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Pervasive, Accurate and Reliable Location Based Services for Emergency Responders

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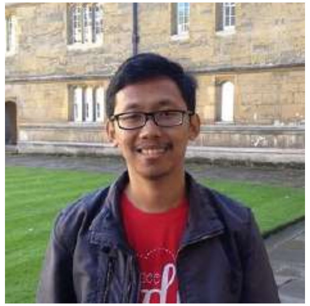
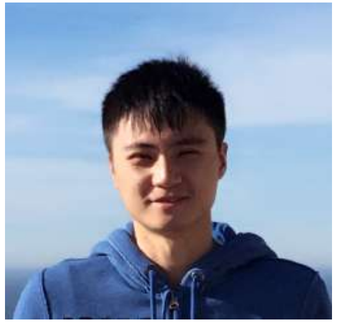
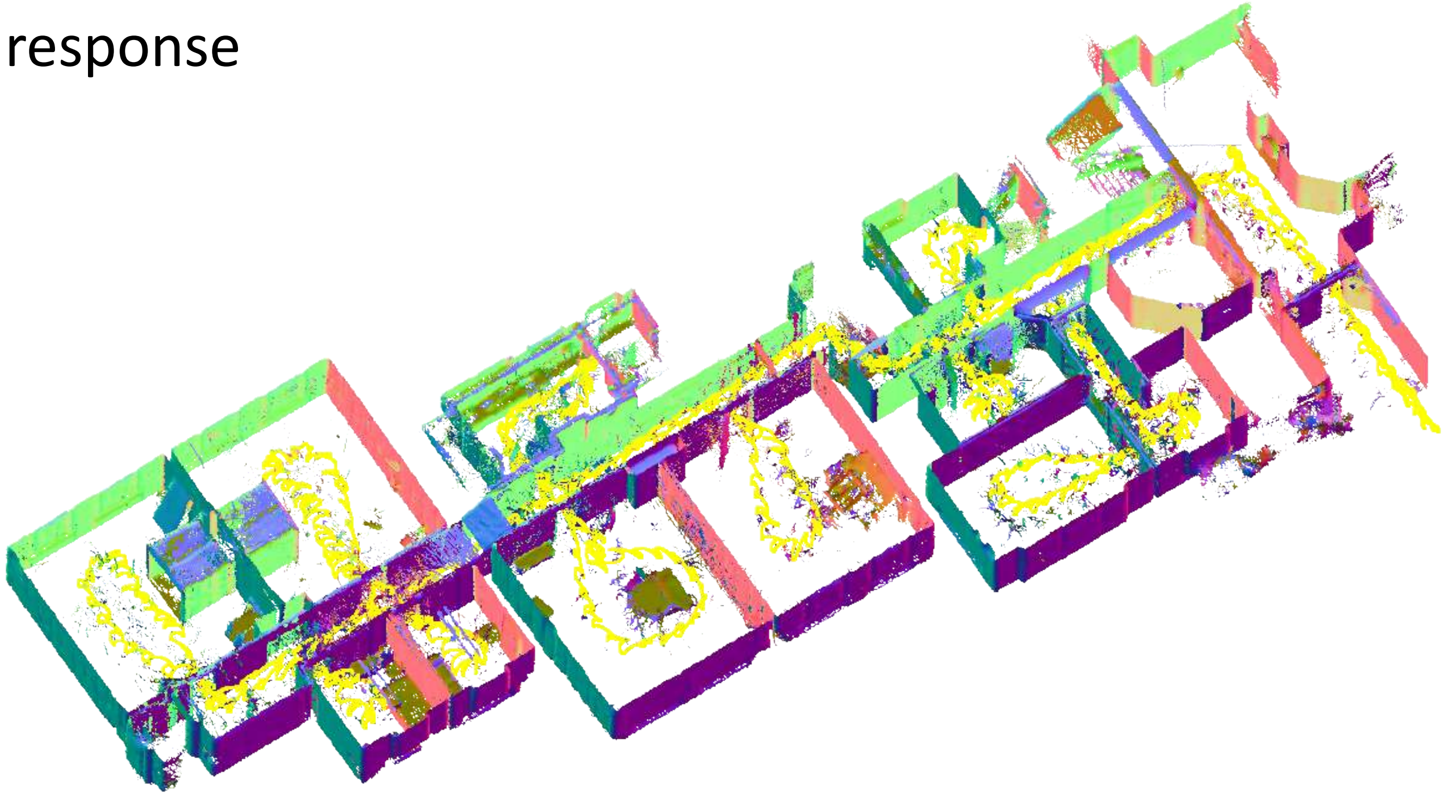




