39th Canadian Symposium on Remote Sensing, June 19-21, 2018

EKF and Smoothing-based UAV Positioning Using UWB and IMU Fusion

Jungwon Kang[1], **Kunwoo Park**[1], Gunho Sohn[1], Mozhdeh Shahbazi[2], Patrick Ménard[3]

[1]York University

[2]University of Calgary

[3]Centre de géomatique du Québec

June 19 2018

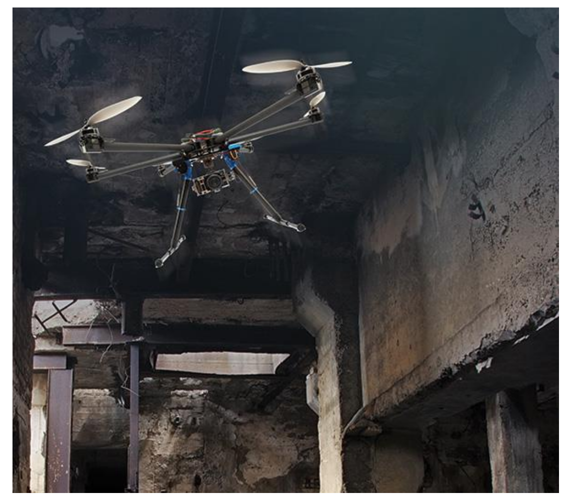
Contents

1. Introduction

UAV application in GPS-denied environment

- Indoor application
- Bridge, Tunnel, Chimney inspection
- High-rise building inspection

AutoModality



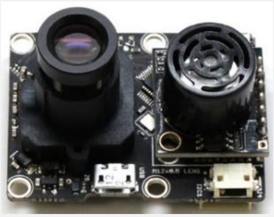
DRAPER

Difficulties of Maneuvering a Drone in GPS-denied environment

Alternative Sensors for UAV Positioning

- Image-based Camera: highly sensitive to the surroundings
- Ranging-based UWB sensor: resistant to severe multipath

