NRI: Collaborative Research: Autonomous Quadrotors for 3D Modeling and Inspection of Outdoor Infrastructure

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Motivation

- A lack of frequent and thorough inspection of the nation's civil and industrial infrastructure (e.g., bridges, power plants, refineries) increases likelihood and severity of accidents
- Human inspection is limited due to its safety concerns (for tall and narrow structures) and high cost (requires cranes and climbing utilities)
- Autonomous UAV assisted inspections with on-board sensing can provide highly accurate and up-to-date maps of the structure (due to more frequent inspections) while maintaining low cost

Objective

- Develop the sensing, estimation, and control technology necessary for enabling small-size quadrotors to assist humans in visual inspections

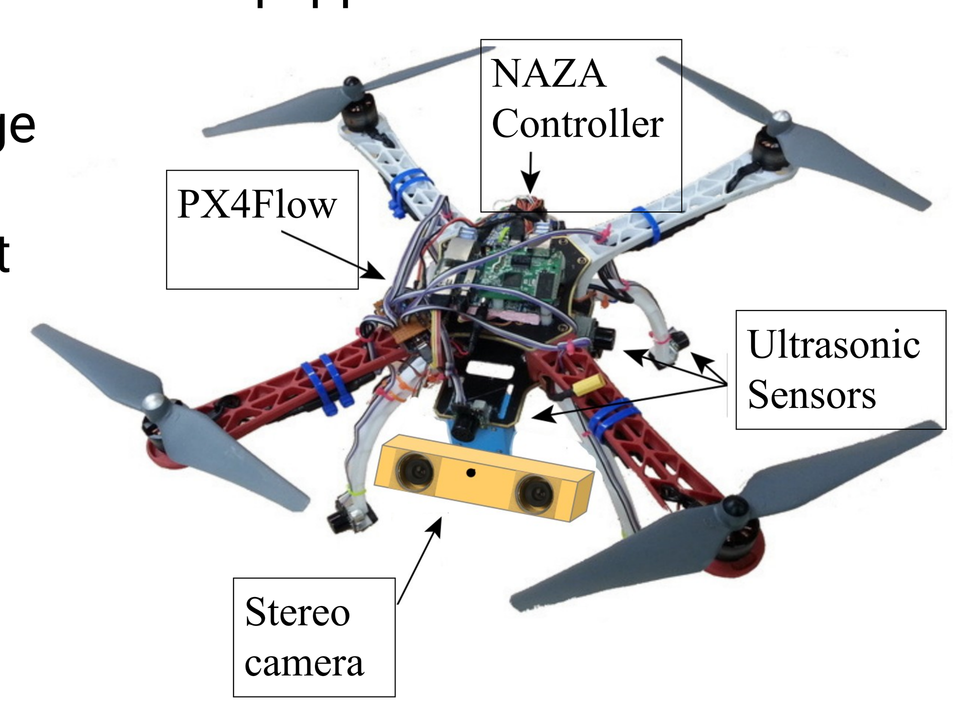
Research Thrusts

1. **Structure mapping:** Combine visual and inertial data to create sparse/dense 3D maps
2. **Representations:** Efficiently represent the map for different purposes (GUI, Obstacle detection and avoidance, etc)
3. **Active sensing:** Find a minimum deviation path from the predetermined, obstacle-free trajectory which bounds the localization uncertainty and maximizes the information gain for mapping
4. **StereoVINS:** Employ measurement selection in VINS to efficiently perform consistent map-based localization and real-time map expansion
5. **Dense stereo:** Given pose estimates from StereoVINS, develop a dense stereo algorithm for obstacle avoidance and visualization
6. **Control:** Design a robust controller to reject outdoor wind disturbances and reliably avoid un-modeled obstacles

Research Platform

DJI quadrotor equipped with:

- NAZA attitude controller
- 8 MaxBotix ultrasonic range finder (obstacle detection)
- PX4Flow measuring height and velocity
- Stereo cameras & IMU
- NVIDIA TK1 GPU
- ARM processor



