Visual-Inertial SLAM on NUance Car Dataset

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Agenda

- Problem Statement
- Brief ORB-SLAM Background
- ORB-SLAM3 Installation and Configuration
- ROS Integration
- NUance Implementation
- Parameter Tuning
- Data Collect
- Results
- Analysis
- Conclusion

Problem Statement

Conduct Visual-Inertial SLAM using ORB-SLAM3 and validate its performance on real data

- ORB-SLAM3 is one of the top open-source VI-SLAM algorithms
- Authors claim robust performance in indoor and outdoor environments

***Abstract*—This paper presents ORB-SLAM3, the first system able to perform visual, visual-inertial and multi-map SLAM with monocular, stereo and RGB-D cameras, using pin-hole and fisheye lens models.**

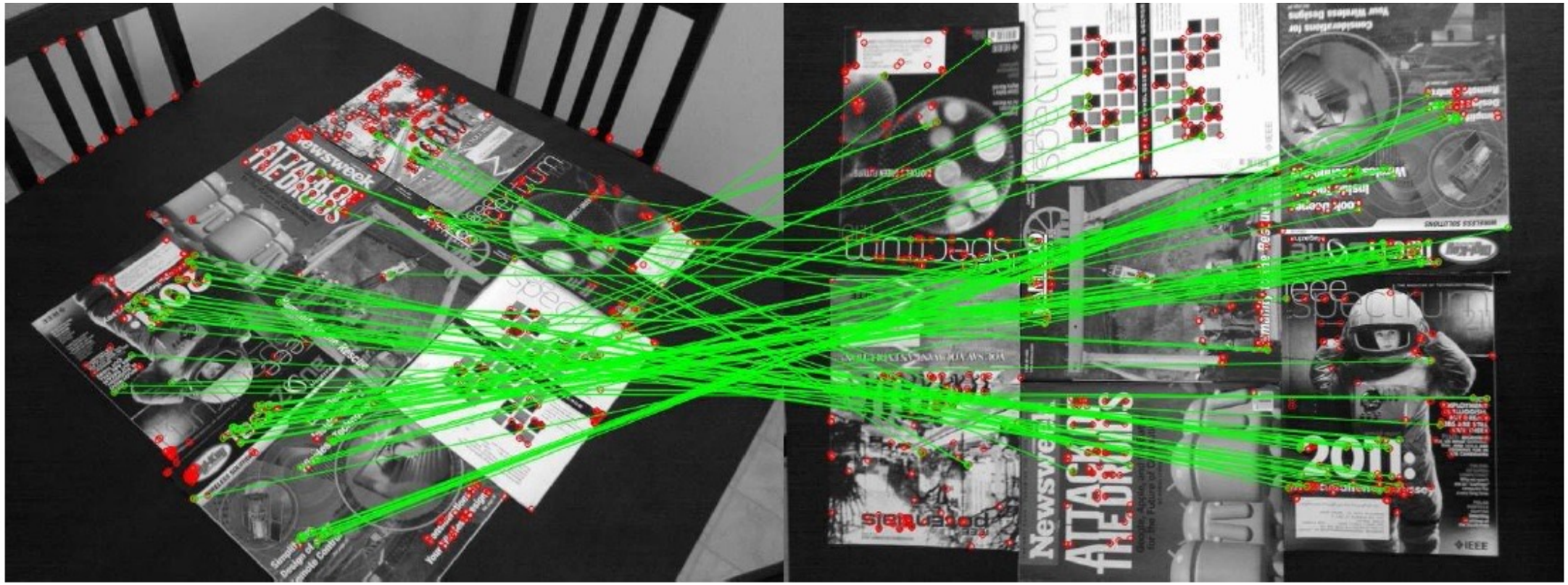
Our experiments show that, in all sensor configurations, ORB-SLAM3 is as robust as the best systems available in the literature, and significantly more accurate. Notably, our stereo-inertial

Macario Barros, Andréa & Moline, Yoann & Carrel, Frédérick & Michel, Maugan & Corre, Gwenolé. (2022). A Comprehensive Survey of Visual SLAM Algorithms.

C. Campos, R. Elvira, J. J. G. Rodríguez, J. M. M. Montiel and J. D. Tardós, "ORB-SLAM3: An Accurate Open-Source Library for Visual, Visual–Inertial, and Multimap SLAM,"