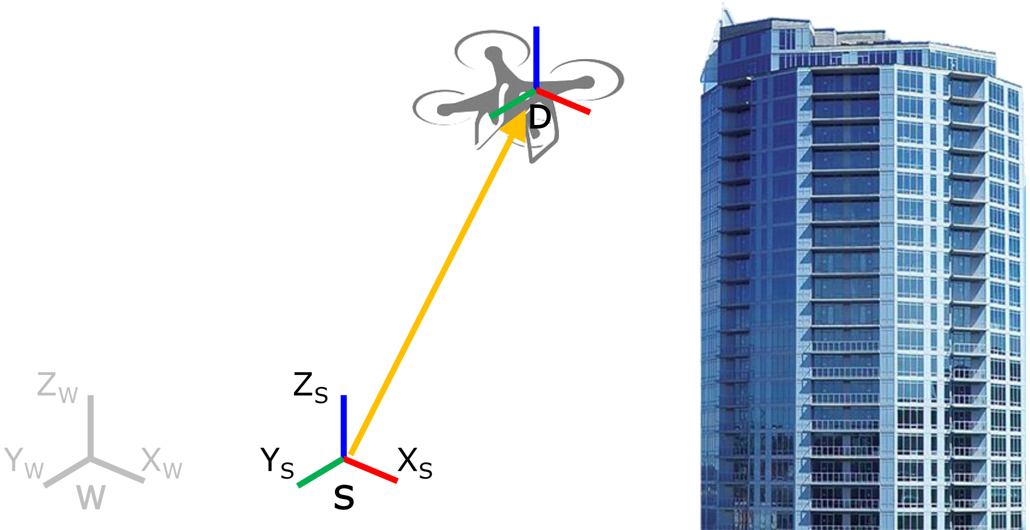
Skybotix VI-Sensor



PX4FLOW optical flow camera board

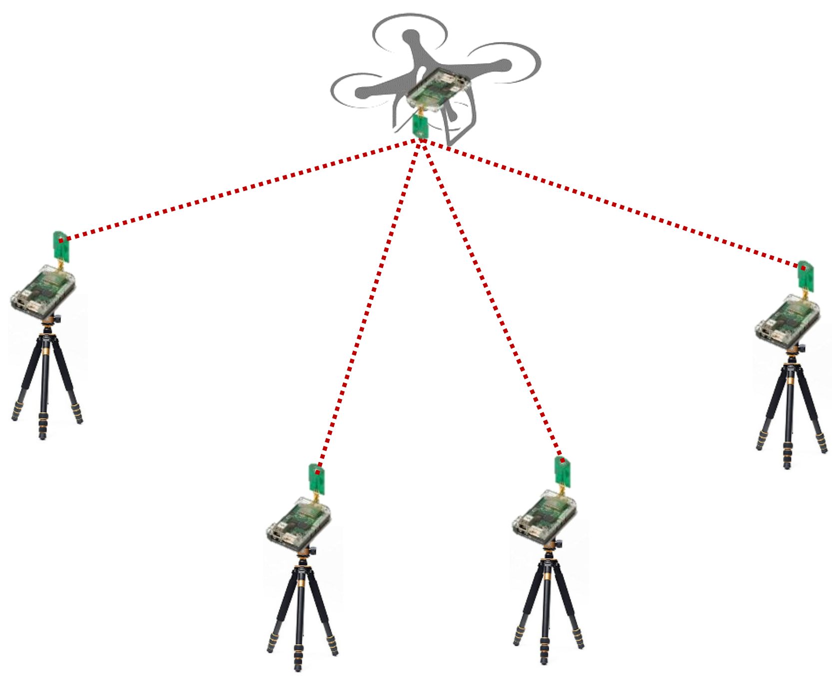
Time Domain PulsOn 440

Decawave TREK1000



Ultra-Wideband-Based positioning

- Robust to multipath and non-line-of-sight (NLOS) effects
- cm-level ranging error
- Wide range applicable
- Light weight, low power consumption



Related Works

Filtering based

UWB Sole System K. Guo 2016, B. Dewberry 2016

- Issue 1: Estimation of UWB station position
- Issue 2: Trilateration & Kalman Filter

GPS-UWB Coupled System K. Hausman 2016, J. Wang 2016

- Issue 1: Relative coordination between W and S
- Issue 2: Fusion of W-based pose and S-based one

Range-Only SLAM F. Fabresse 2015

- Issue 1: Initialization with Gaussian mixture model
- Issue 2: Range-Only Simultaneous localization and mapping

Smoothing based

Graph Optimization Approach C. Wang, 2018

Research objective

- Comparison between two algorithms
  - A Comparison of SLAM Algorithms with Range Only Sensors [F. Herranz, 2014]
  - Incremental Smoothing vs. Filtering for Sensor Fusion on an Indoor UAV [S. Lange, 2013]

- Which one is the best methodology for UAV positioning?
  - Accuracy, Robustness, Speed…etc.

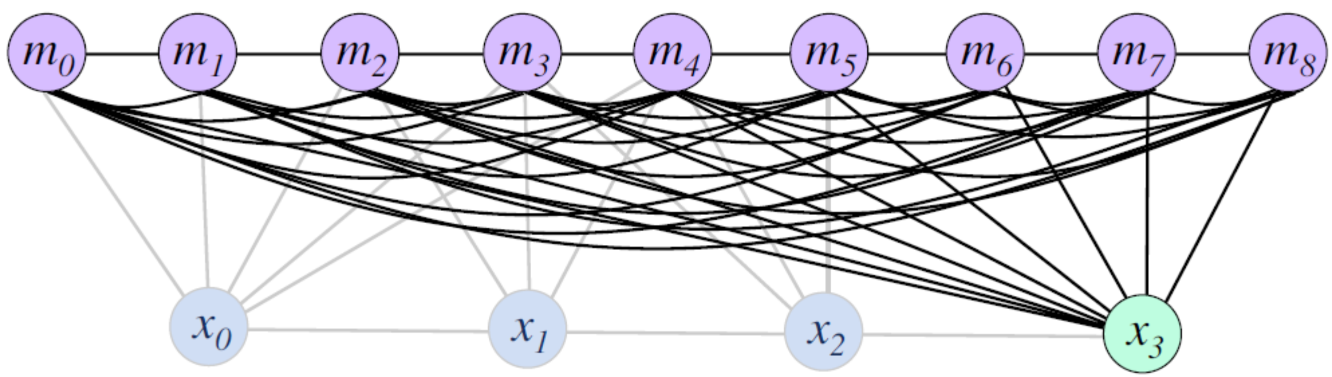
2. EKF vs Smoothing for UAV Positioning Using UWB & IMU

2.1 Filtering & Smoothing

2.2 EKF & Smoothing for UAV Positioning Using UWB & IMU

Filtering & Smoothing (1/2)

- Filtering
  - Summarizing all experience with respect to the last pose, using a **state vector** and the associated **covariance matrix** (→ Eliminating all past poses)
  - Following the 'predict / correct' approach

