EECE5554 - ROBOT SENSING AND NAVIGATION

ORB SLAM -3

Group 11

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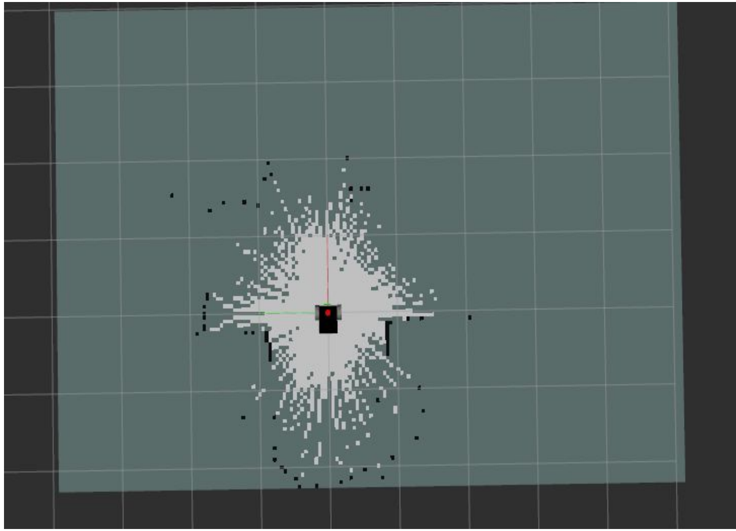
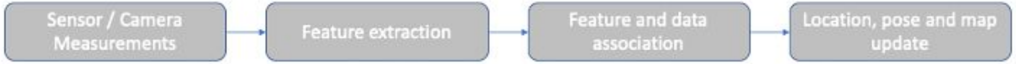
What is SLAM?

- SLAM is a process where a mobile robot creates and utilizes a map to determine its location in an environment.
- Both the trajectory of the platform and the location of all landmarks are estimated without a priori knowledge of location.
- SLAM has two parts
  - Localization
  - Mapping





Sensor / Camera Measurements → Feature extraction → Feature and data association → Location, pose and map update

Simplified generic feature-based SLAM process

Lidar SLAM or Visual SLAM?

Lidar SLAM Vs Visual SLAM

Accuracy: LIDAR sensor can measure distances with high precision.

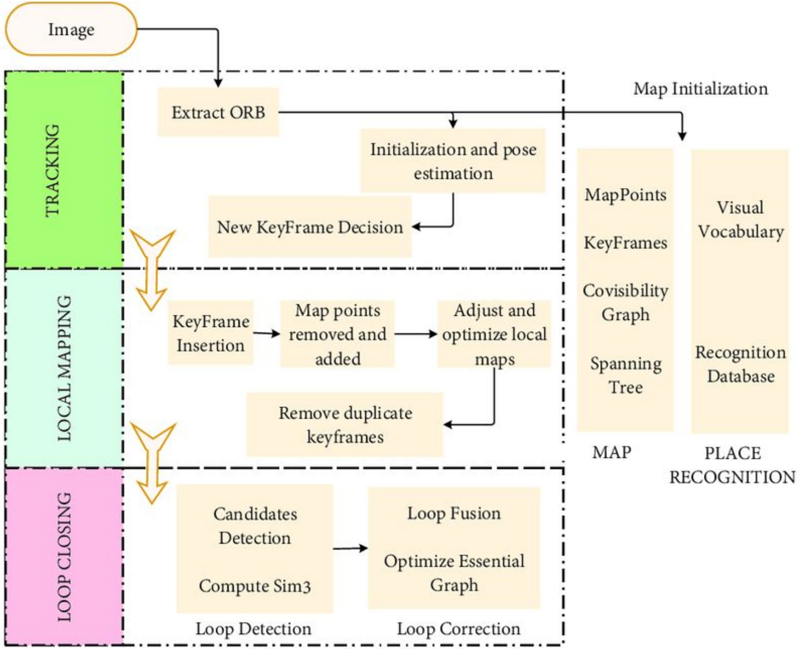
Reliability: LIDAR sensors are less affected by environmental factors.