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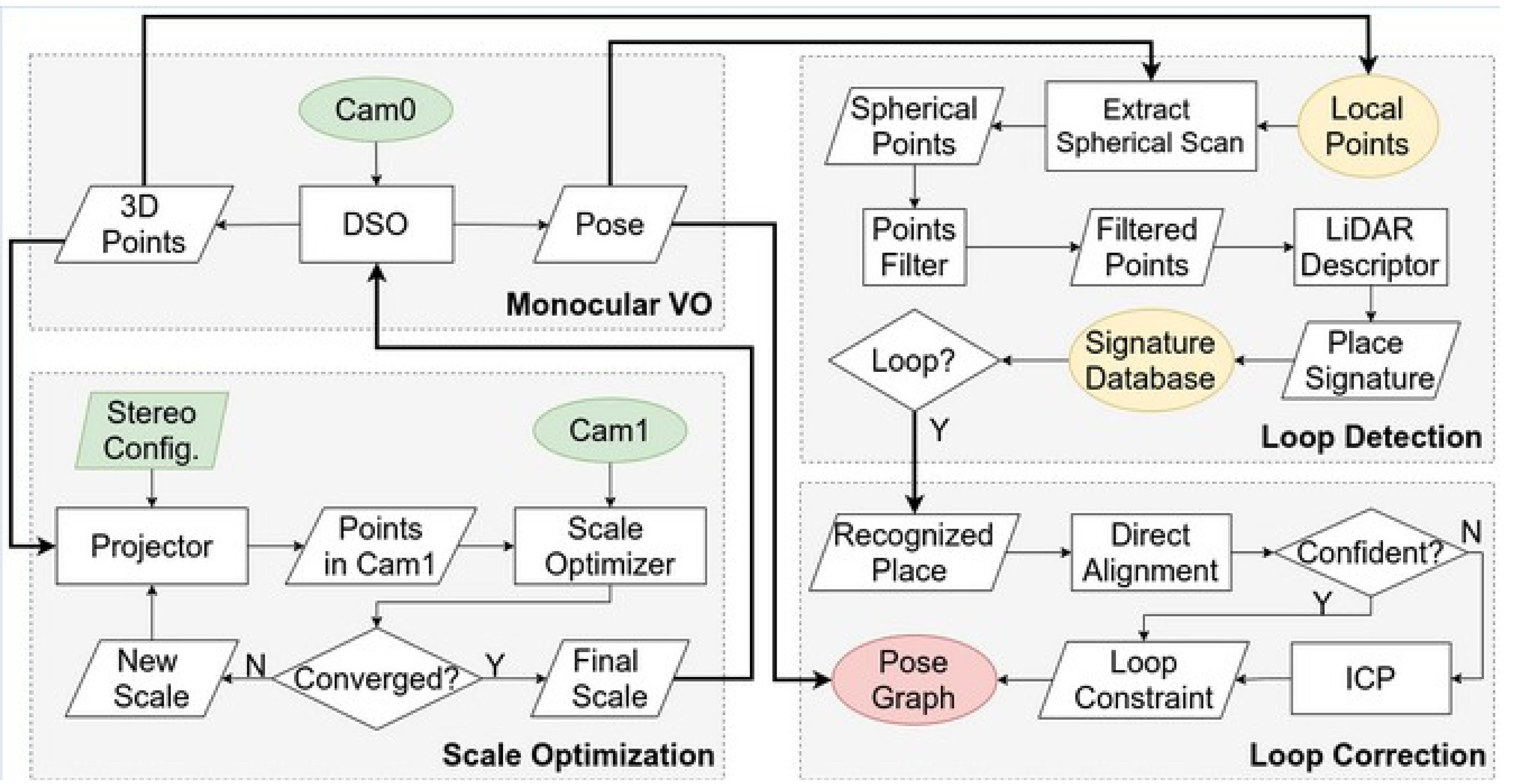
Research highlights and directions