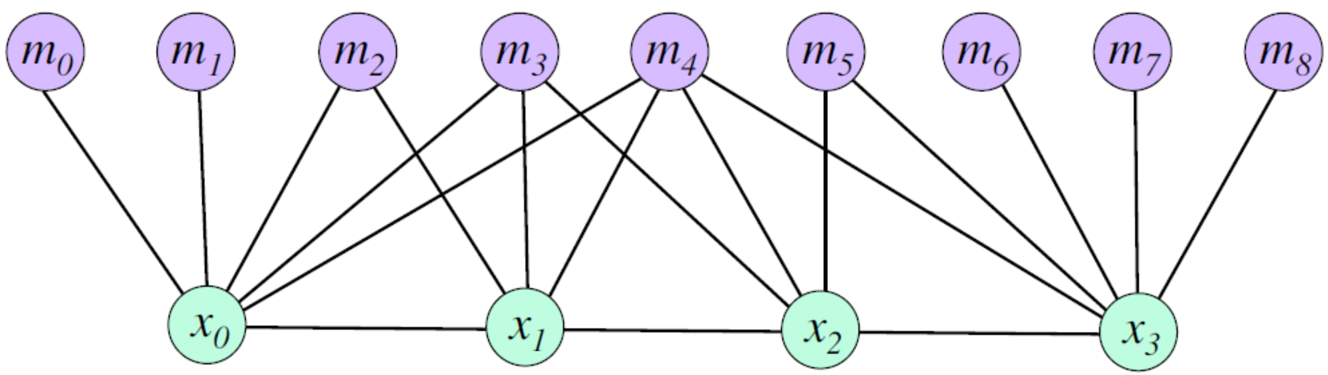


x_i: vehicle pose at time i
m_k: kth landmark

*The figure is excerpted from [M. Chli, 2017].

Filtering & Smoothing (2/2)

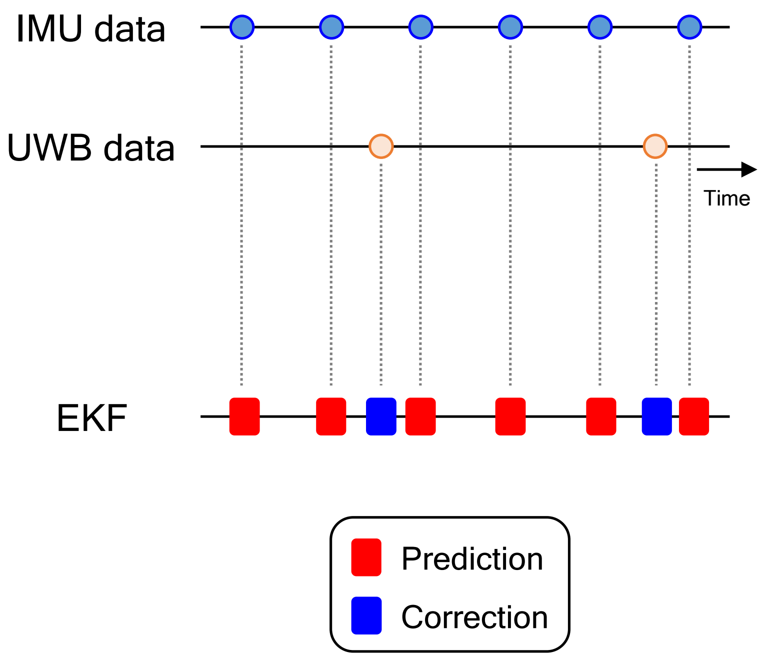
- Smoothing
  - Minimizing the total least-squares cost function.
  - Solving for the constraints between poses and landmarks.
  - Can result in a globally consistent solution.



*The figure is excerpted from [M. Chli, 2017].

EKF & Smoothing for UAV Positioning Using UWB & IMU (1/2)

- Filtering
  - EKF



UAV pose state

$$\mathbf{x} = \begin{bmatrix} \boldsymbol{v} \\ \boldsymbol{\alpha}^b \\ \boldsymbol{\Omega}^b \\ \boldsymbol{p} \\ \boldsymbol{q} \end{bmatrix}$$

- $\boldsymbol{v}$: 3D linear velocity of UAV
- $\boldsymbol{\alpha}^b$: 3D bias of accelerometers in UAV body frame
- $\boldsymbol{\Omega}^b$: 3D bias of gyroscopes in UAV body frame
- $\boldsymbol{p}$: 3D Coordinates of the UAV
- $\boldsymbol{q}$: Any minimal representation of 3D rotation matrix

Control input

$$\boldsymbol{u} = \begin{bmatrix} \boldsymbol{\alpha}^S \\ \boldsymbol{\Omega}^S \end{bmatrix}$$