Speed: Visual SLAM is faster than LiDAR SLAM due to quicker image capture, influenced by system computational power and environmental complexity.

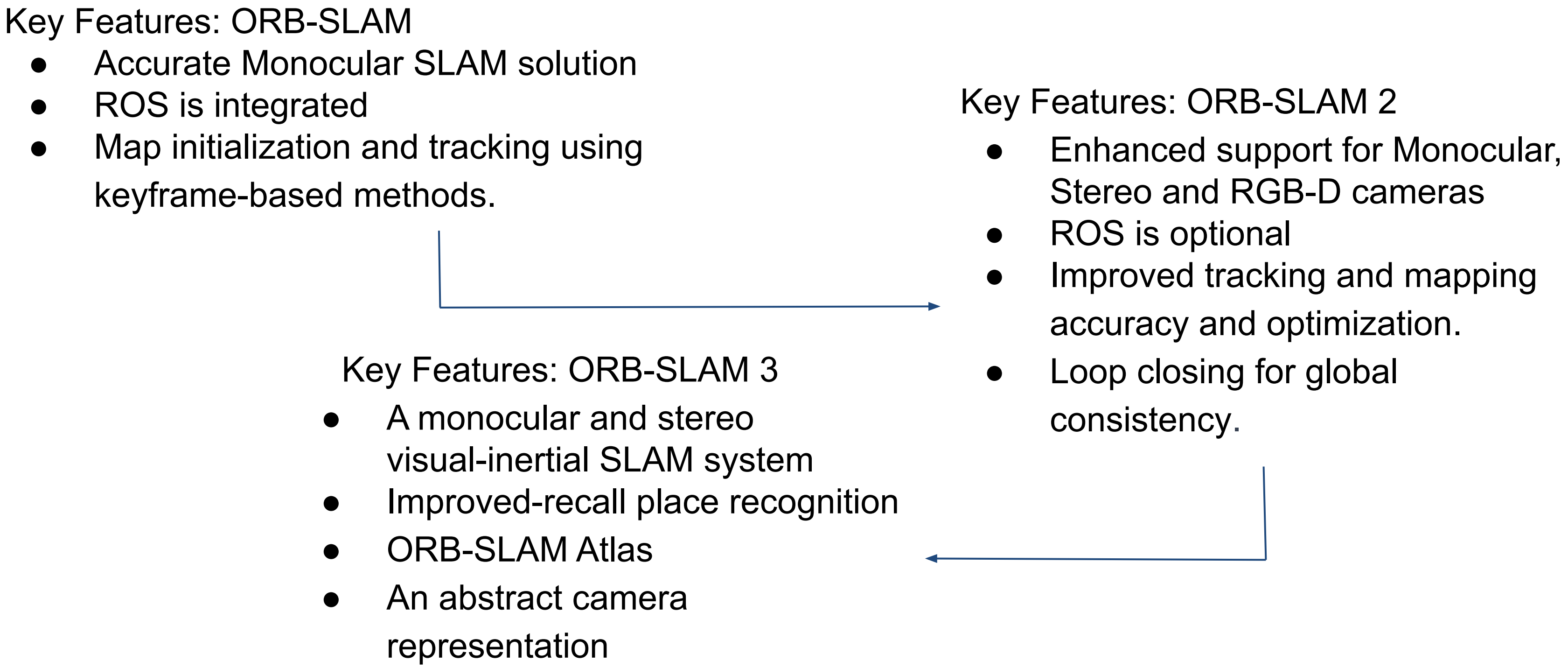
Cost: LIDAR sensors are more expensive and require more processing power.

