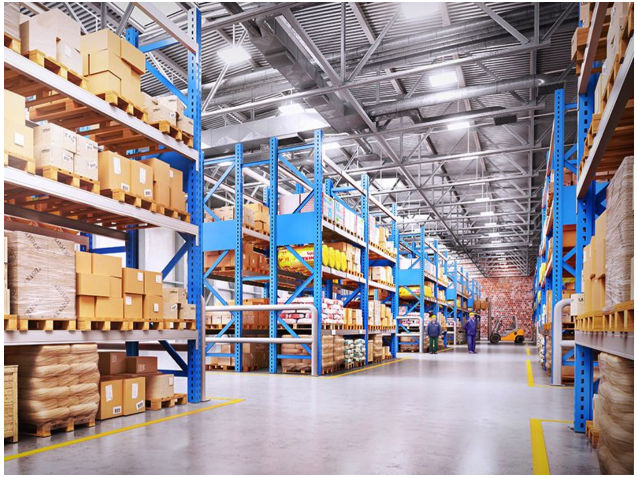
Visual Inertial Odometry for Miniature Autonomous Blimp

Senior Design Team XXLs - Jan 22

Potential Applications

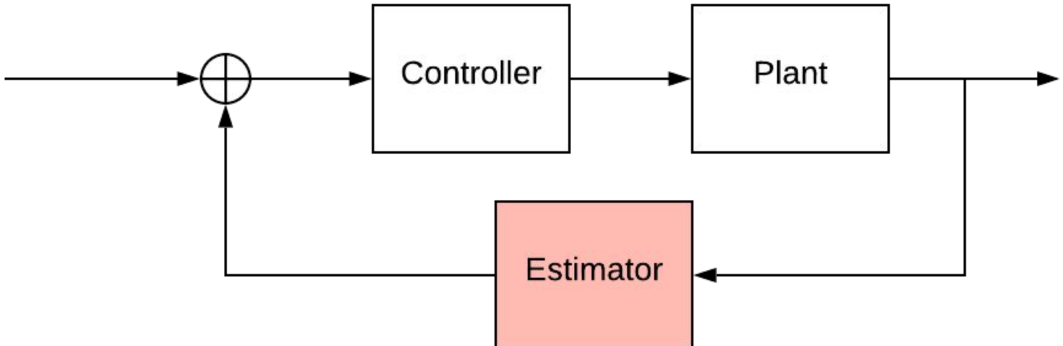
1. Crowded environment deployment such as airport and metro human traffic monitoring.
2. Patrolling large indoor area such as warehouse, and factory.



Problem Statement

- Potential for larger indoor environment deployment.
- Limited by external localization system.
- Visual Odometry is a good choice considering the Blimp's payload capacity.
- IMU is added to compensate for the lack of scale in VO.

- Goal: Enhance navigation capability of blimp via Visual Inertial Odometry.



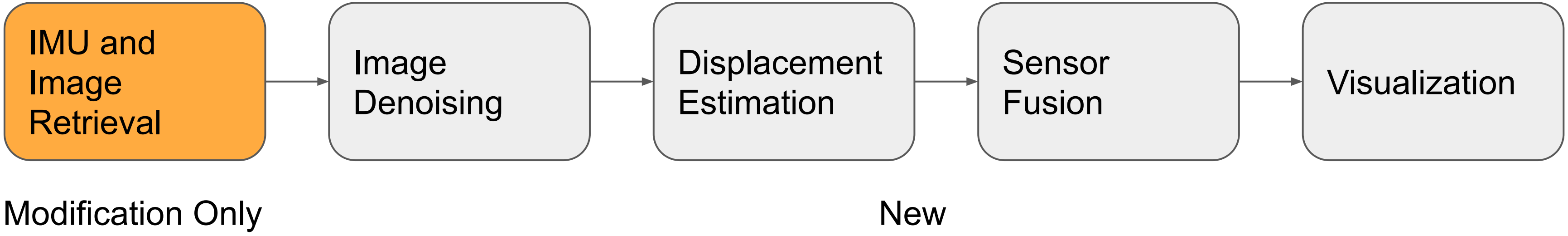
Presentation Structure

- Final Deliverables
- Task Breakdown
  - Hardware and Firmware Modification
  - Camera Calibration
  - Image Processing and Denoising
  - Conventional Visual Odometry
    - Feature matching to essential matrix
    - Essential matrix to homogeneous transformation
  - Sensor Fusion
  - Visualization
- Demo
- Schedule and Gantt Chart