Goal

To track first responders under *various* adverse conditions during emergency response scenarios



Visibility Constraints

Search and rescue procedures highly depend on visibility levels.

Smoke will limit the speed with which firefighters move.

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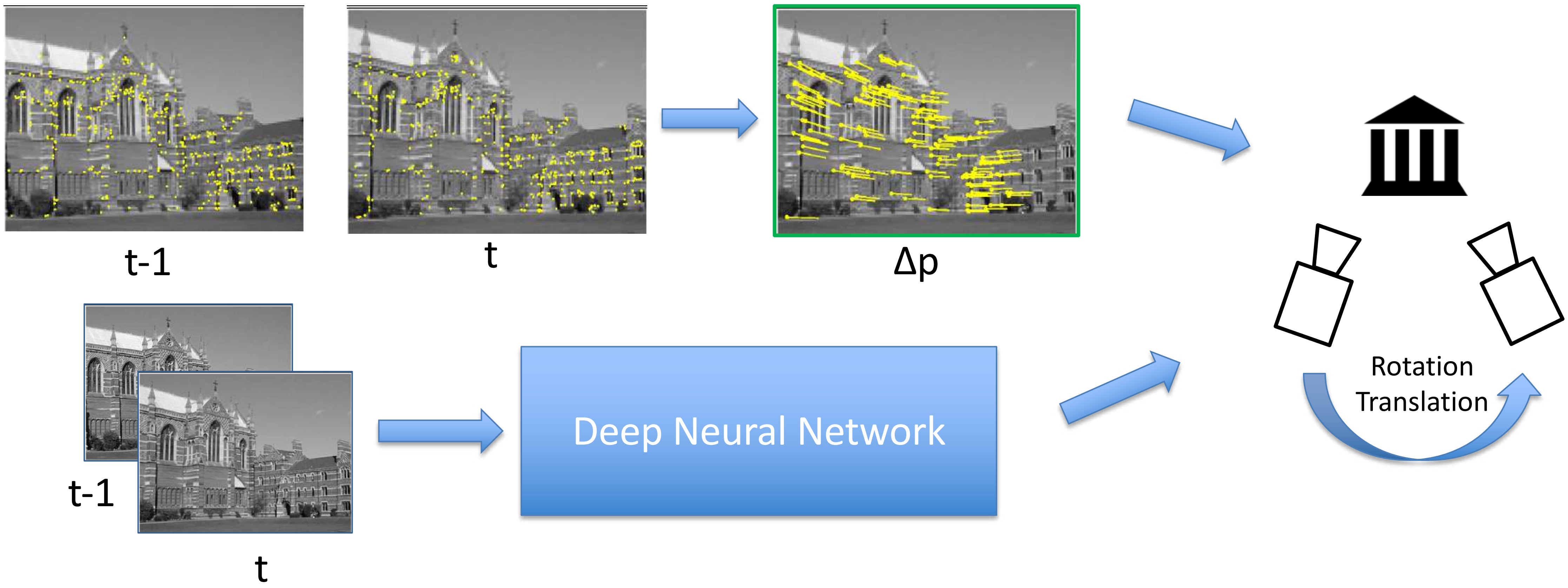
Challenges under good visibility

No GPS, Wi-Fi, or electricity is available.

