Distributed Visual-Inertial Cooperative Localization

[Award #: 1924897]

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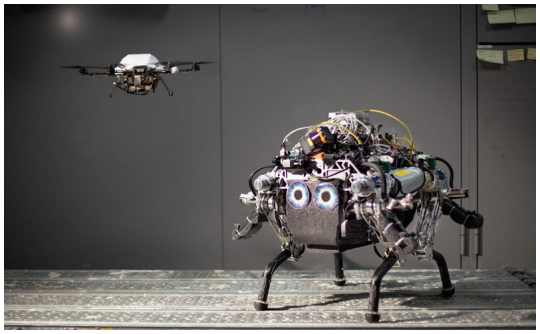
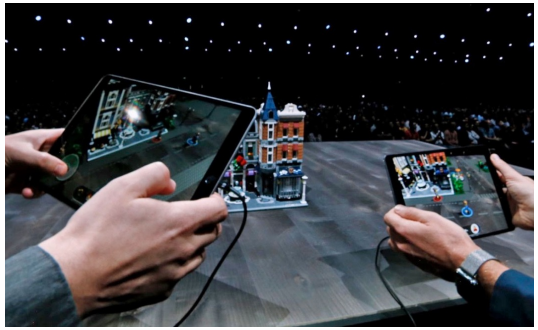
Introduction

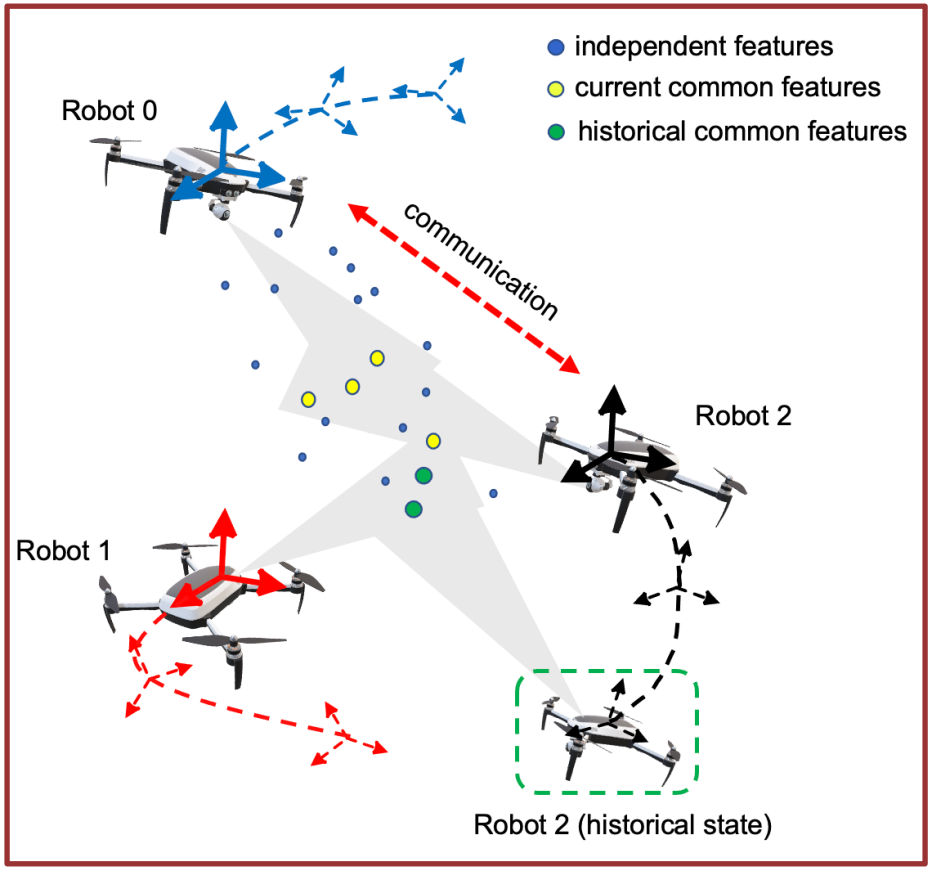
- Multi-robot systems can **collaborate** to accomplish missions more efficiently and robustly.
- Visual-Inertial Cooperative Localization (VI-CL) leveraging **additional geometric constraints** to improve localization accuracy of the whole group.
- Distributed estimation is more **scalable, robust, and efficient** as compared to centralized estimators.
- **Contributions**: An efficient distributed state estimator for multi-robot VI-CL w/o requiring simultaneous viewing of common features:
  - Consistent estimation based on Covariance Intersection (CI).
  - Efficient common SLAM and VIO feature updates.
  - Historical loop-closure matching across time and robots to reduce localization drift.





Algorithm

- Problem setup:
  - Multiple robots exploring an environment:
    - Robots, when in communication range, send feature info., current and historical states.
    - Each robot tracks a short “sliding window” of clones.
    - Other robot’s states are related through common feature observations.
  - Different features can be categorized:
    - *Independent*: Only one robot sees these features.
    - *Current common*: Seen from multiple robots that only constrain their current “sliding window”.
    - *Historical common*: The feature seen by one robot currently was seen by another robot before, but not currently.
- Proposed approach:
  - Use common feature constraints to improve the localization accuracy and limit long-term navigation drift.