Final Deliverables

Series of ROS Nodes performing following functions:

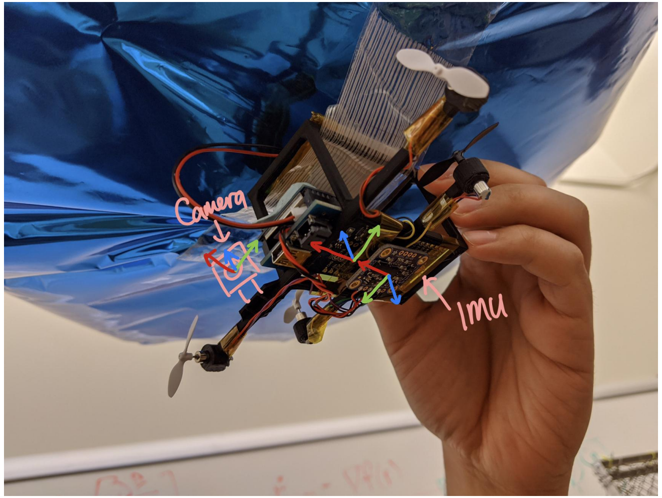
1. IMU and Image Retrieval
2. Image Denoising & Augmentation
3. Feature Detection and Displacement Estimation
4. Sensor Fusion
5. Visualization



Hardware & Firmware: Xu

- Data to be retrieved
  - Image-Displacement (Optitrack) Pair for VO
  - Linear acceleration and angular velocity data (IMU)
- Blimp-side
  - Data retrieval from IMU through I^2C
  - IMU data transmission through serial to ground station
- ROS-Side
  - IMU Data retrieval
  - Static transform tree for IMU, camera, blimp center
  - Transform publisher for map frame twist message to blimp frame twist

$\Delta \mathbf{x} = \mathbf{x_{t+1}} - \mathbf{x_t}$ and image at time t



Camera Calibration: Lyu

- Sample images of Chessboard
- Camera Matrix (K)

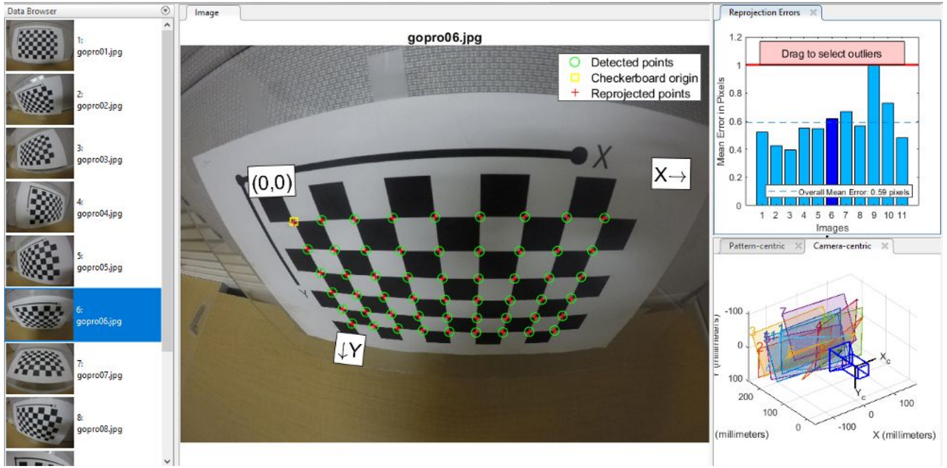
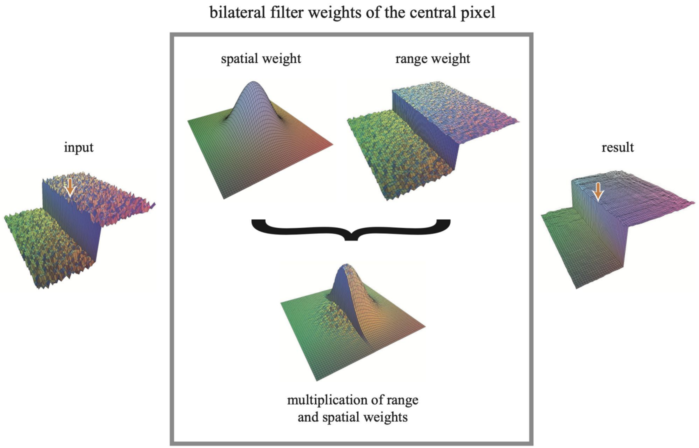