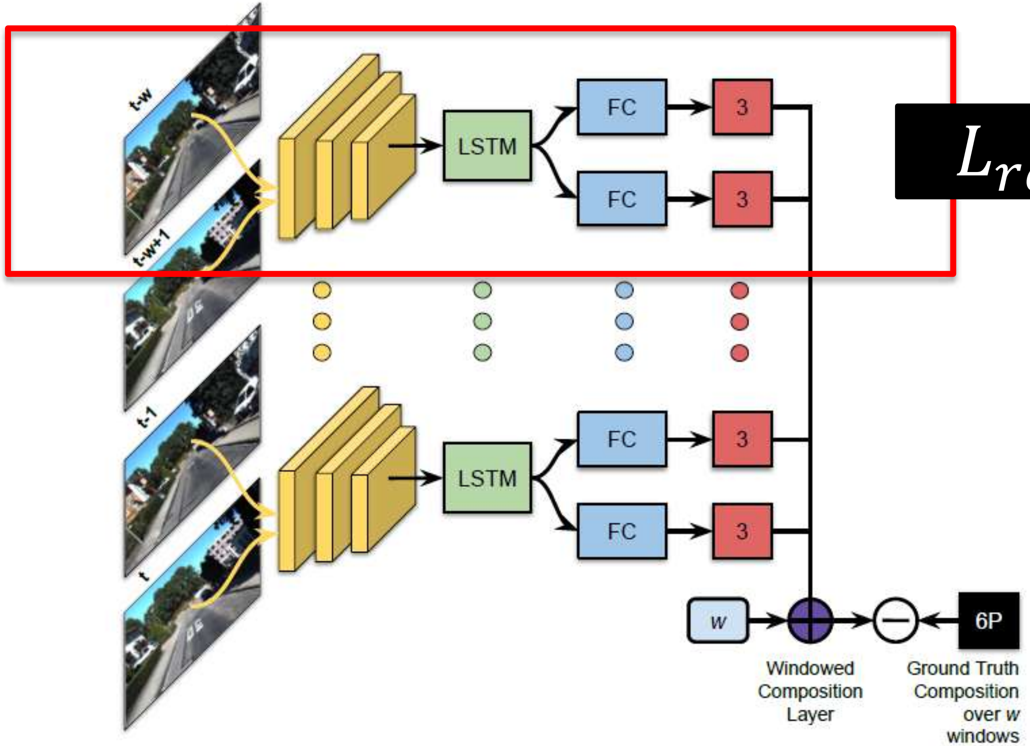
Current Challenges:

- Limited bandwidth
- Error due to frame-by-frame motion estimation
- Training data not always available

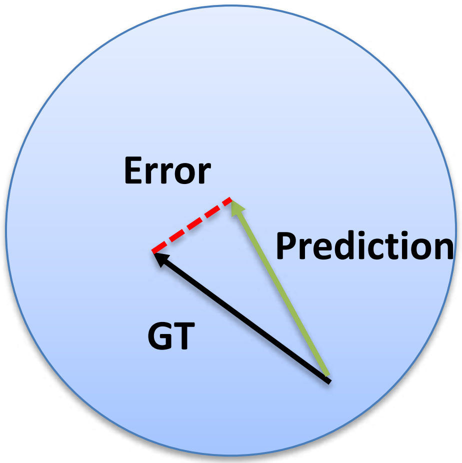
Visual Odometry



Visual Odometry with Geometry Aware-Curriculum Learning (GA-CL)