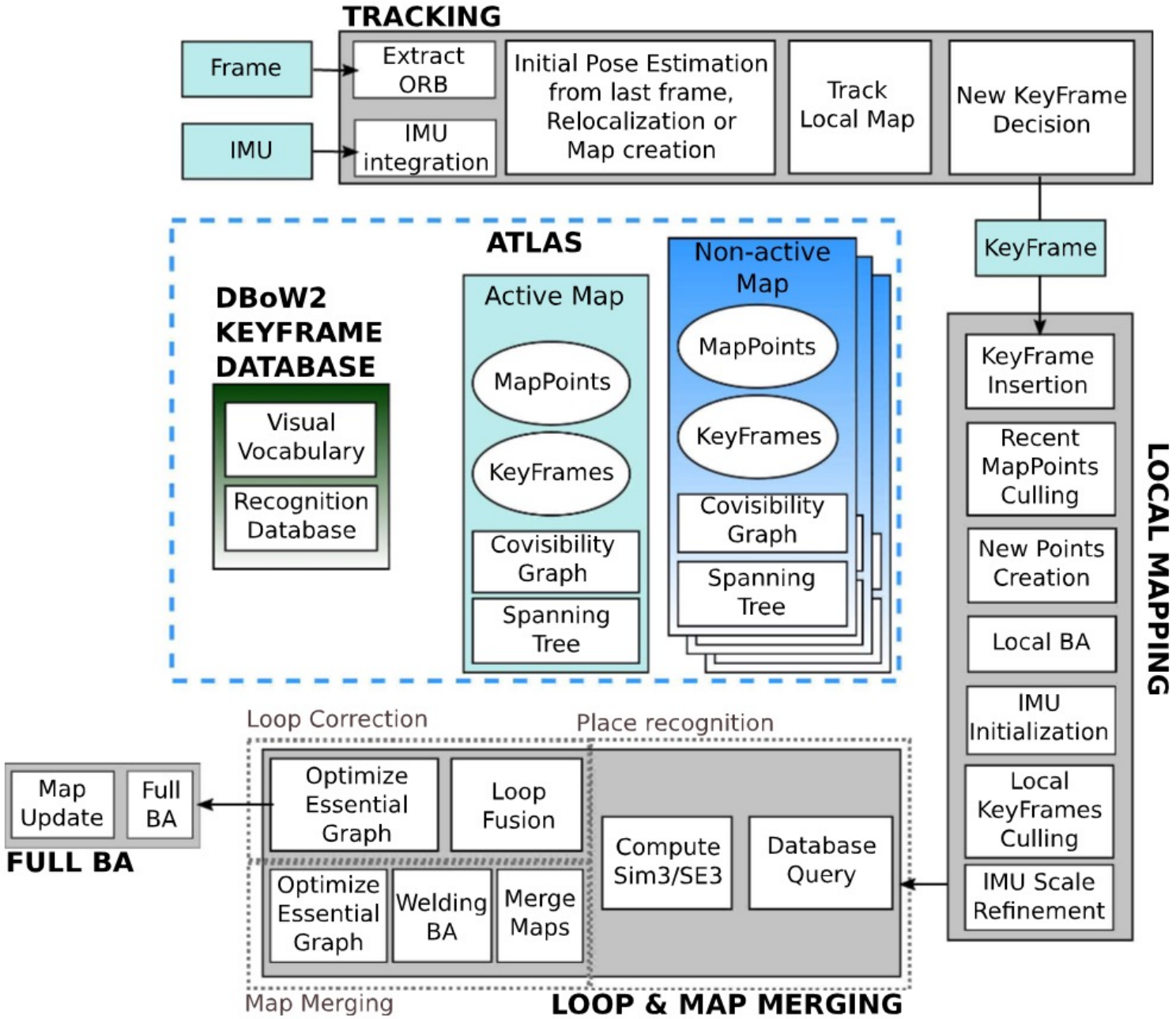
ORB Feature Detector - Review

- Oriented FAST and Rotated BRIEF (ORB)
  - Addition of a fast and accurate orientation component to the FAST keypoint detector
  - Efficient computation of oriented BRIEF descriptor features
  - A learning method for decorrelating BRIEF features under rotational invariance, leading to better performance in nearest-neighbor applications



[ORB and Feature Detection Detailed Summary]

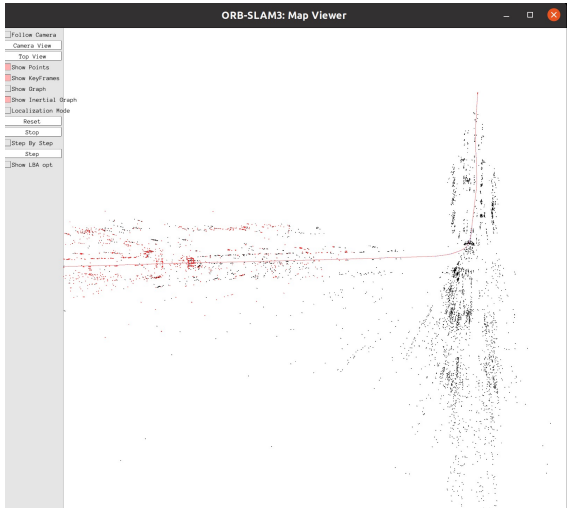
ORB-SLAM3 Algorithm - Review



ORB-SLAM3 Installation and Testing

- ORB-SLAM3 released Version 1.0 on 22 December 2021.
  - This release came with tons of build and dependency issues
  - Had to get files/examples from previous release
- Working Branch

  https://github.com/cmanore25/ORB_SLAM3
- EuRoC dataset
  - Image with features overlay.
  - Visualizer for map points, keyframes, trajectory
  - Has no data output. Cannot be used for analysis.



ROS Integration

- Rviz & hector trajectory server - trajectory, pose, point cloud visualization
- img_view - watch live raw data input
- Rostopic tools - monitor data rate, camera parameters, etc.
- ROS Wrapper allows for flexible inputs and outputs
  - Preprocessing nodes (like CLAHE)
  - Postprocessing trajectory published to ros topic
- Working Branch: https://github.com/cmanore25/orb_slam3_ros_wrapper

Working in ROS on TUM-VI (Stereo-Inertial) dataset

Demonstration of Stereo-Inertial ORB_SLAM3 working with ROS on the TUM-VI dataset:

https://www.youtube.com/watch?v=qgXXpfL5U2A

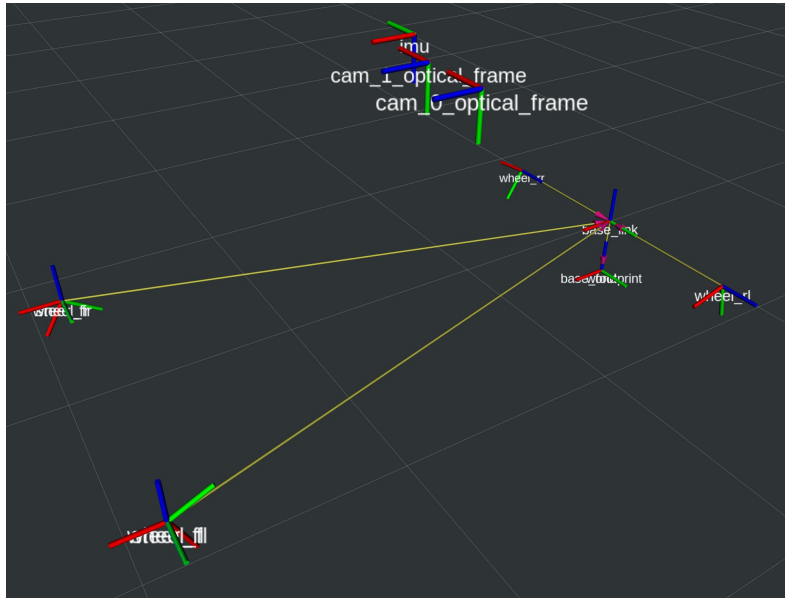
NUance Implementation

- Stereo Camera calibration parameters between Cam0 and Cam1
- IMU noise parameters using VN-100 data from Lab 3
  - Accelerometer and Gyroscope Bias Characterization
    - Standard deviation of stationary IMU data
  - Accelerometer and Gyroscope Random Walk Characterization[1]

$$\sigma = \sqrt{\frac{\delta t}{t}} \cdot \mathrm{BS}$$

BS = Bias Instability
δt = Sampling Period
t = Averaging Time for bias instability measurement (tau)