Image Processing: Shen

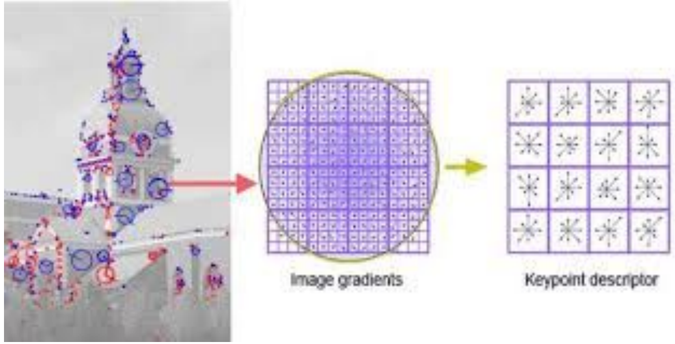
- Why Denoising?

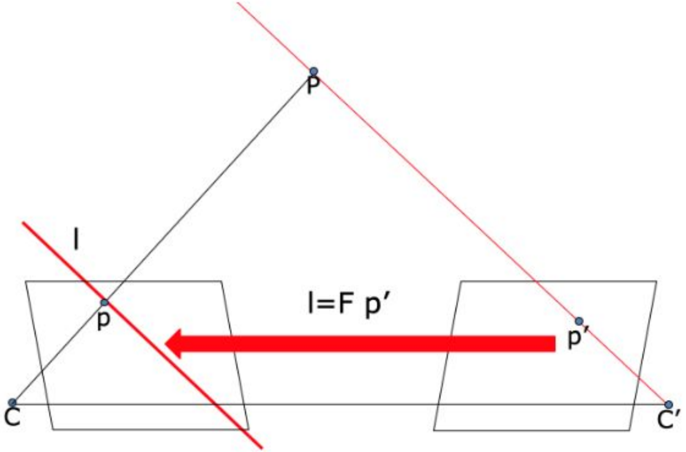
- Bilateral Filter
  - Edge Protection
  - Spatial & Range
- Median Filter
  - Median of nearby pixels