Understanding ORB-SLAM

- ORB-SLAM comes from Oriented FAST and Rotated BRIEF (ORB) features to detect and match keypoints in images.
- Combined techniques, such as loop closing and pose optimization, to achieve robust and accurate localization and mapping.
- The system is divided into three threads
  - Tracking
  - Local mapping
  - Loop closing



ORB-SLAM to ORB-SLAM 3



Key Features: ORB-SLAM

- Accurate Monocular SLAM solution
- ROS is integrated
- Map initialization and tracking using keyframe-based methods.

Key Features: ORB-SLAM 2

- Enhanced support for Monocular, Stereo and RGB-D cameras
- ROS is optional
- Improved tracking and mapping accuracy and optimization.
- Loop closing for global consistency.

Key Features: ORB-SLAM 3

- A monocular and stereo visual-inertial SLAM system
- Improved-recall place recognition
- ORB-SLAM Atlas
- An abstract camera representation

ORB-SLAM 3

- It is a feature-based tightly-integrated visual-inertial SLAM system.
- It is a multiple map system that relies on a new place recognition method with improved recall.
- Reuse in all the algorithm stages all previous information.
  - Short-term data association
  - Mid-term data association
  - Long-term data association
  - Multi-map data association

ORB-SLAM 3

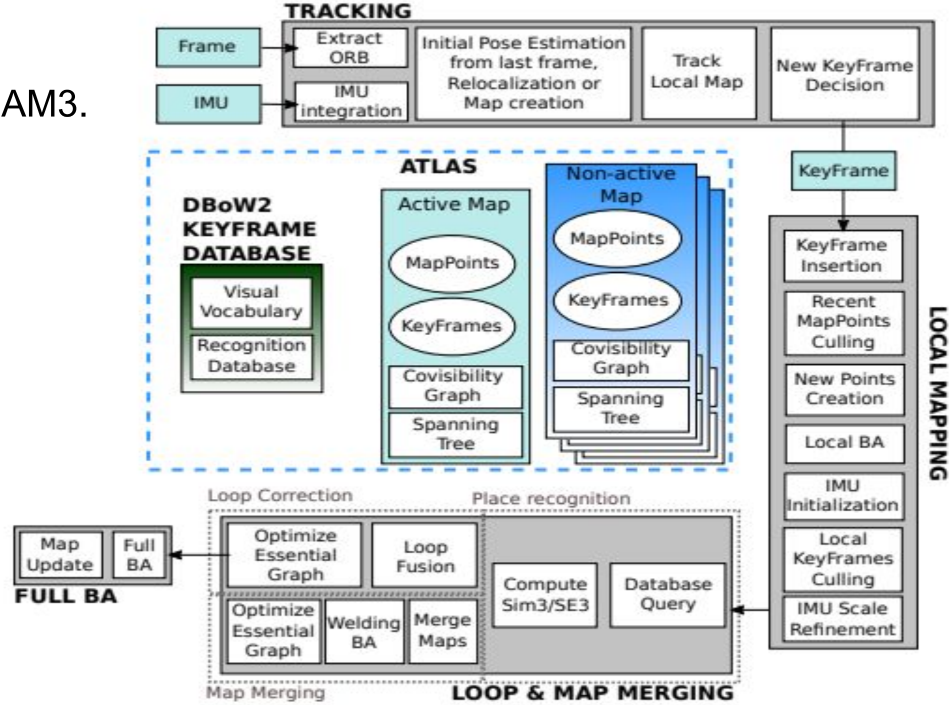
The main techniques used for estimation and data association:

- **Visual SLAM:**
- **Visual-Inertial SLAM:**
- **Multi-Map SLAM:**

SYSTEM FRAMEWORK

Main system components of ORB-SLAM3.