- Determine IMU-to-Cam transform
  - Using ROS transform tree data
  - https://github.com/cmanore25/transforms



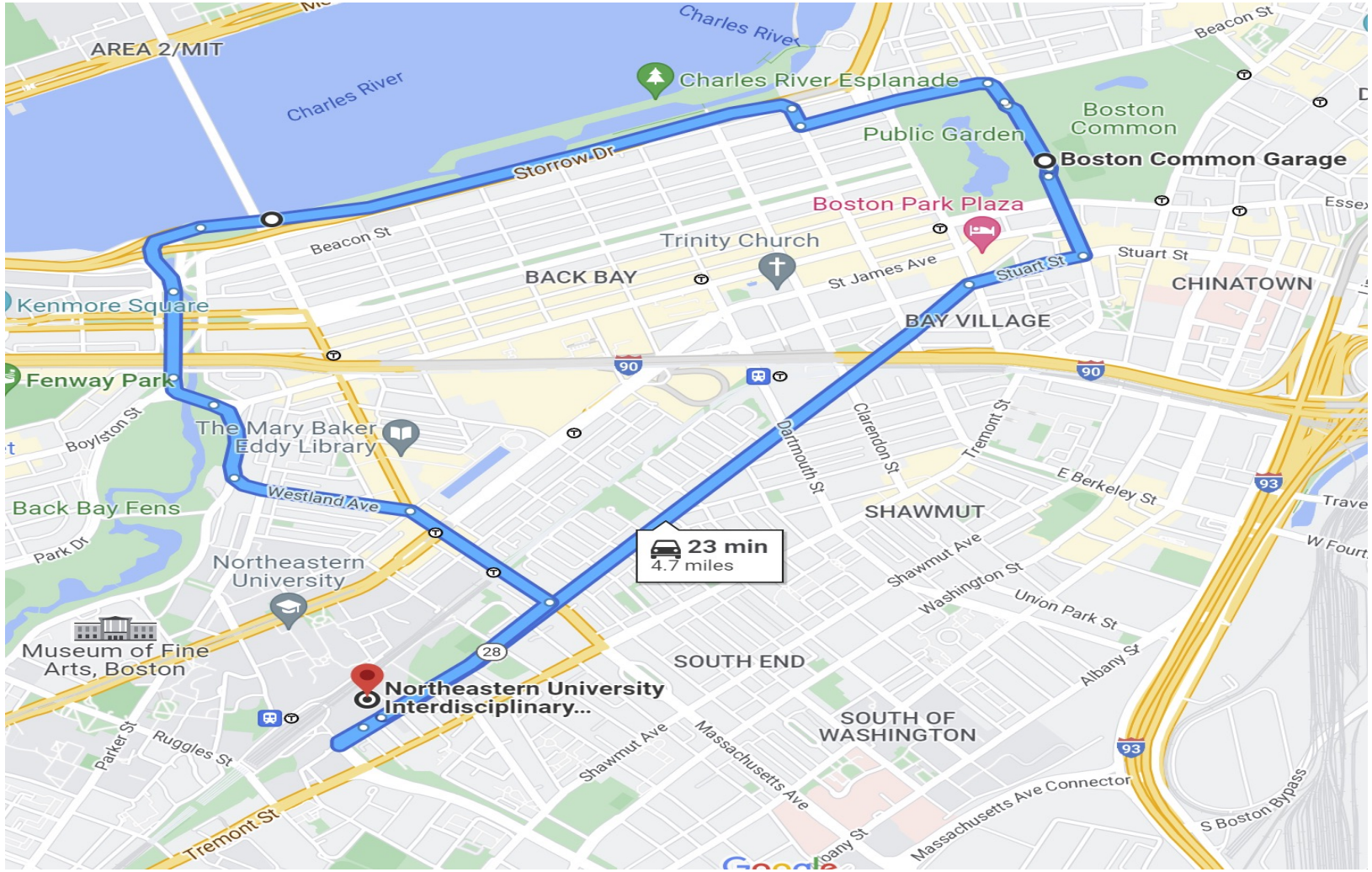
[1]Woodman, Oliver. “An Introduction to Inertial Navigation.” University of Cambridge. Technical Report, No. 696. August 2007, pg. 29.

NUance Tunable Parameters

System Parameters		
thFarPoints	Ignore points beyond a certain distance	200
Stereo.ThDepth	Close/Far Threshold	621.15
ORB Parameters		
nFeatures	Number of features per image	3000
scaleFactor	Scale Factor between levels in scale pyramid	1.2
nLevels	Number of levels in scale pyramid	8
iniThFAST	Cell size for divided image that FAST extracts features	20
minThFAST	If no features are detected from iniThFAST, try this lower value	7