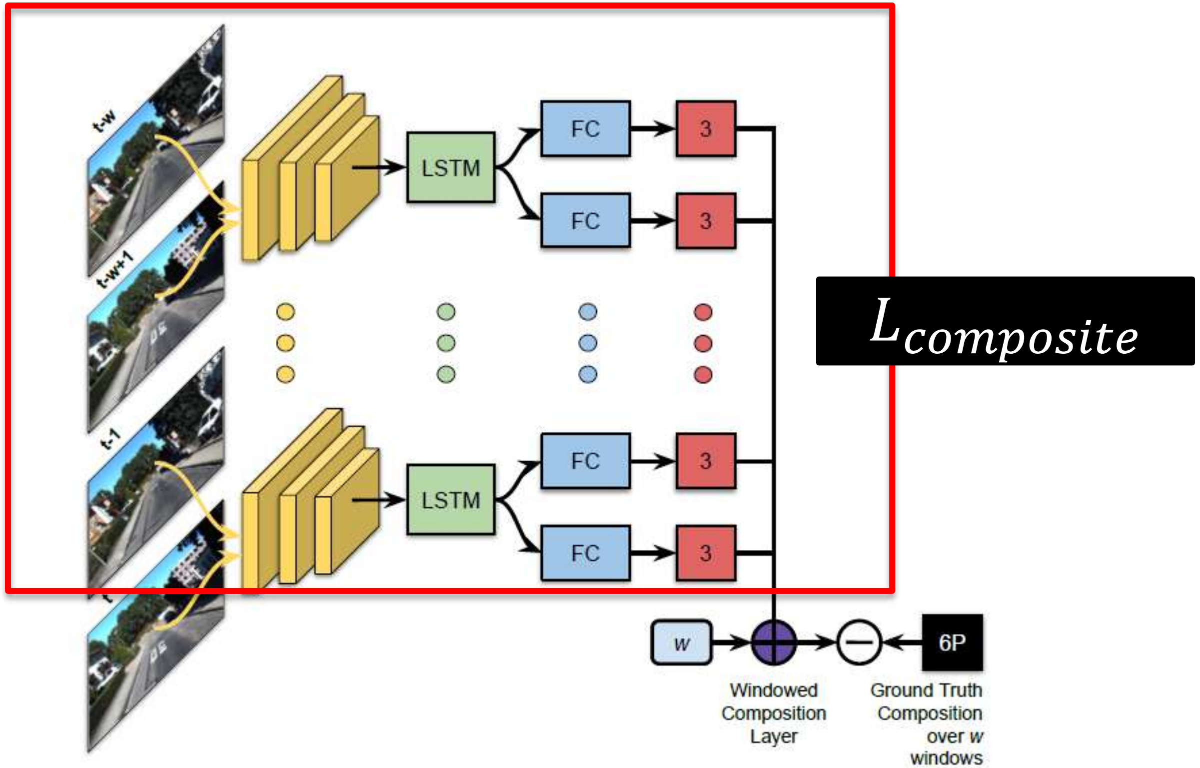
$L_{relative}$

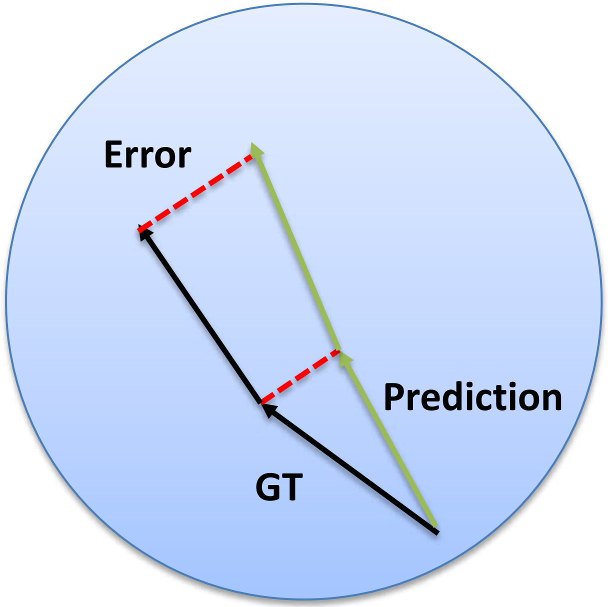


GA-CL: Gradually learning from $L_{relative}$ to $L_{composite}$

"Learning Monocular Visual Odometry through Geometry-Aware Curriculum Learning" -ICRA 2019
Muhamad Risqi U. Saputra, Pedro P. B. de Gusmao, Sen Wang, Andrew Markham, and Niki Trigoni

Visual Odometry with Geometry Aware-Curriculum Learning (GA-CL)





