ANALYSIS

Compared to centralized algorithms like **Gauss–Newton**, **G-solver** — based on Gaussian Belief Propagation — requires more iterations to converge. This trade-off is worthwhile for scalability, and alternative message scheduling could further improve convergence



REAL-WORLD VALIDATION



Comparison between the **G-solver** applied to real-world incremental SLAM and the **UcoSLAM** pipeline. The scene depicts a smartphone camera moving within a room containing multiple ChArUco targets