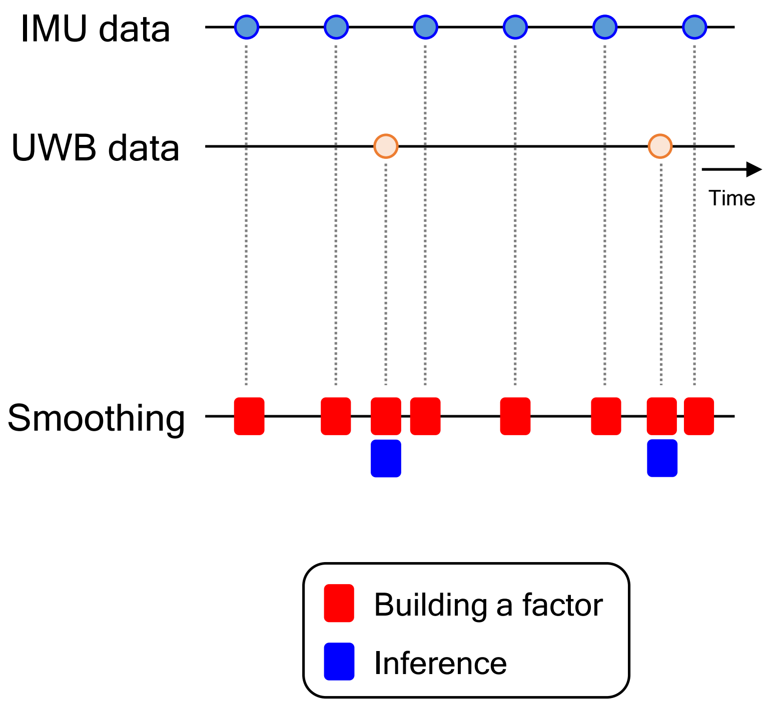
- $\boldsymbol{\alpha}^S$: IMU measurements of acceleration
- $\boldsymbol{\Omega}^S$: Angular rates measured by IMU

UWB measurement model

$$r_{\mathrm{t}} = \|\boldsymbol{p} - \boldsymbol{p}^{UWB}\| + \eta_t$$

EKF & Smoothing for UAV Positioning Using UWB & IMU (2/2)

- Smoothing
  - Building a Factor Graph & doing inference by iSAM2



Finding optimal estimate $\hat{\mathbf{x}}$

$$\hat{\mathbf{x}} = arg\,\min_{\mathbf{x}}(\textstyle\prod_i f_i(\mathbf{x}_i))$$

IMU Factor

$$f^{IMU}(\mathbf{x}_{i,}\mathbf{x}_{i-1}, \boldsymbol{c}_i) \triangleq d(\mathbf{x}_i - h(\mathbf{x}_{i-1,}\mathbf{c}_{i-1}, \boldsymbol{\Omega}_{i,}\boldsymbol{\alpha}_i))$$

$$f^{bias}(\boldsymbol{c}_i, \boldsymbol{c}_{i-1}) \triangleq d(\boldsymbol{c}_i - g(\mathbf{c}_{i-1}))$$