- Tracking
- Mapping
- ATLAS
- Loop Cloosing



Tracking

- The goal is to get Pose (T), Velocity(v) and biases(b)(assumed to be brownian)
- Done using VO, IO and VIO (IMU Initialization)
- In VO
  - Good initial estimate but the map scale is bad
  - Extracts features using ORB algorithm
  - Creates a keyframe
  - Performs visual only bundle adjustment to estimate the pose
- In IO
  - Scale converges fast when treated as an optimization variable in BA
  - Uses Pose estimated from VO and IMU measurements
  - Calculate a term called inertial residual
  - Solve the optimization problem to get pose

Tracking

- In VIO
  - Combines VO and IO into a single optimization problem
  - Uses IMU pre-integration to calculate Inertial Residual
  - Combines Visual and Inertial residuals to form an optimization problem
  - Solves problem using factor graphs to get the required pose
- If tracking is lost for 20s, new map created
- If new map tracking is lost 15s after IMU initialization, map is discarded

Re-Localization

- Required to find the position based on previous info when tracking fails
- Uses an algorithm called Max Likelihood Perspective n Points (MLPnP)
- MLPnP works on any type of camera

Place Recognition

- Find Candidate Key frames
- Look for nearby Keyframes with similar matching map points
- Compute Transformation using RANSAC to align map points and choose best transformation
- Refine the Transformation by solving a nonlinear optimization problem
- Verify false positives
- Verify gravity vector

If this is done, the algorithm goes into map merging

Loop closing/Map Merging

- Transformation is applied to 2 maps to be merged in a small region
- Merged maps transition into the new active map
- Common map points are removed to avoid duplicate points
- Local BA is performed in the welding window
- Once the maps are merged the poses are recalculated by optimizing the new essential graph

CAMERA MODEL and CALIBRATION

- ORB-SLAM assumed in all system components a pin-hole camera model.
- SLAM systems rectify either the whole image, or the feature coordinates, to work in an ideal planar retina.
- This forces to crop-out the outer parts of the image, losing the advantages of large Field of View
  - Relocalization:

    ORB-SLAM solves the relocalization problem by setting a Maximum Perspective-n-Point algorithm (MLPnP) that is completely decoupled from the camera model as it uses projective rays as input.
  - Non-rectified Stereo SLAM:

    Considering the stereo rig as two monocular cameras having:

    1) a constant relative SE transformation between them, and

    2) optionally, a common image region that observes the same portion of the scene.

VISUAL-INERTIAL SLAM

ORB-SLAM-VI provides a fast and accurate IMU initialization technique with pin-hole and fisheye cameras.

- **IMU Initialization:**
  - Vision-only MAP Estimation
  - Inertial-only MAP Estimation
  - Visual-Inertial MAP Estimation

VISUAL-INERTIAL SLAM

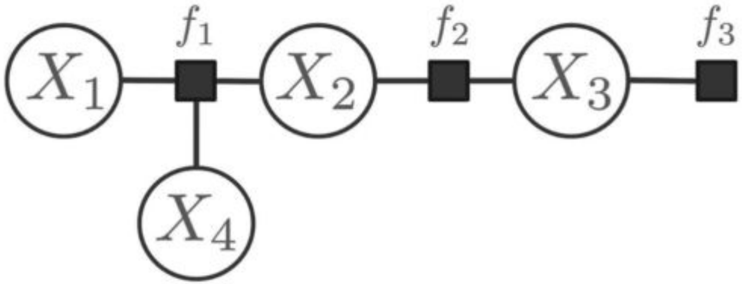
Tracking and Mapping:

- Tracking solves a simplified visual-inertial optimization where only the states of the last two frames are optimized, while map points remain fixed.

Robustness to tracking loss

- visual-inertial system enters into visually lost state when less than 15 point maps are tracked, and achieves robustness.
- If the system gets lost within 15 seconds after IMU initialization, the map is discarded.
- This prevents to accumulate inaccurate and meaningless maps.

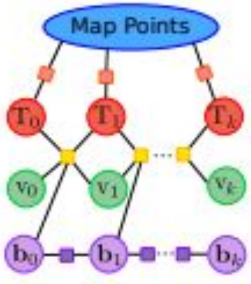
FACTOR GRAPHS



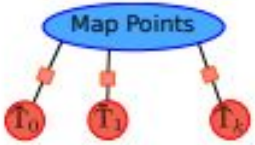
$$g(X_1,\ldots,X_4) = f_1(X_1,X_2,X_4)\,f_2(X_2,X_3)\,f_3(X_3)$$

- Bi-partite graph.
- Simplification of Probability Distributions.
- Used to visualise independence relations between variables.
- Efficient execution of inference tasks.
- Used to solve least-square problems.