Conventional Visual Odometry: Xie

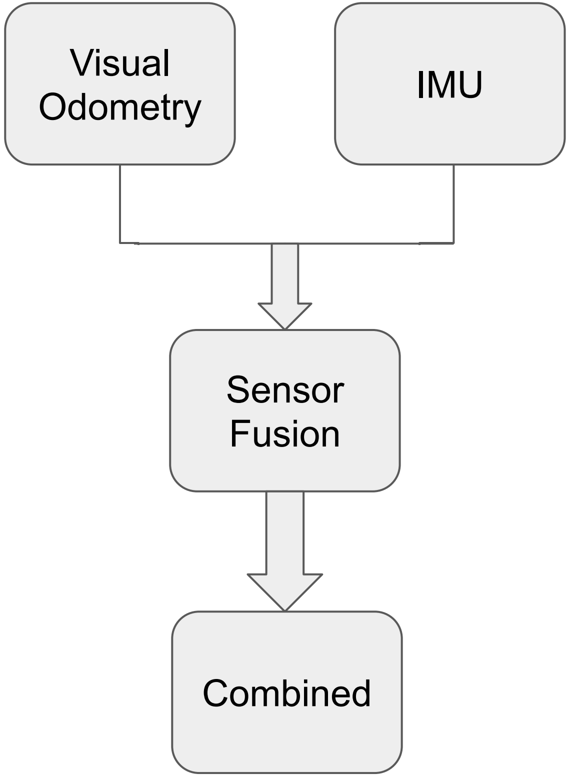
1. Feature Extraction (Harris Corner Detector & SIFT Feature Descriptor)
2. Feature Matching (Nearest Neighbor Distance Ratio Test)
3. Fundamental Matrix Estimation (Least Squares Optimization with RANSAC)
4. Essential Matrix Calculation (E = K' * F * K)
5. Essential Matrix to Transformation (**Lyu**)





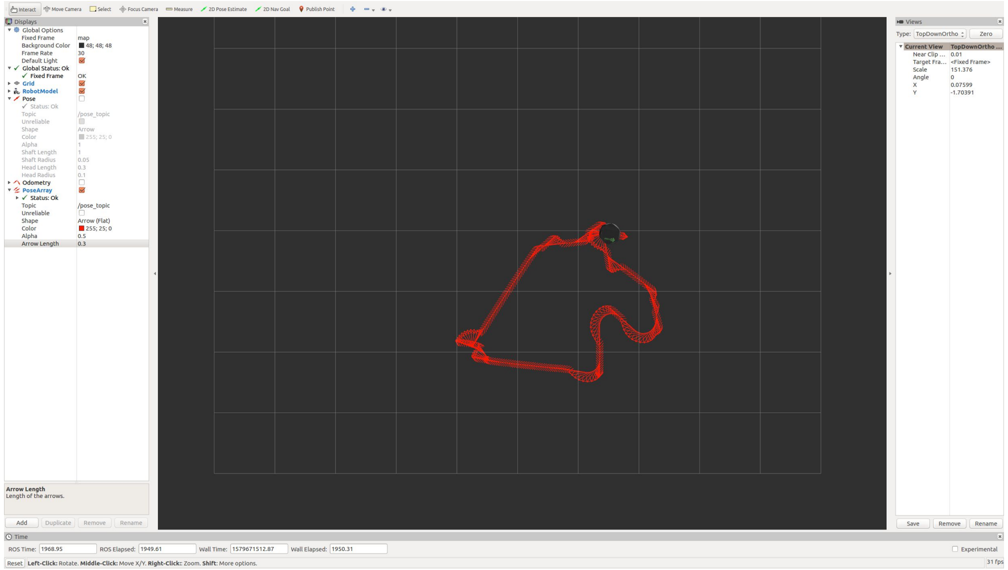
Simplified Sensor Fusion: Xu

- Merge VO and IMU to produce pose estimation.
- Approach
  - Calculate VO covariance by comparing visual odometry data with ground truth odometry from Optitrack system. IMU covariance from datasheet.
  - Weighted sum of measurements.
  - Dead Reckoning to produce pose estimation.
  - Not using kalman filter because system identification would be needed.