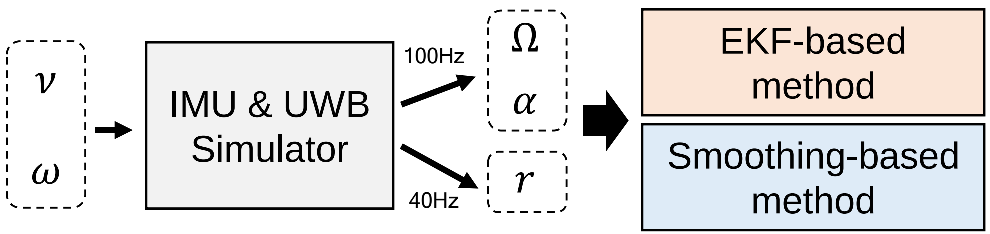
UWB Factor

$$f^{UWB}(\mathbf{x}_i\,) \triangleq d(\mathbf{x}_i - h(r_i))$$

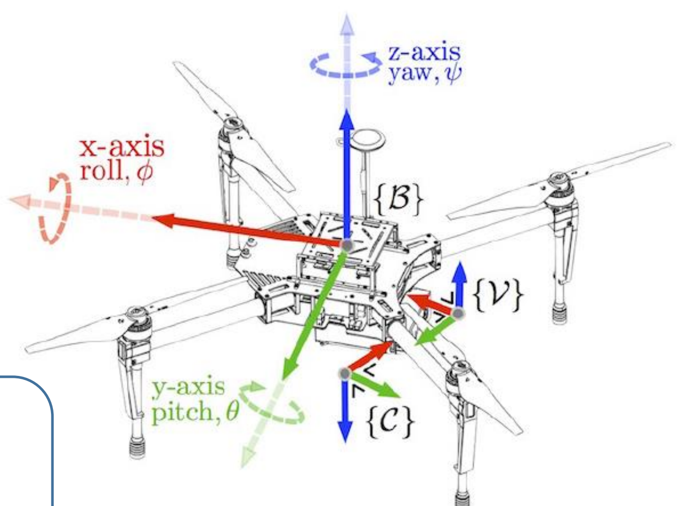
3. Experimental Results

Simulation

▪ Setup

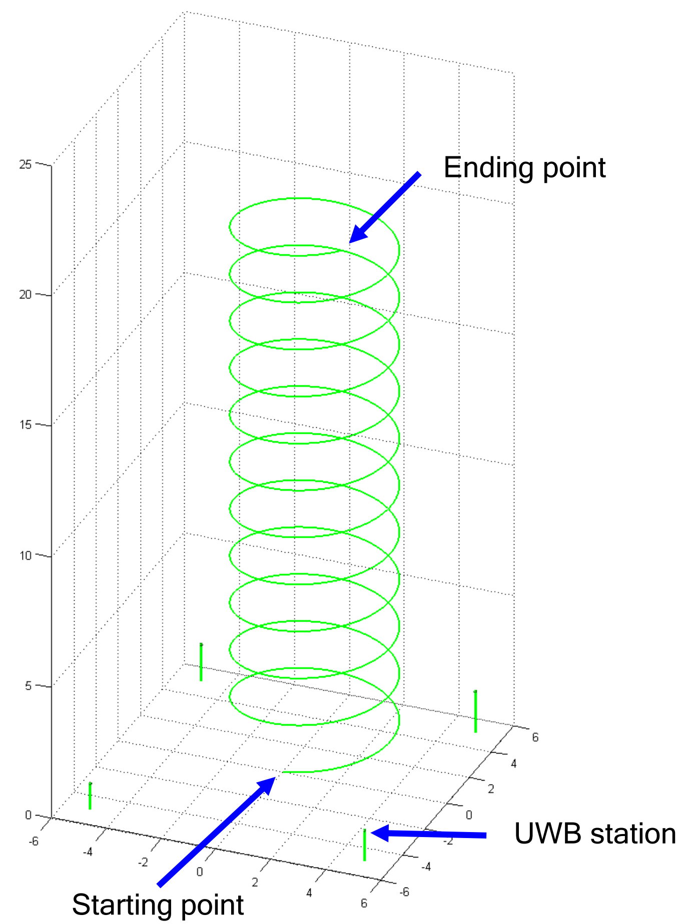


Virtual IMU & UWB data generation and its application to each method



Axes configuration

*Excerpted from [I. Sa, 2017]



Ground truth trajectory
(Simulating spiral trajectory)

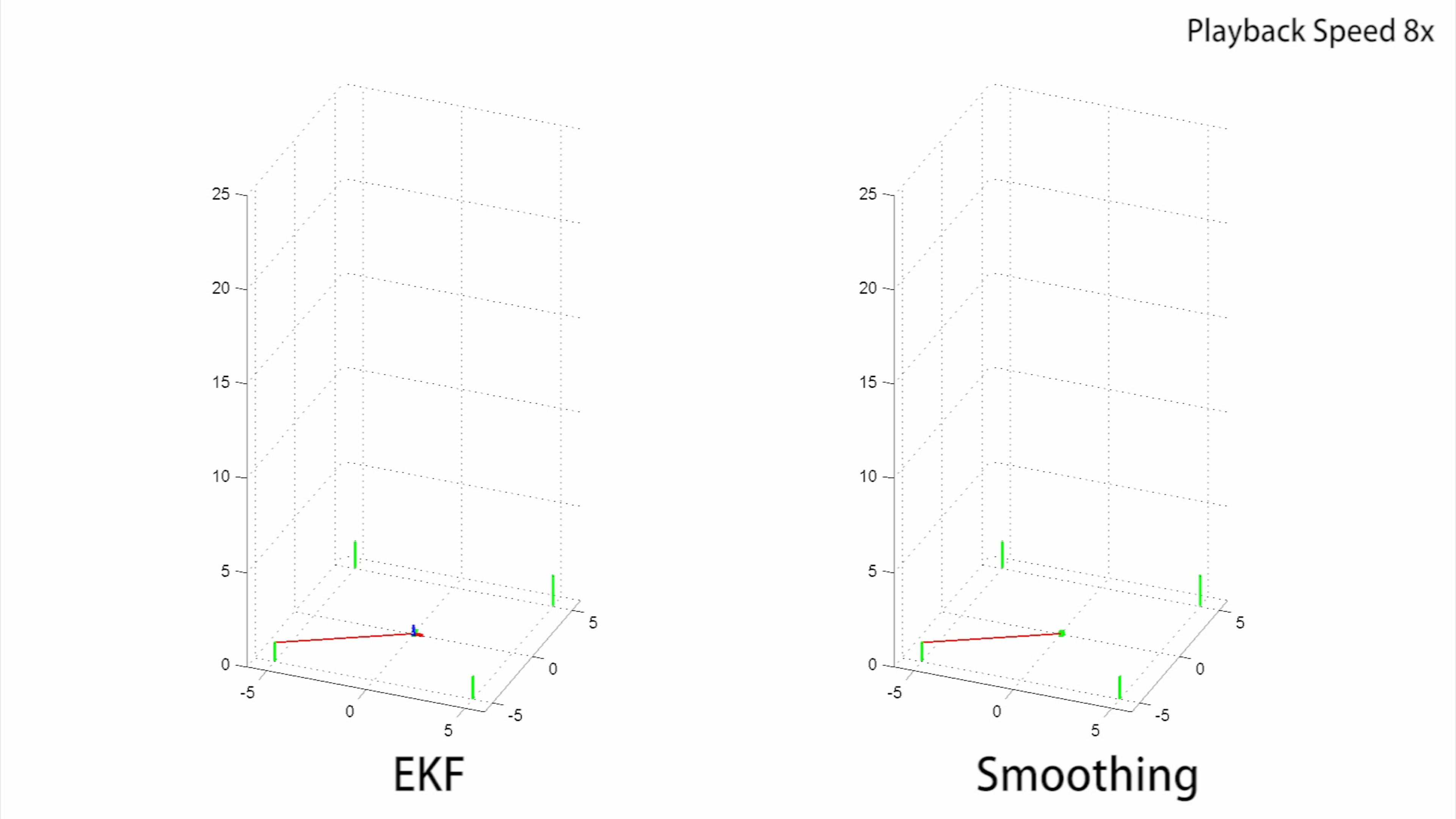
ν:linear velocity
ω: angular velocity (in world frame)