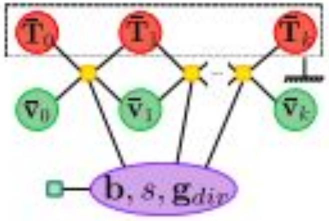
FACTOR GRAPHS



(a) Visual-Inertial



(b) Visual-Only



(c) Inertial-Only

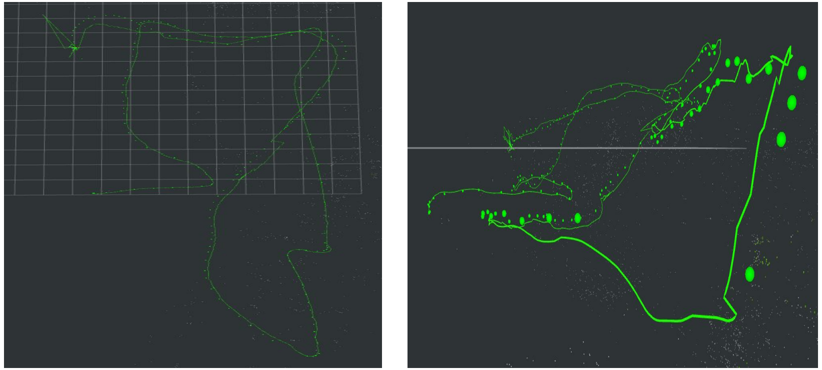
$$\mathcal{Y}_k^* = \underset{\mathcal{Y}_k}{\arg\min} \left(\|\mathbf{b}\|^2_{\Sigma_b^{-1}} + \sum_{i=1}^{k} \|\mathbf{r}_{\mathcal{I}_{i-1,i}}\|^2_{\Sigma^{-1}_{\mathcal{I}_{i-1,i}}} \right)$$