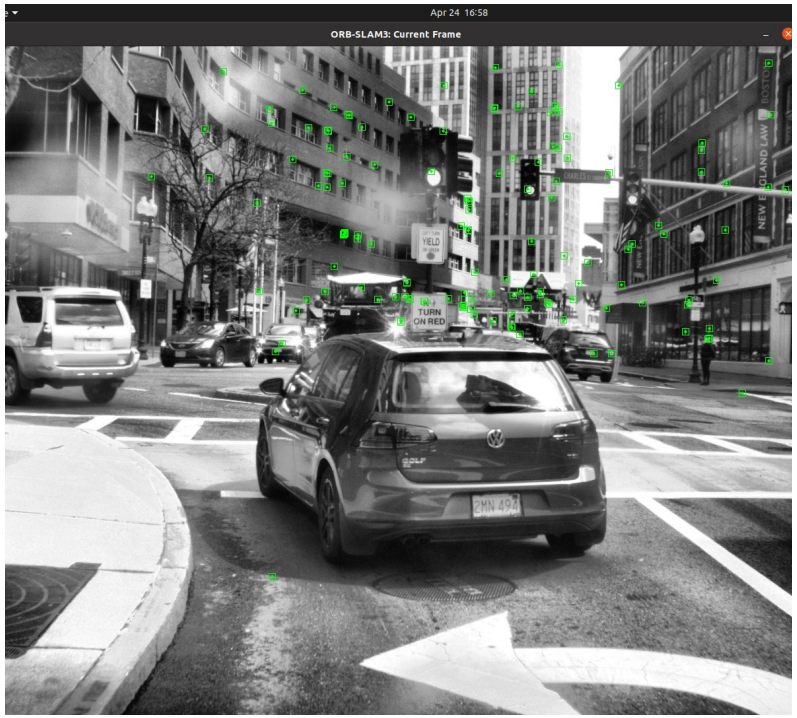
NUance Car Data Collects

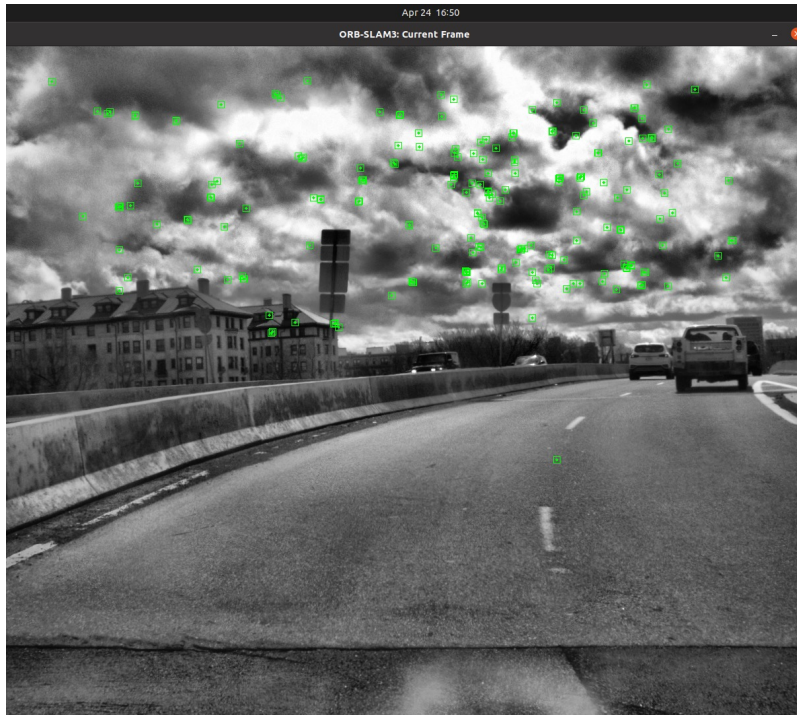
- From 08 April 2022
- Route:



Our Dataset

- Includes wide variety of landscapes
  - Close in by buildings
  - Open spaces
  - Garage
- High speeds (~50 mph)
- Multiple loop closures
- 30 minutes long





Issues with Collected Data

- Smudges on cameras prevented good feature tracking.
- Image is slightly blurry compared to Comm Ave/Newbury St Dataset
- Low contrast

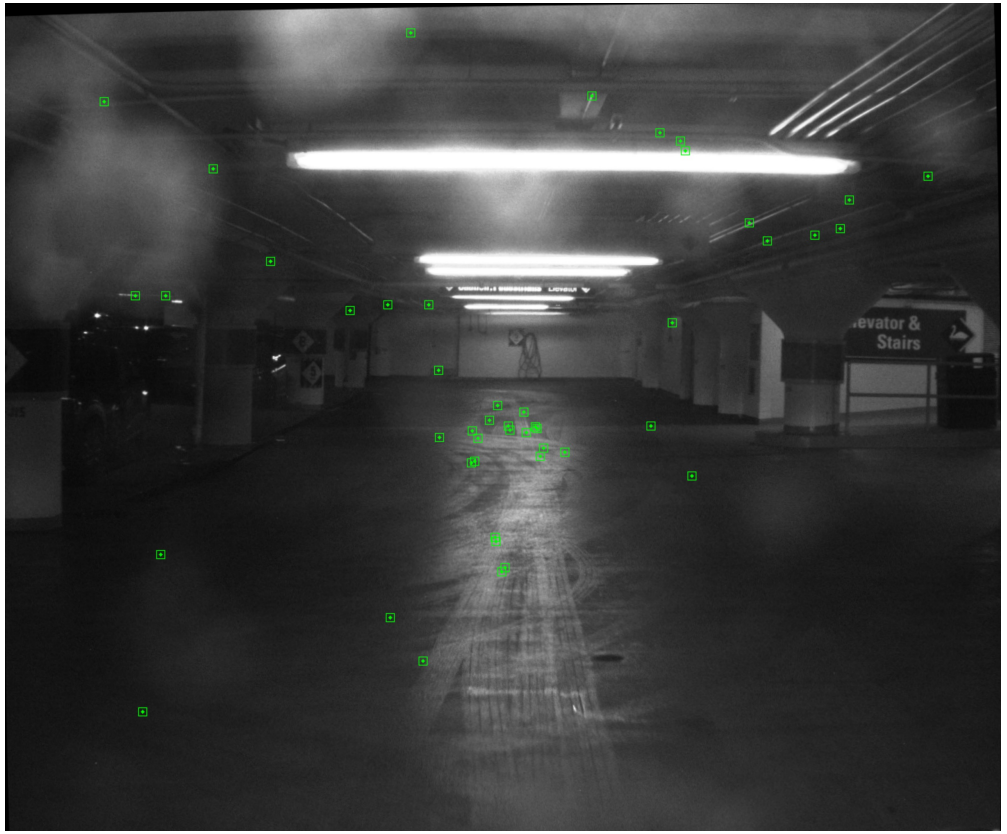
Issues with Collected Data

- CLAHE is an optional image preprocessor that provides higher contrast.
- Inputs
  - Grid size: cuts image up into grid and equalizes in each tile
  - Clip limit: specifies the how much the intensity PDF is flattened. Lower means flatter.
- High grid size and low clip limit for garage with bright lights

raw image

CLAHE gridsize 15, clip limit 3

Issues with Collected Data



raw image

CLAHE gridsize 15, clip limit 3

NUance Car Provided Dataset

- From 01 February 2020
- Route:

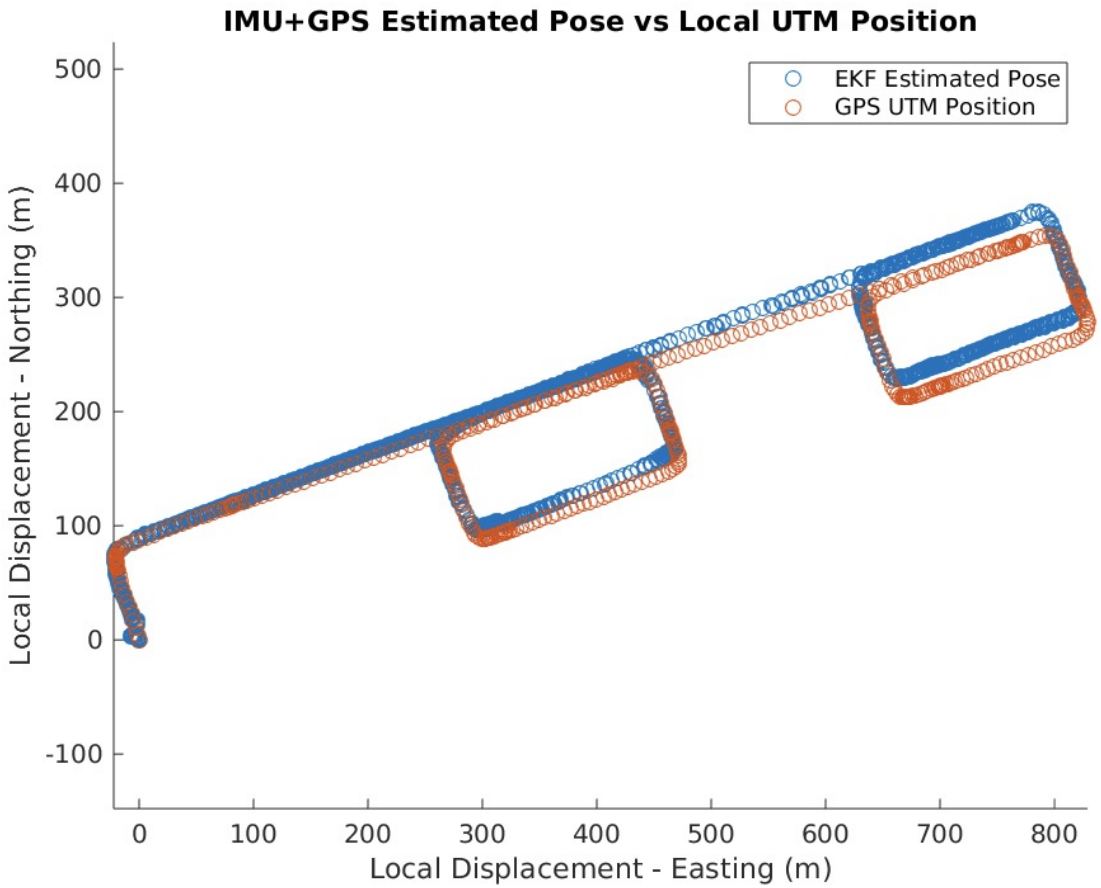
Video Demonstration

Loop closure on provided NUance car dataset:

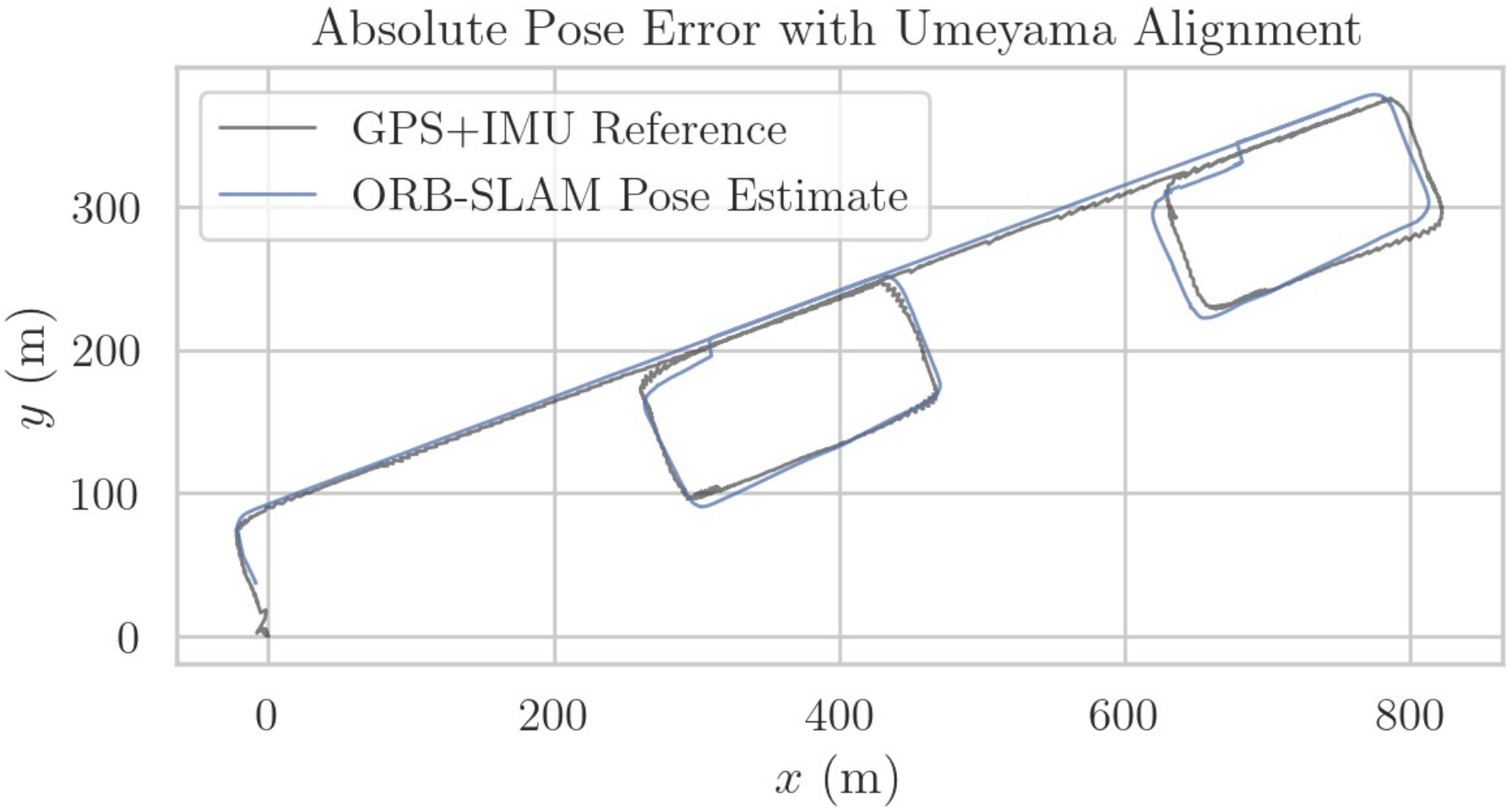
https://youtu.be/zdDk7nShIZg

Obtaining Reference Odometry

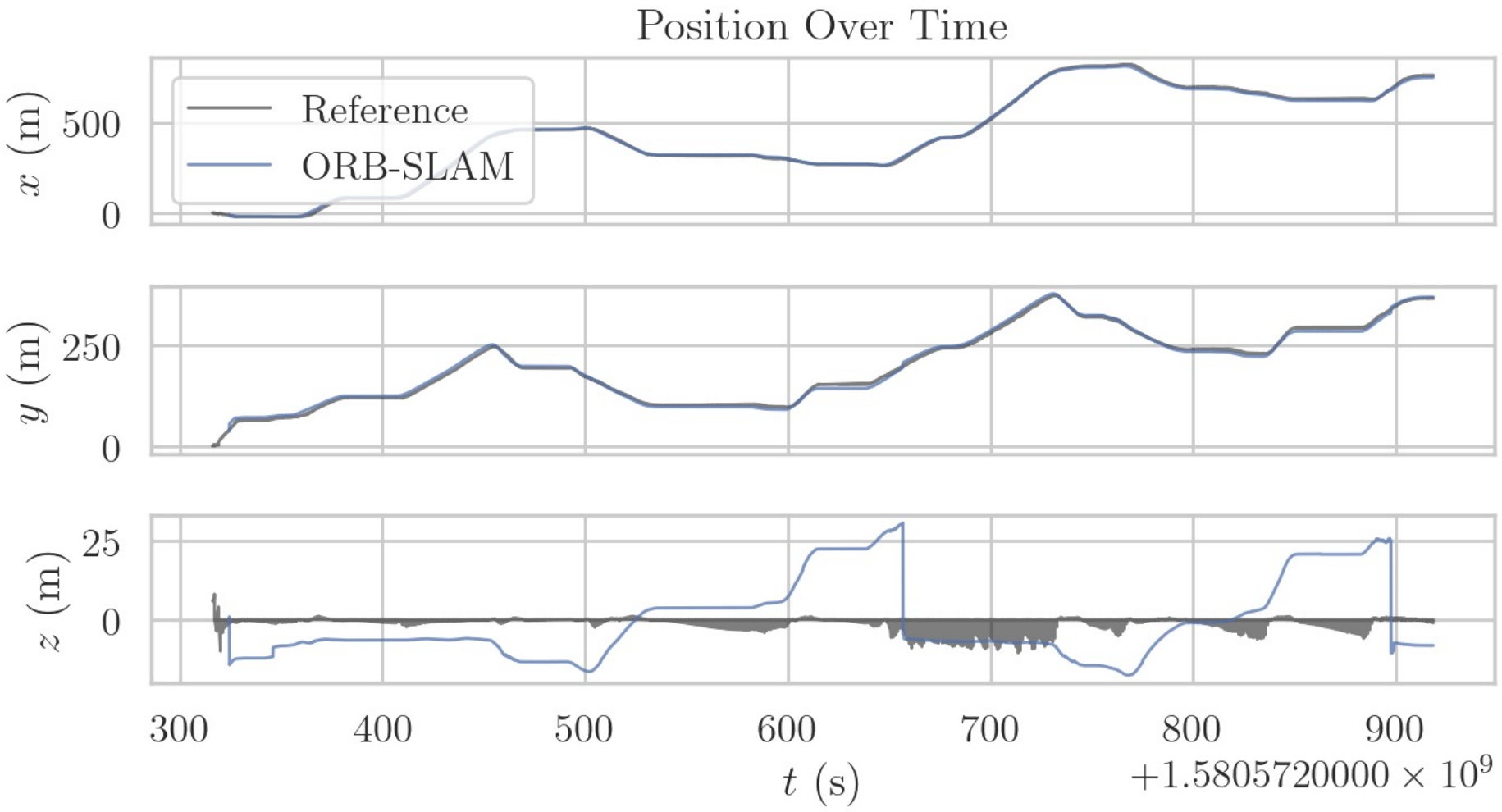
- Extended Kalman Filter created to fuse GPS+IMU



ORB-SLAM3 Results – Absolute Pose Error



ORB-SLAM3 Results – Error Over Time



Although ORB-SLAM3 ranks higher in stereo inertial single-session processing of outdoors1, there is still a significant drift (≈ 60 m).