Ω : angular velocity, $\sigma_\Omega = 0.5 rad/s$

α : linear acceleration, $\sigma_\alpha = 0.1 m/s^2$
r : UWB range, $\sigma_r = 0.05m$

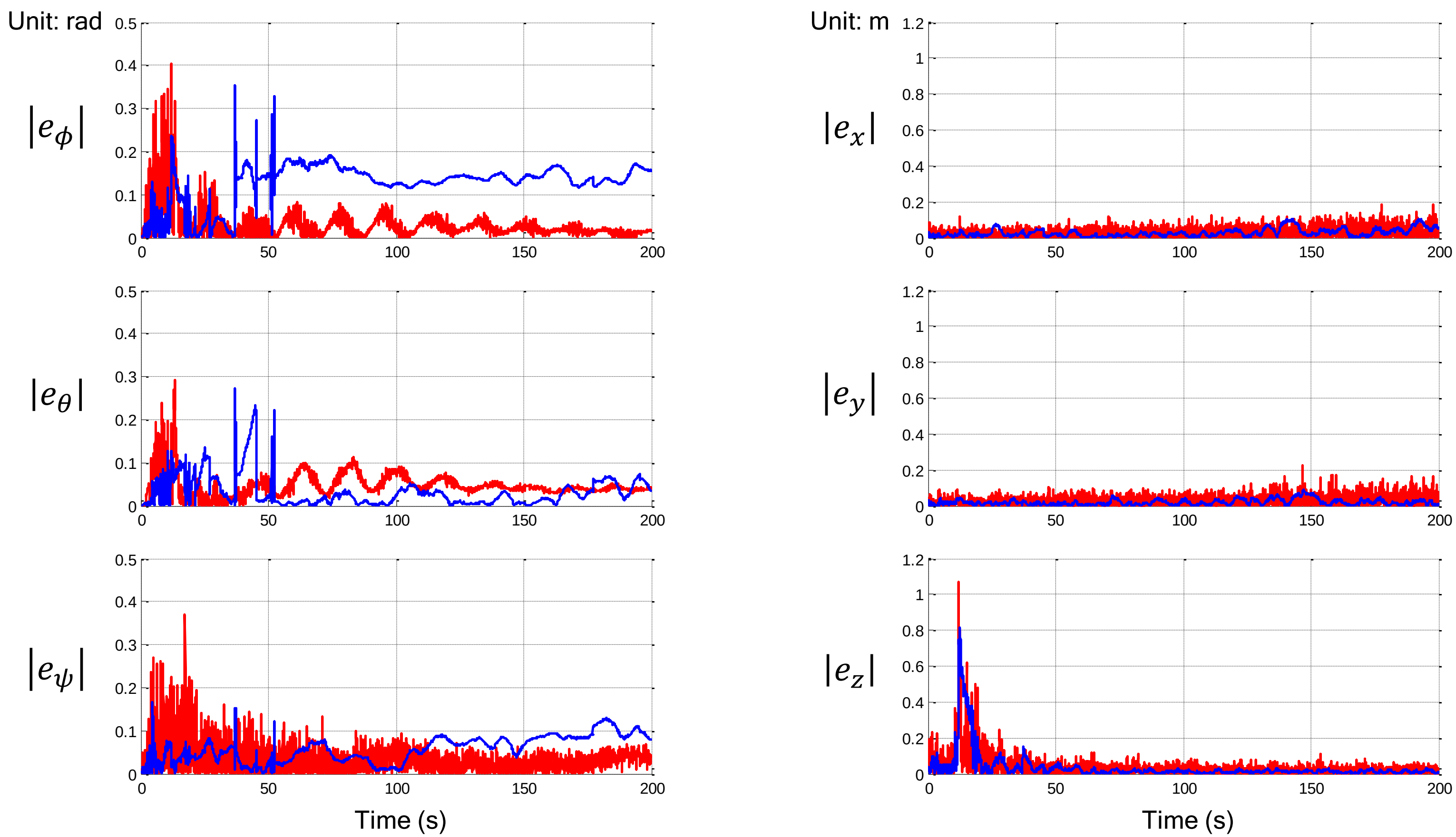
Simulation Result (1/3)

- Result Movie



Simulation Result (2/3)