T: Pose

v: Velocities between keyframes

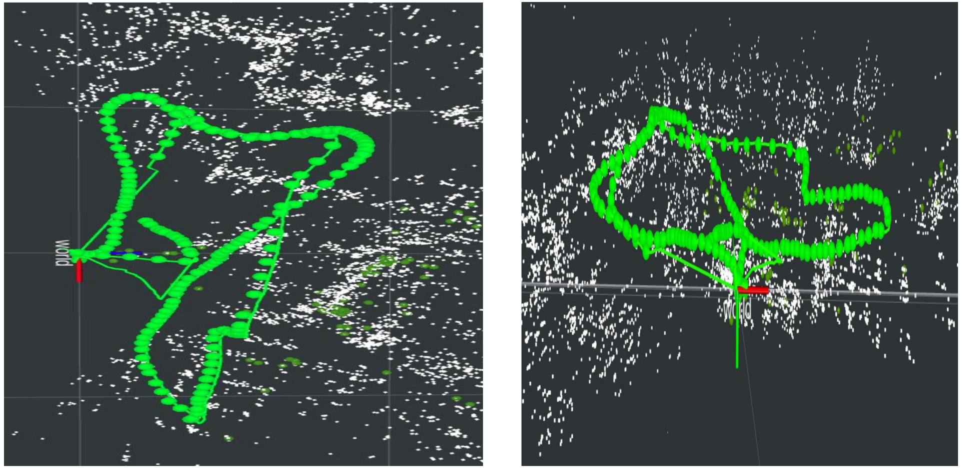
b: Accelerometer and gyroscope biases

EUROC DATASET



Monocular Mode

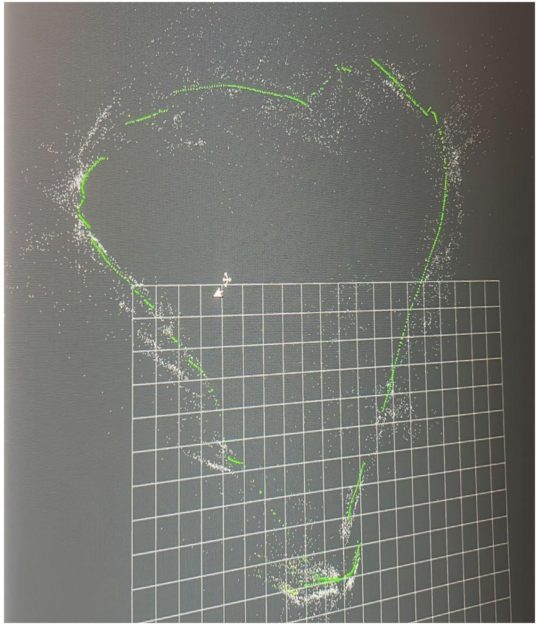
Monocular + IMU Mode

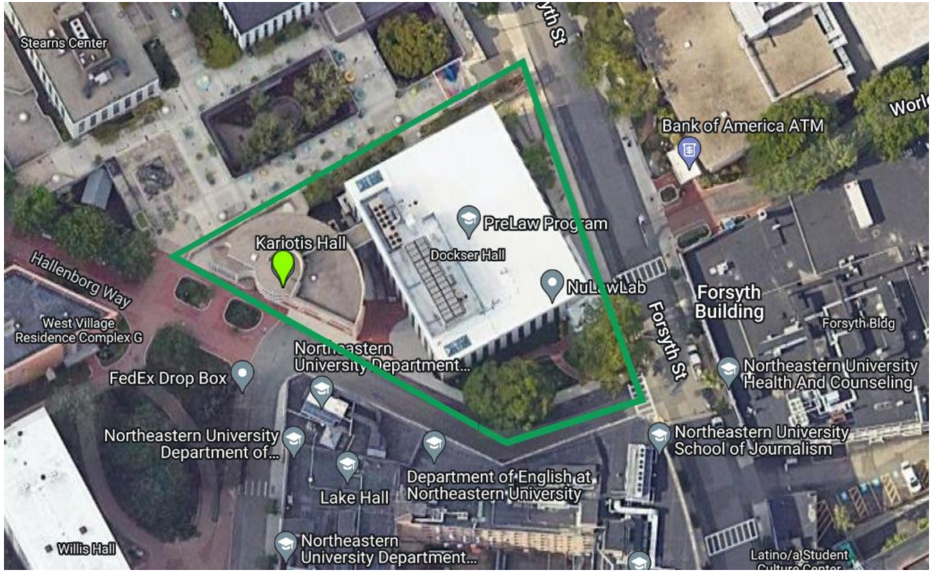


Indoor Snell Dataset

Access all the videos here

Outdoor Dataset

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PreLaw Program
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NuLawLab
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Forsyth Building
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Forsyth St
West Village Residence Complex G
Northeastern University Department...
FedEx Drop Box
Northeastern University Health And Counseling
Northeastern University Department of...
Northeastern University School of Journalism
Lake Hall
Department of English at Northeastern University
Willis Hall
Northeastern University Department...
Latino/a Student Culture Center

Access all the videos [here]

CHALLENGES

- Pangolin is not supported by every system and makes everything crash if its not disabled (it is required to build)
- Monocular mode is REALLY inconsistent
- Faces challenges in handling dynamic environments and large-scale mapping.
- Sudden Camera movement in corners loosing mapping points.
- Some failure cases under challenging conditions such as weak and repetitive texture, and bad illumination.

FUTURE IMPLEMENTATION

- Integration of an object detection module for semantic segmentation
- Test out a monocular depth detection algorithm to see if it performs any better
- Fuse Lidar odometry with Visual Inertial Odometry
- See if any of the above can give us the full path taken by NUANCE dataset

Q&A