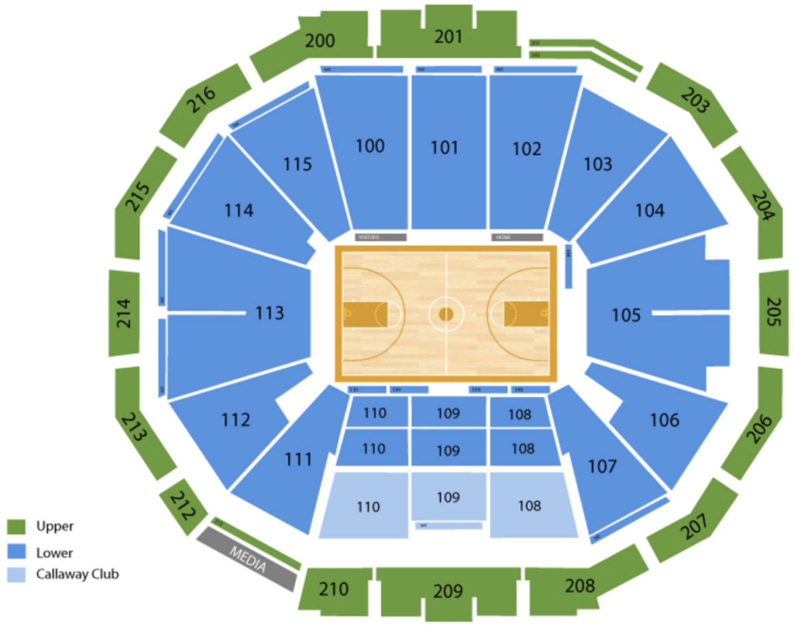
Visualization: Shen

1. ROS node subscribing to current position, and publishing visualization message to rviz (world frame).
2. Rviz config file to launch with specified visualization enabled.



Demo Plans

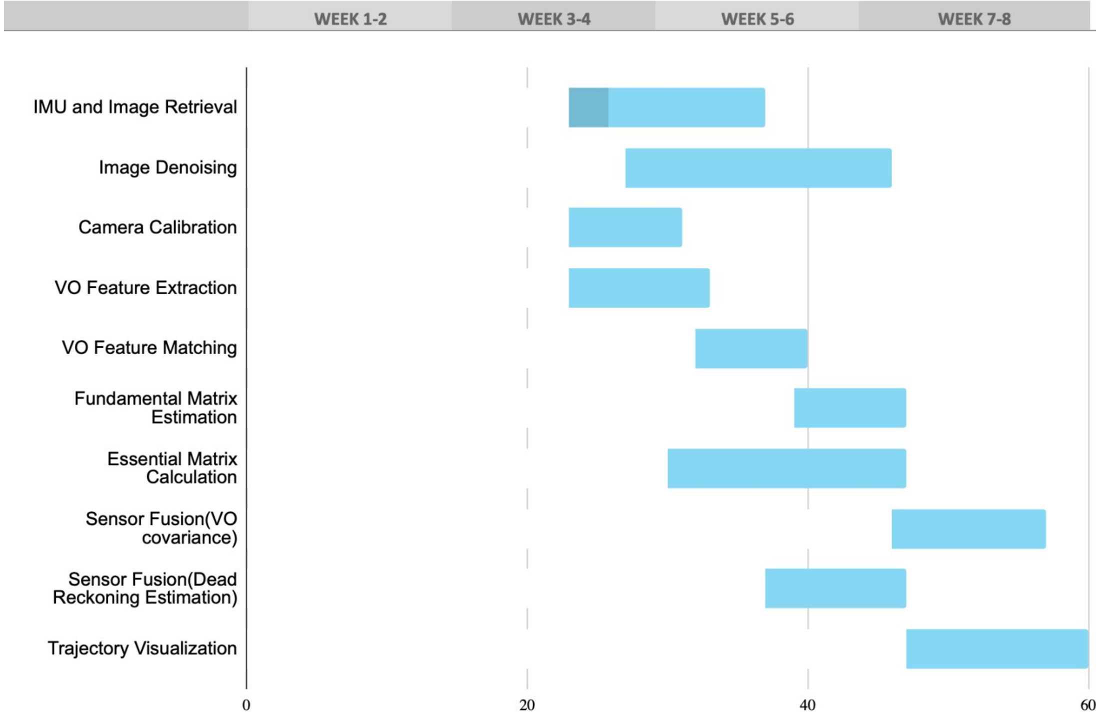
- Location
  - Requested demo place to be inside McCamish to Dr. Frazier. Will update once we heard back.
- Content
  - Control blimps through joystick, plot estimated pose on laptop to show the capability of visual inertial odometry.
  - Allow visitors to control the blimp.
  - Attach wire to blimp for safety concern.