- UAV Orientation & Translation
  - Absolute error over time



roll(ϕ), pitch(θ), yaw(ψ)

Simulation Result (3/3)

- UAV Orientation & Translation
  - RMS error

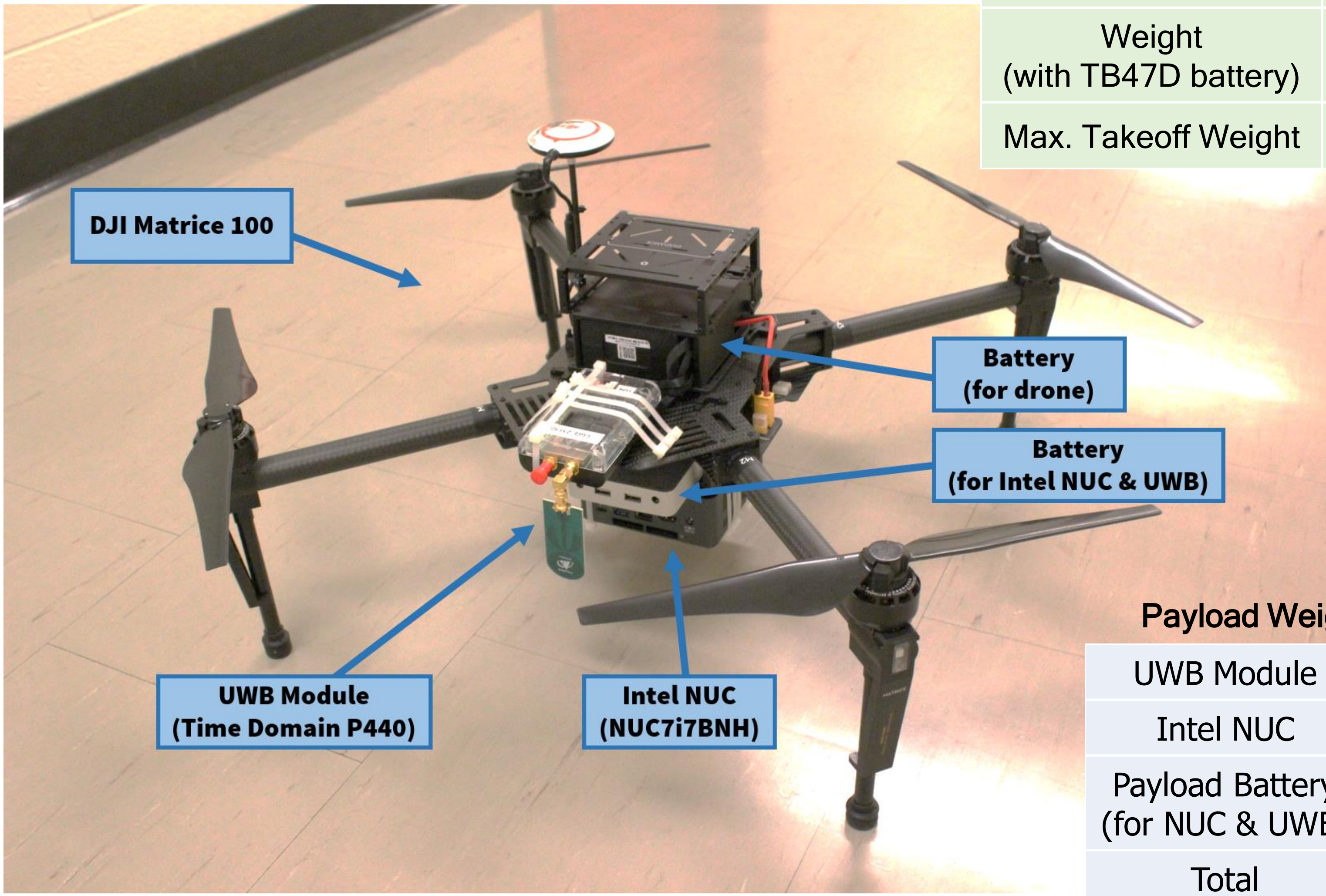
	roll (rad)	pitch (rad)	yaw (rad)	x (m)	y (m)	z (m)
EKF	**0.0478**	0.0544	**0.0467**	0.0392	0.0407	**0.0790**
Smoothing	0.1344	**0.0459**	0.0651	**0.0352**	**0.0253**	0.0893

Experiment Preparation with Real Systems (1/5)

- DJI Matrice 100 with Payload

DJI Matrice 100

Diagonal Wheelbase	0.65m
Weight (with TB47D battery)	2.355kg
Max. Takeoff Weight	3.600kg