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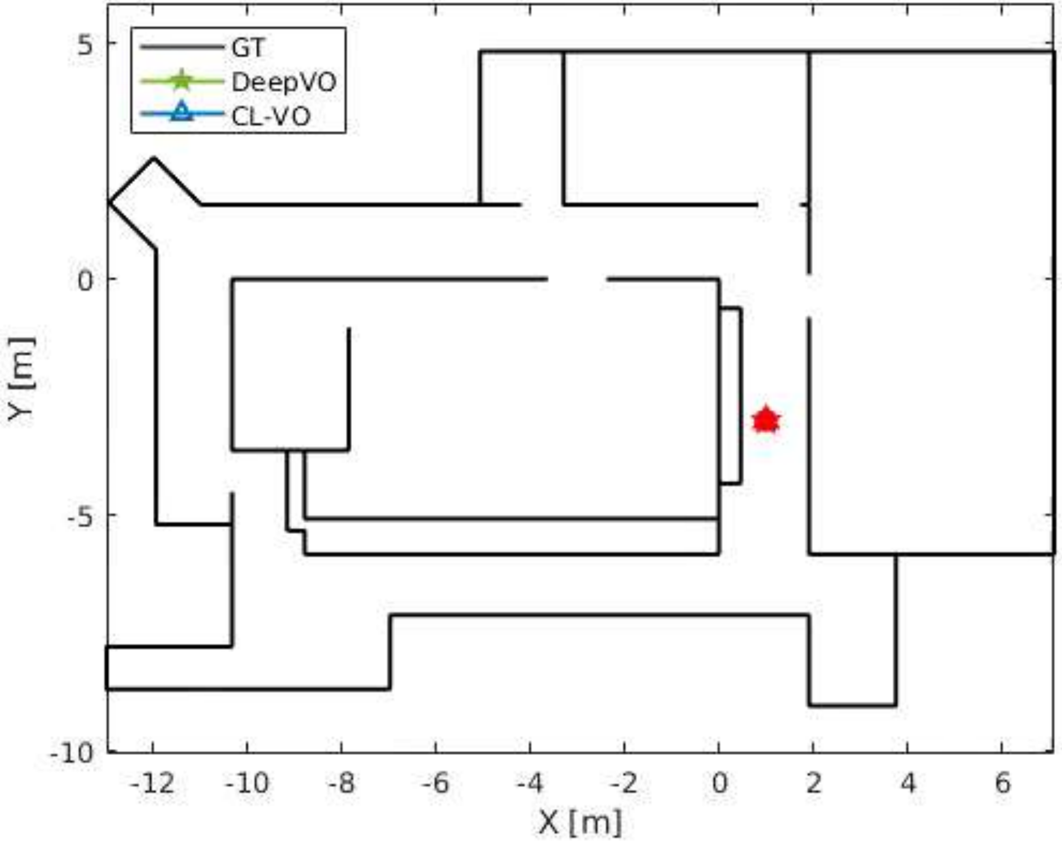


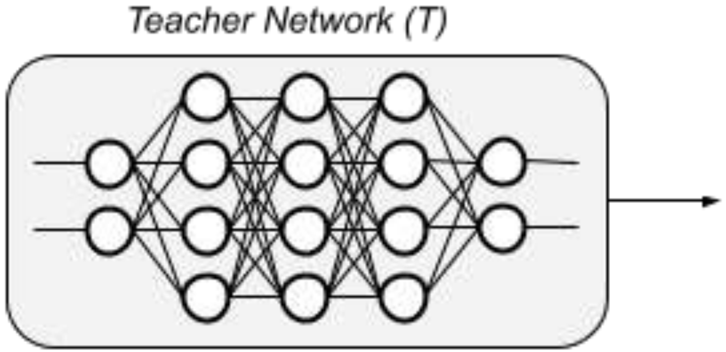
"Learning Monocular Visual Odometry through Geometry-Aware Curriculum Learning" -ICRA 2019
Muhamad Risqi U. Saputra, Pedro P. B. de Gusmao, Sen Wang, Andrew Markham, and Niki Trigoni

Visual Odometry with Geometry Aware-Curriculum Learning (GA-CL)