Quantitative ORB-SLAM3 Results

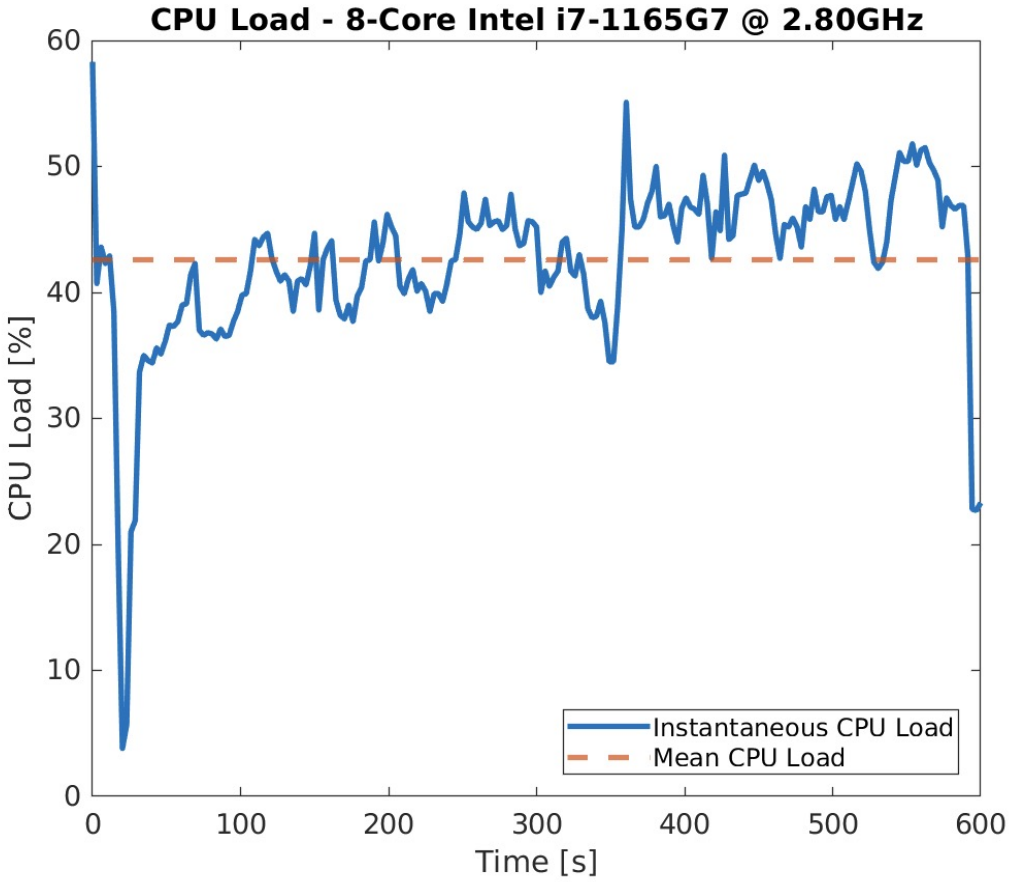
Quantitative Error Statistics – NUance	
RMSE (m)	15.660 m
Trajectory Length (km)	2.08 km
% Error	0.753 %

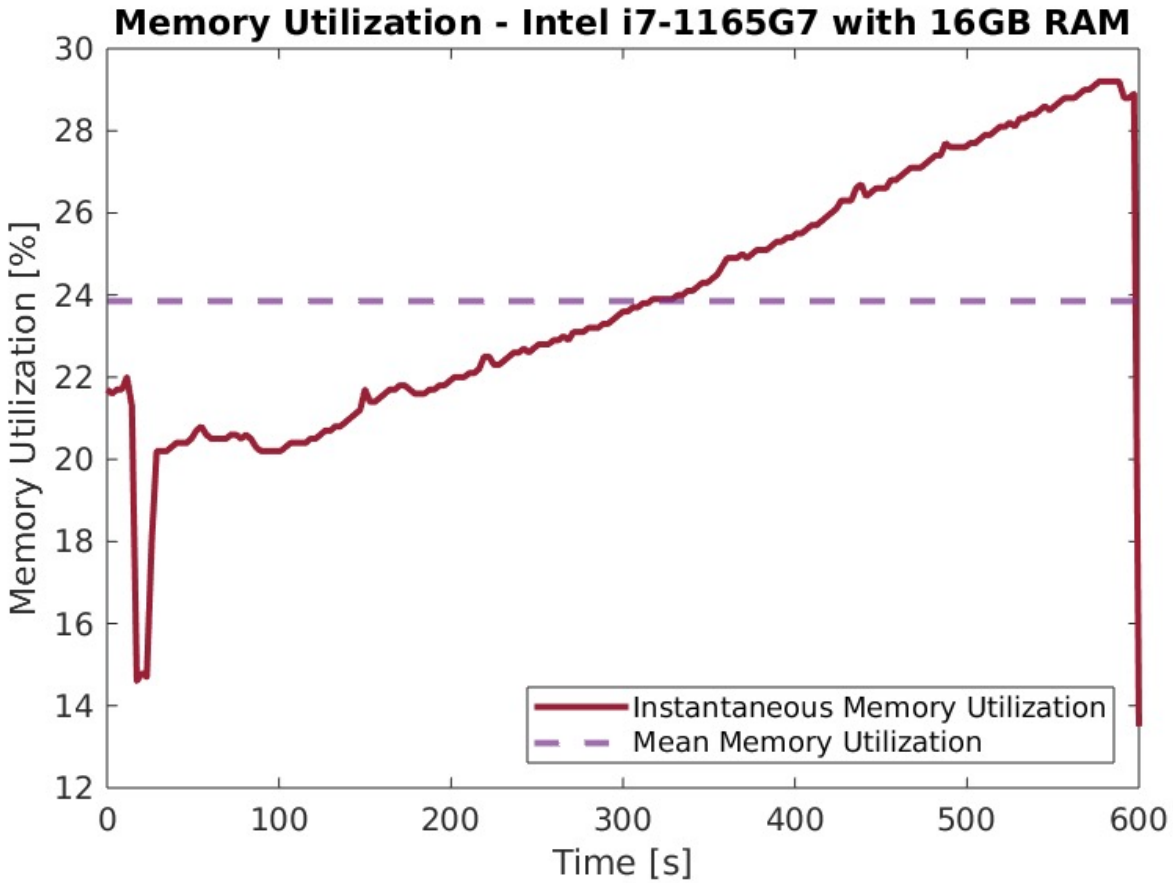
ORB-SLAM3 Paper Error Statistics – TUM VI outdoors6 sequence	
RMSE (m)	10.70 m
Trajectory Length (km)	2.045 km
% Error*	0.523 %