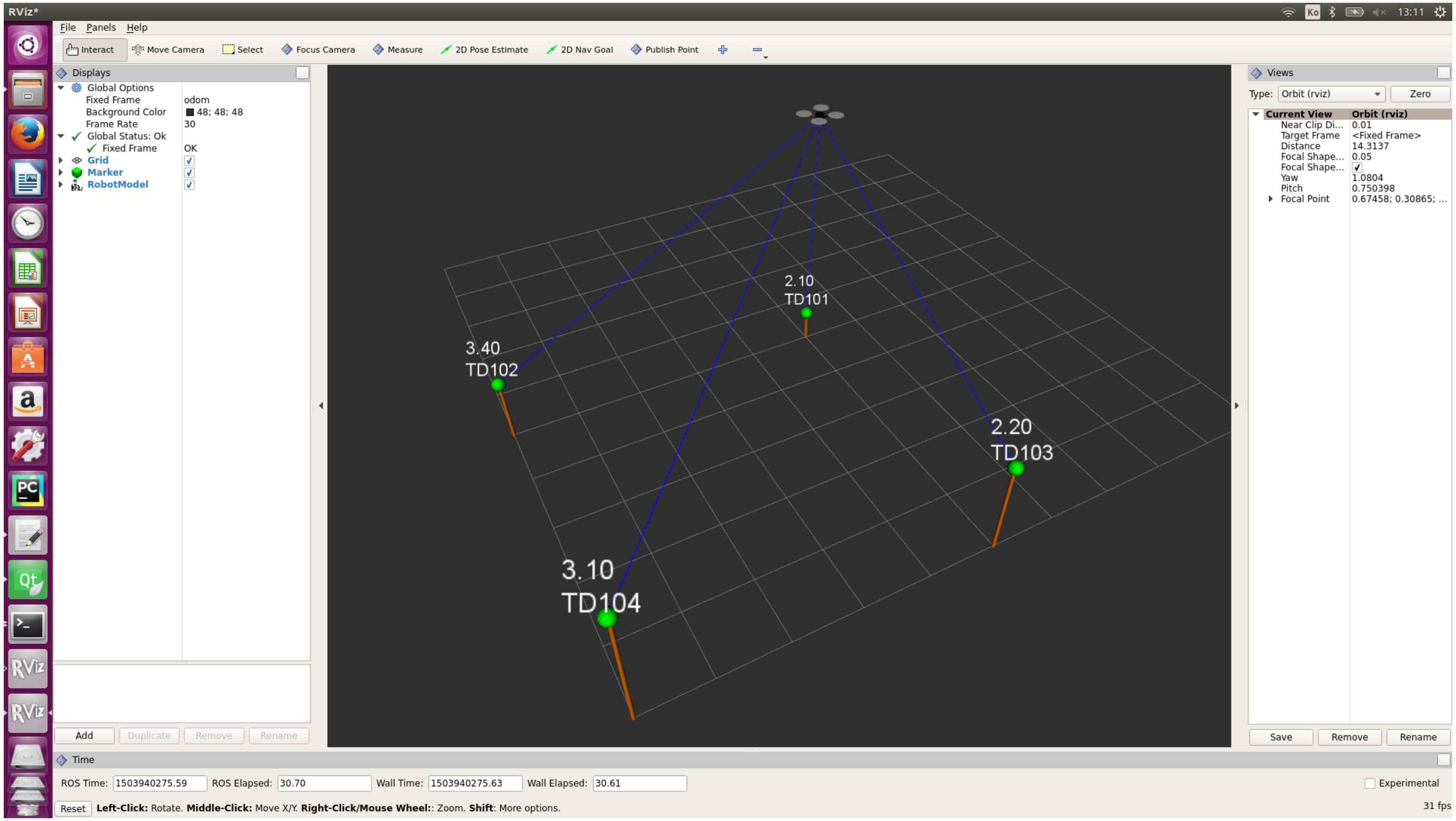


Payload Weight [kg]

UWB Module	0.112
Intel NUC	0.728
Payload Battery (for NUC & UWB)	0.542
Total	1.382

Experiment Preparation with Real Systems (2/5)

- ROS Package for Data Logging Using DJI Matrice 100
  - Developed using ROS Kinetic in Ubuntu 16.04



Screenshot of Rviz (ROS visualization tool)

Experiment Preparation with Real Systems (3/5)

- UWB

Time Domain PulsOn 440

Website	http://www.timedomain.com/products/pulson-440/
Dim/Weight	56 x 103 x 18mm, 45g
Input Voltage	4.5 to 48V DC
Interface	Ethernet, USB, Serial, SPI, CAN
Performance	accuracy: 2.1cm, data rate: 125 Hz
Max Range	300 m to 1100 m

Experiment Preparation with Real Systems (4/5)

- Indoor Space for Experiment

Experiment Preparation with Real Systems (5/5)

- Ground Control Station

4. Conclusion & Future Work

Conclusion & Future Work

- Conclusion
  - Implemented EKF and smoothing based UAV localization algorithms using UWB and IMU data
  - Validated through simulation.
    (However, it is not enough. We will need more further analysis.)

- Future Work
  - Further analysis on comparison of EKF and Smoothing
  - Validation using real experiment data