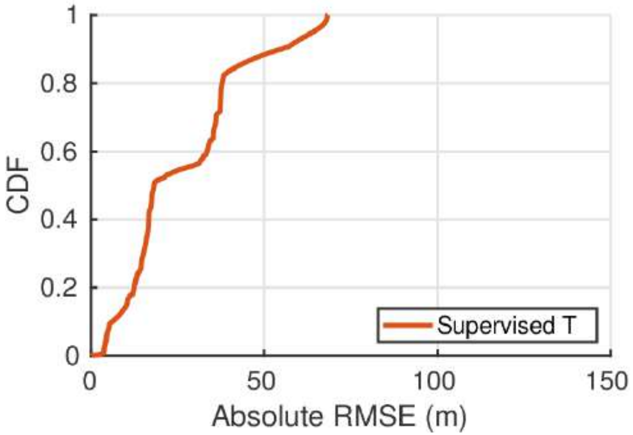
- GA-CL improves translation and rotation by 21% and 16% respectively compared to training with standard relative loss
- State-of-the art visual odometry results
- Where adequate illumination is available, accurate odometry is possible

Efficient Deep Neural Odometry

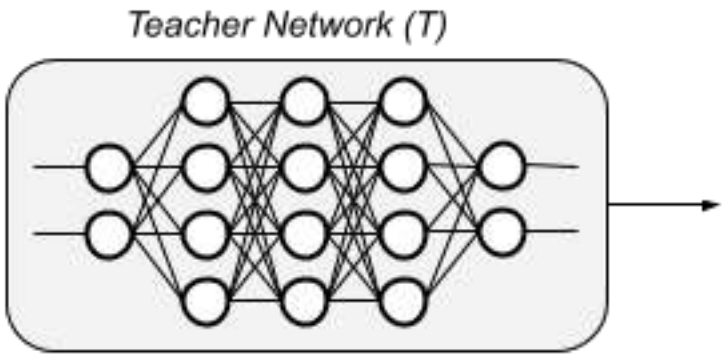
Full input Images **(32 fps)**



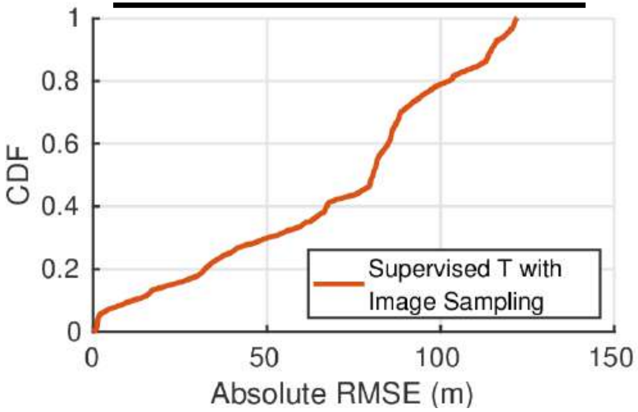
GPU server



Sub-sampled input images **(12 fps)**



Embedded device