Results: Distributed VI-CL [IROS 21]

- VI-CL Estimator built on top of **OpenVINS.**
- Common features improved trajectory **accuracy** over independent robot state estimation.
- The accuracy of **Distributed** estimators is competitive with centralized estimations at a **fraction of computational cost.**
- Historical matching is **crucial** to ensure constraints during realistic scenarios:
  - 27% frames matched to other robots' **most recent frames.**
  - 42% frames have matched if using **historical.**

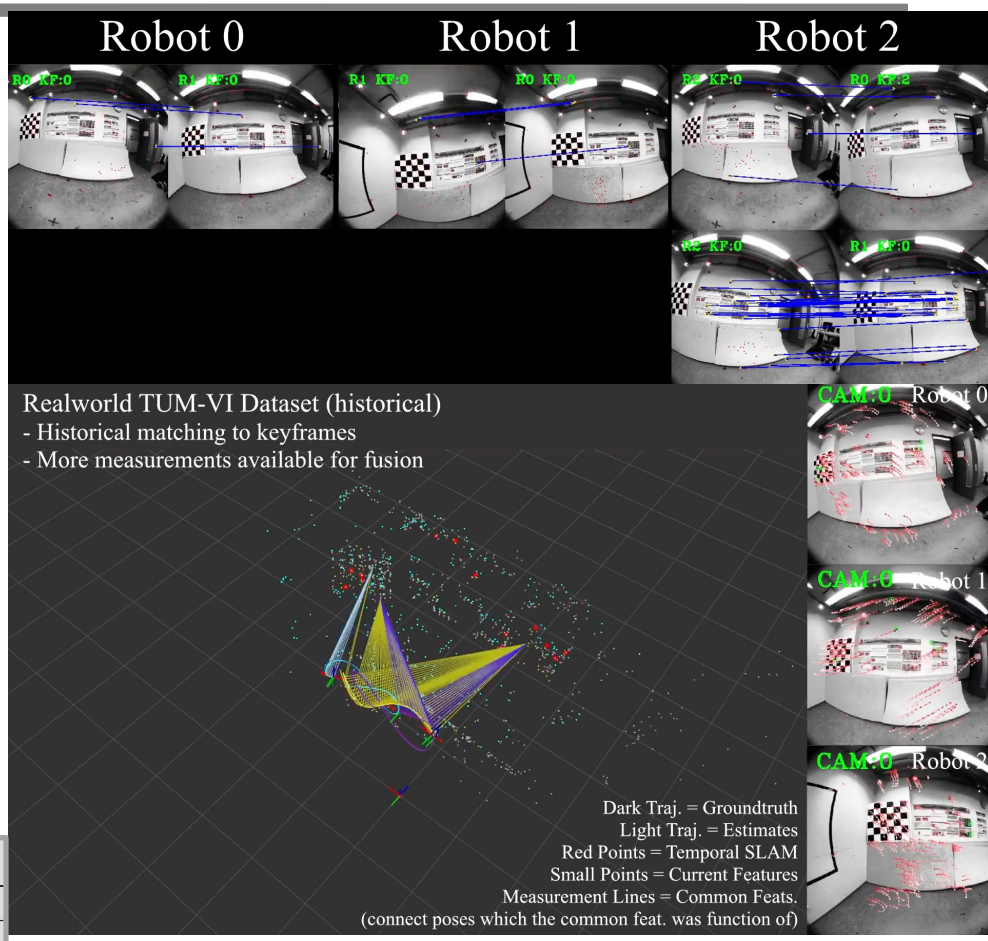


Table 1: Relative pose error (RPE) on TUM-VI datasets in degrees / meters averaged over all robots for the dataset.

Algorithm	40m	60m	80m	100m	120m
indp-slam	1.818 / 0.093	2.833 / 0.126	2.604 / 0.154	2.774 / 0.185	2.716 / 0.215
ce-cmsckf	**1.358** / 0.071	**1.321** / 0.091	1.357 / 0.108	0.843 / 0.128	0.932 / 0.140
ce-cmsckf-cslam	1.758 / **0.069**	1.350 /**0.079**	**1.027** / **0.100**	**0.718** / 0.119	0.938 / **0.130**
dc-cmsckf	1.662 / 0.075	2.005 / 0.104	1.605 / 0.129	1.142 / 0.141	1.531 / 0.170
dc-cmsckf-cslam	1.800 / 0.080	2.642 / 0.093	2.233 / 0.106	1.544 / **0.114**	0.934 / 0.157
dc-full-window	1.768 / 0.075	2.218 / 0.091	1.788 / 0.109	1.257 / 0.123	**0.854** / 0.159
dc-full-history	**1.213** / **0.067**	**1.232** / **0.061**	**1.029** / **0.065**	**1.004** / **0.068**	**0.784** / **0.072**

Inclusion of common features always improves both centralized and decentralized estimators.

Historical matching able to outperform all other methods (even the centralized)!

OpenVINS open source [ICRA 20]: https://github.com/rpng/open_vins

Summary

- Other significant results achieved in 2021-2022:
  - MIMC-VINS: Multi-IMU multi-camera VINS [TRO 22]
  - DRI-VINS: Decoupled right invariant error states for VINS [RA-L 22]
  - FEJ2: Consistent visual-inertial state estimator design [ICRA 22]
  - Code-VIO [ICRA 21] ***(Best Paper Finalist in Robot Vision)***
  - MINS: Multi-sensor aided inertial navigation system [ICRA 21]
  - MPTAM: Markov parallel tracking and mapping [ICRA 21]
  - C-VIO: Cooperative visual-inertial odometry [ICRA 21]

- My Research Lab: Robot Perception and Navigation Group (RPNG)

YouTube

GitHub

Thank you!