*author notes that no loop closures were detected in this sequence

Computational Performance Results

- CPU Load and Memory Utilization tested on Samsung Galaxy Book Flex (Intel i7-1165G7 @ 2.80 GHz, 16GB RAM)





Conclusion

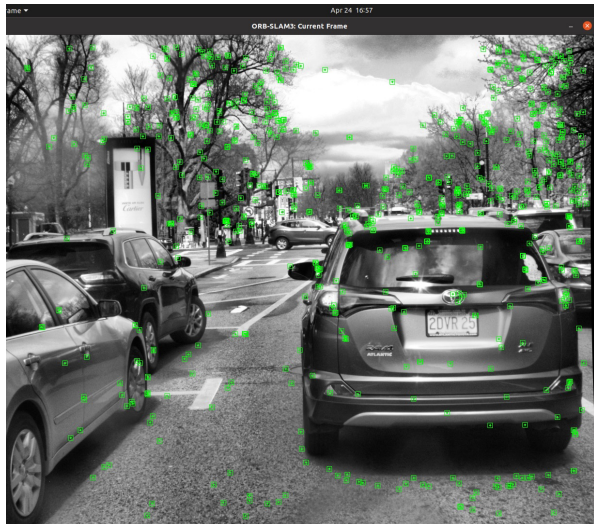
- ORB-SLAM3 did not run as well on NUance as it did in their paper results on the TUM outdoor dataset
  - However, the results are still pretty good
- Issues with the camera feed in the collected dataset prevented testing in more challenging environments
- While the algorithm shows promising performance, the current state of their repository prevents ORB-SLAM3 from being an outstanding open-source algorithm

Questions?

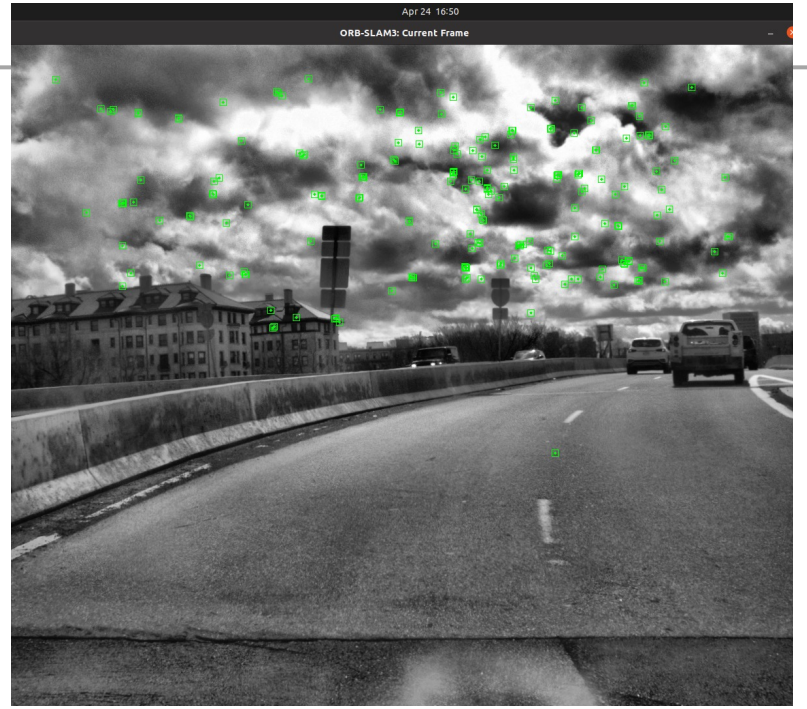
Random Notes

- “Another important aspect of ORB-SLAM3 concerns the proposed initialization technique that relies on the Maximum-a-Posteriori algorithm individually applied to the visual and inertial estimations, which are later jointly optimized. ”
- “However, authors in [76] demonstrated significant errors results of ORB-SLAM3 online performance. In [77], the algorithm obtained a good performance, but failed to process all the sequences, and obtained inaccurate estimates in outdoor sequences.”
- Original authors used CLAHE on outdoor datasets

Our Dataset


Apr 24 16:57
ORB-SLAM3: Current Frame


Apr 24 16:50
ORB-SLAM3: Current Frame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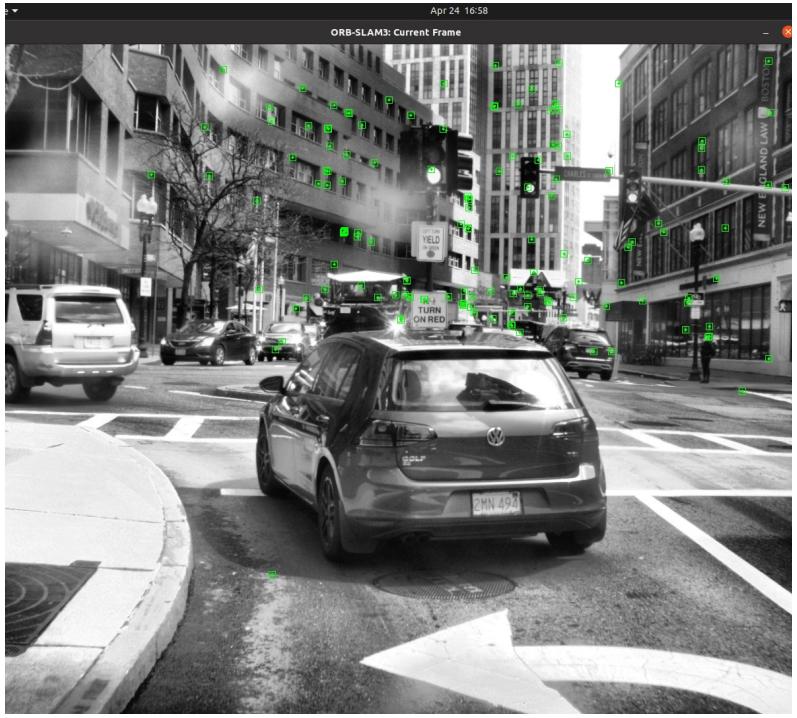
ORB-SLAM3: Current Frame


Apr 24 16:58
ORB-SLAM3: Current Frame


Apr 24 16:58
ORB-SLAM3: Current Frame