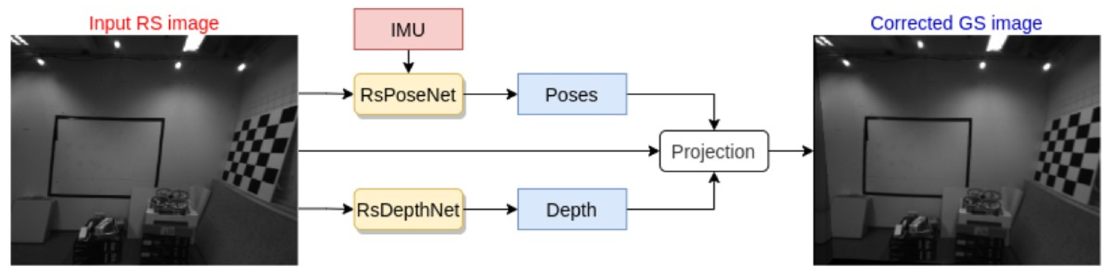
1. Fast Direct Stereo Visual SLAM

- *Key results:*
  - Monocular VO used to estimate poses and to generate 3D points, Scale Optimization estimates and maintains the scale of the VO, Loop Detection detects loop closures, Loop Correction estimates the relative poses of loop closures and optimizes the poses globally
  - Matches state-of-the-art (SOTA) in accuracy, at higher computational efficiency suitable for small, embedded platforms [1]
- *Ongoing work:*
  - Integrate with continuous-time spline VIO
  - Extensive qualitative and quantitative validation of current implementation



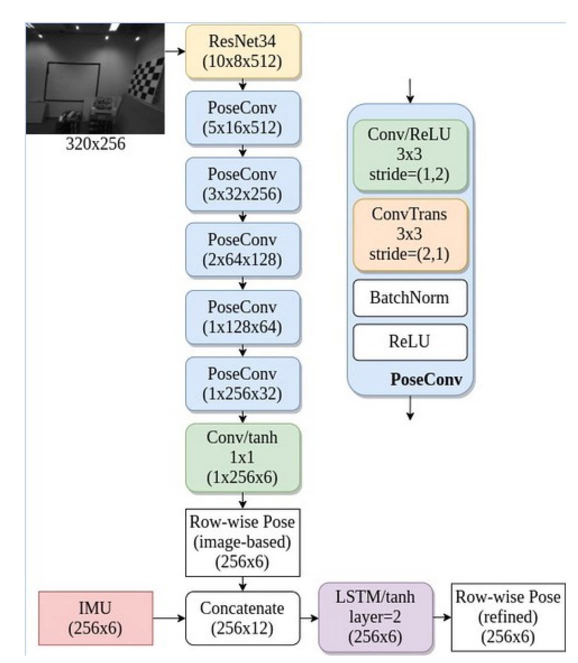
2. IMU-Assisted Deep Learning of Single-View Rolling Shutter Correction

- *Key results:*
  - Using a deep neural network to predict depth and row-wise pose from a single image for rolling shutter correction
  - Incorporating inertial measurement unit (IMU) data into the pose refinement process greatly enhances the pose prediction compared to SOTA [2]
- *Ongoing work*
  - Evaluate benefits in full-loop SLAM compared to SOTA systems
  - Optimize network and runtime to reduce resource usage and increase efficiency