Accuracy drop 160%

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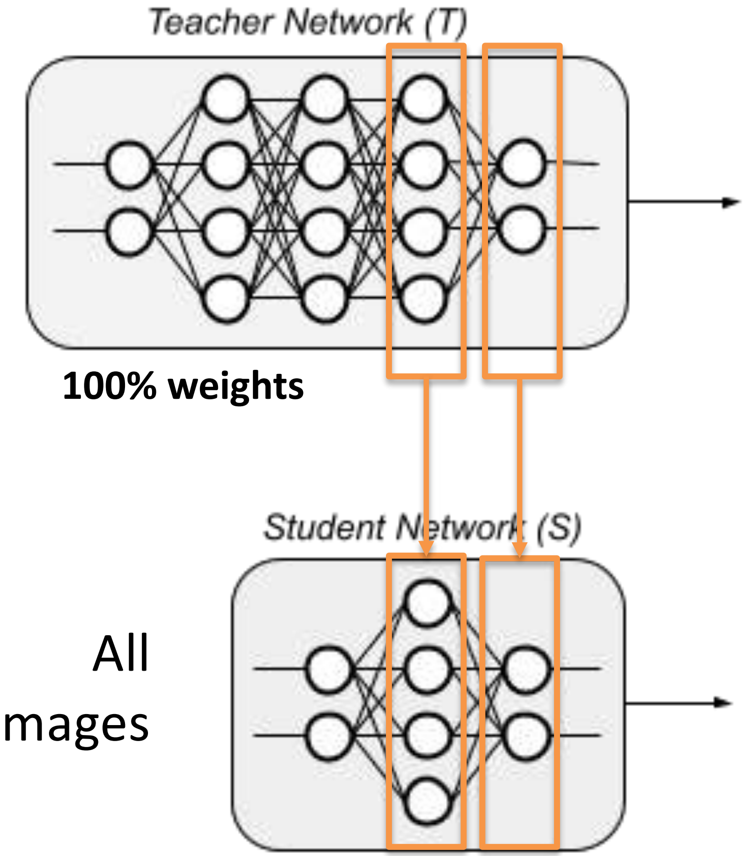
Efficient Deep Neural Odometry

All Images



100% weights

All images

7.05% weights

Transfer the knowledge from **T** to **S** only when we trust **T**

- Teacher loss is used as confidence score
- Relies on easier example which **T** is good at

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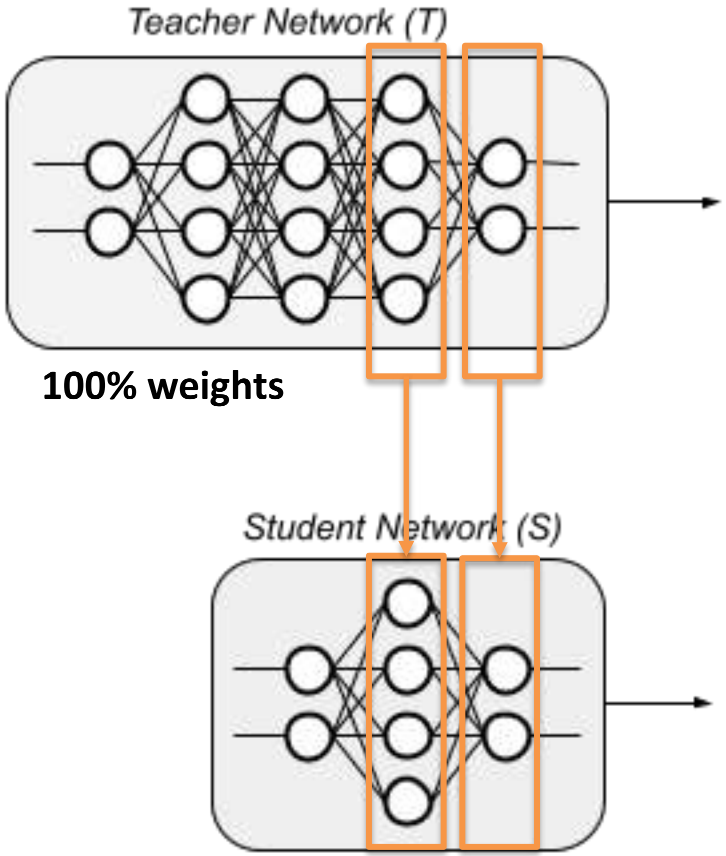
Efficient Deep Neural Odometry