Tentative Schedule

TASK NAME	START DATE	END DATE	DURATION* (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
IMU and Image Retrieval	1/23	2/5	14	Ruoyang	20%
Image Denoising	1/27	2/14	19	Yifan	0%
Camera Calibration	1/23	1/30	8	Fanzhe	0%
VO Feature Extraction	1/23	2/1	10	Yilun	0%
VO Feature Matching	2/1	2/8	8	Yilun	0%
Fundamental Matrix Estimation	2/8	2/15	8	Yilun	0%
Essential Matrix Calculation	1/30	2/15	17	Fanzhe	0%
Sensor Fusion(VO covariance)	2/15	2/25	11	Ruoyang	0%
Sensor Fusion(Dead Reckoning Estimation)	2/6	2/15	10	Ruoyang	0%
Trajectory Visualization	2/16	2/28	13	Yifan	0%

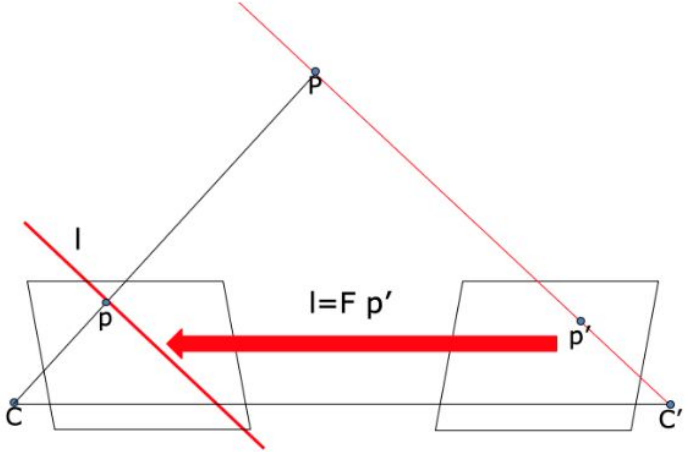
Gantt Charts



Appendices

- Math behind Fundamental Matrix Estimation
- Fundamental Matrix to Homogeneous Transformation
- Sensor Fusion

Fundamental Matrix Estimation (least square problem)



$$1 = [a, b, c]$$

$$x = [u, v, 1]$$

$$x_0^T F x_1 = 0$$

$$\begin{bmatrix} u_0 & v_0 & 1 \end{bmatrix} \begin{bmatrix} f_{11} & f_{12} & f_{13} \\ f_{21} & f_{22} & f_{23} \\ f_{31} & f_{32} & f_{33} \end{bmatrix} \begin{bmatrix} u_1 \\ v_1 \\ 1 \end{bmatrix} = 0$$

$$d(l, x) = \frac{au + bv + c}{\sqrt{a^2 + b^2}}$$

$$(F) = \sum_i^n \left(d(Fx_1^i, x_0^i)^2 + d(F^T x_0^i, x_1^i)^2 \right)$$

Essential Matrix to Homogeneous Transformation: Lyu

$E = U\Sigma V^T$ Singular Value Decomposition

$$W = \begin{bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$t = VW\Sigma V^T$$

$$R = UW^{-1}V^T$$

$$T = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix}$$

Idea: Find out Epipolar error is minimized

https://people.eecs.berkeley.edu/~yang/courses/cs294-6/lectures/lec7-Sept20.ppt

Sensor Fusion

- Weighted sum of VO and IMU data through standard deviation

$$\boldsymbol{\xi}_{fin} = \sigma_3^2(\sigma_1^{-2}\boldsymbol{\xi}_1 + \sigma_2^{-2}\boldsymbol{\xi}_2)$$

$$\sigma_3^2 = \left(\sigma_1^{-2} + \sigma_2^{-2}\right)^{-1}$$

- Central Limit theorem, based on noise deviations.

Notes

1. Challenges
2. Extension to VIO
   a. Stories wanted to solve
3.


IMU and Image Retrieval
Image Denoising
Displacement Estimation
Sensor Fusion
Visualization