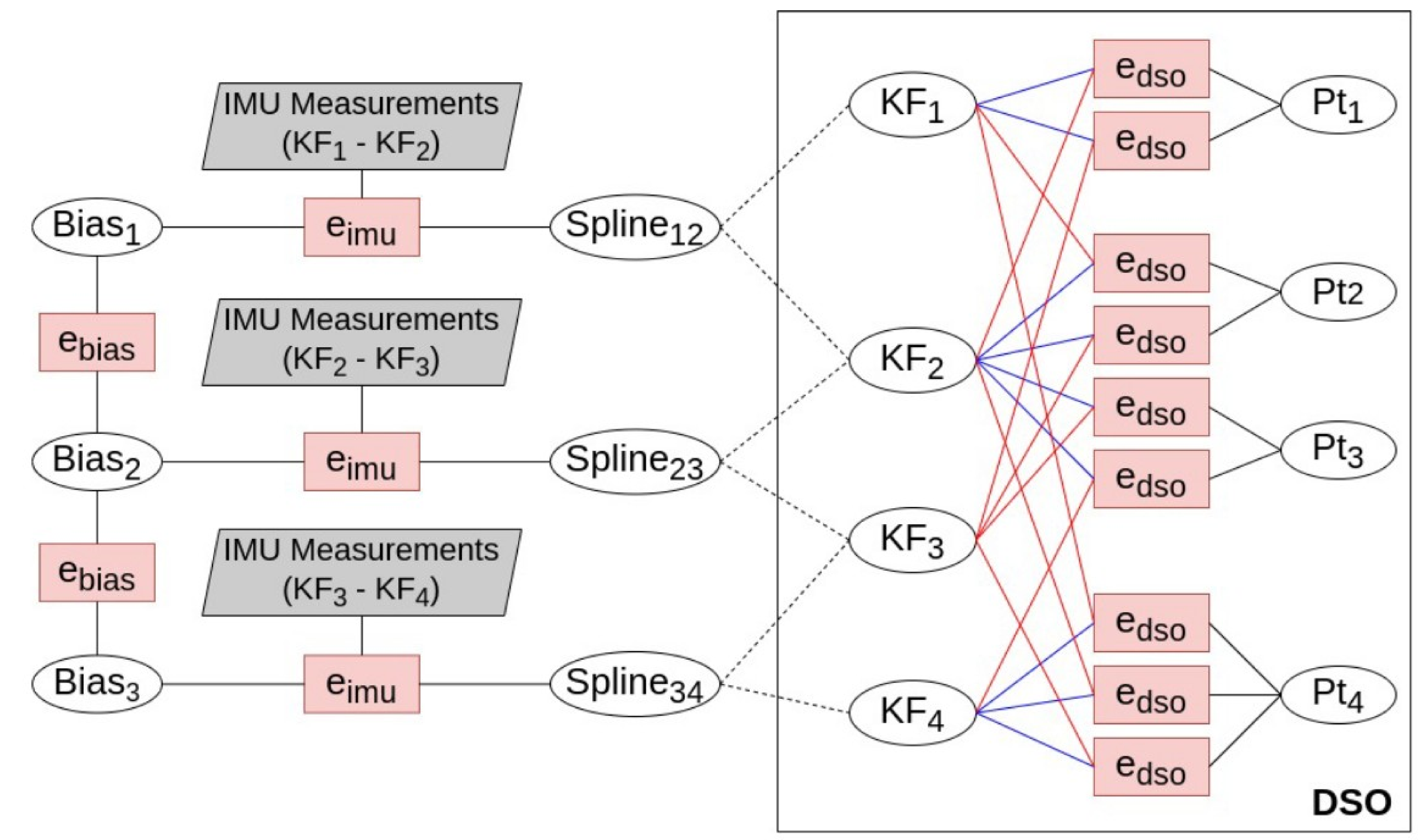
$$EPE(I) = \frac{1}{|I|}\sum_{\mathbf{u}\in I} \left|\left|\Pi(\mathbf{u},d,\mathbf{T}') - \mathbf{u}_{GS_1}(\mathbf{u})\right|\right|_2,$$

$$\Pi(\mathbf{u},d,\mathbf{T}') = \mathbf{K}_{RS}\mathbf{T}'\begin{bmatrix} d\mathbf{K}_{RS}^{-1}\begin{bmatrix}\mathbf{u}\\1\end{bmatrix}\\ 1\end{bmatrix}.$$



3. Continuous-time Spline VIO

- *Key results:*
  - Modeling IMU pose as a cubic spline for continuous-time representation, formulate VIO as constrained nonlinear optimization problem
  - Continuous-time pose representation makes it possible to address many VIO challenges, e.g., rolling shutter distortion and sensors that may lack synchronization [3]
- *Ongoing work*
  - Integrate and evaluate end-to-end SLAM system as Scale-Optimized-Spline (SOS) SLAM



References

[1] Fast Direct Stereo Visual SLAM. Jiawei Mo, Md Jahidul Islam and Junaed Sattar. IEEE Robotics and Automation Letters (RA-L). Vol. 7, No. 2, Pages 778-785, April 2022, doi:10.1109/LRA.2021.3133860.
[2] IMU-Assisted Learning of Single-View Rolling Shutter Correction. Jiawei Mo, Md Jahidul Islam and Junaed Sattar. The Fifth Conference on Robot Learning (CoRL 2021). Hybrid Conference (London, England). November 2021. https://openreview.net/forum?id=Pp0Co2vU28N
[3] Continuous-Time Spline Visual-Inertial Odometry. Jiawei Mo and Junaed Sattar. Accepted for publication at the IEEE International Conference on Robotics and Automation (ICRA 2022). Philadelphia, PA, USA. May 2022.