Full input Images **(32 fps)**

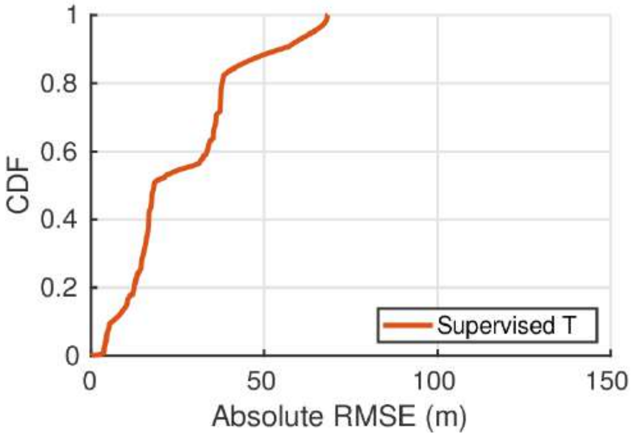


100% weights

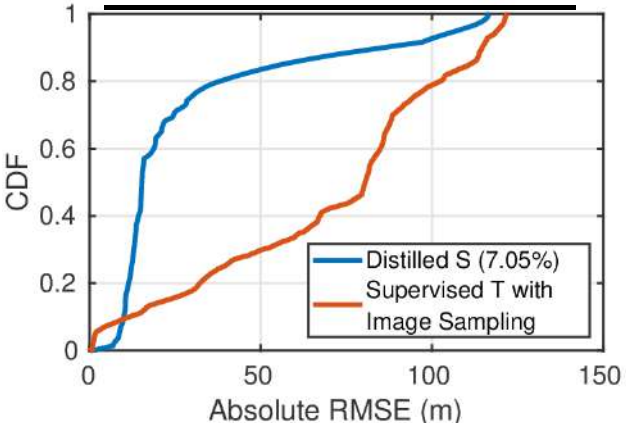
Full input images **(26 fps)**

7.05% weights

GPU server



Embedded device



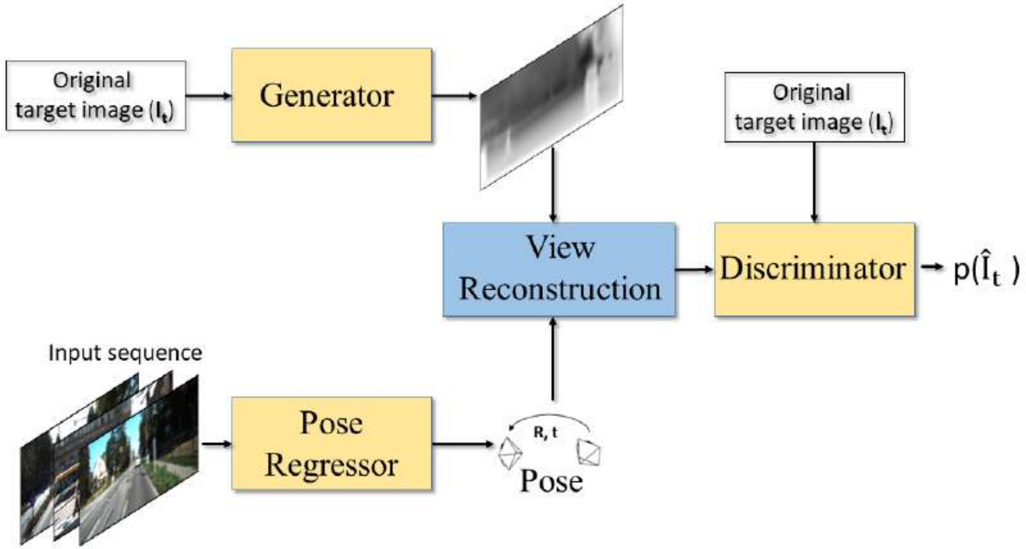
Accuracy drop 8.6%

Efficient Deep Neural Odometry

- This component achieves the same (or even better) tracking performance with smaller computation and memory costs
- This will allow complex deep networks to be deployed to operate in real-time on mobile devices

GANVO: Unsupervised Deep Monocular Visual Odometry and Depth Estimation

- Supervised deep learning methods need plenty of labelled data
- GANVO provides a visual odometry solution for unknown environments
    - The idea is to create a supervisory signal by exploiting the geometry



"GANVO: Unsupervised Deep Monocular Visual Odometry and Depth Estimation with Generative Adversarial Networks" – ICRA 2019
Yasin Almalioglu, Muhamad Risqi U. Saputra, Pedro P. B. de Gusmao, Andrew Markham, and Niki Trigoni.

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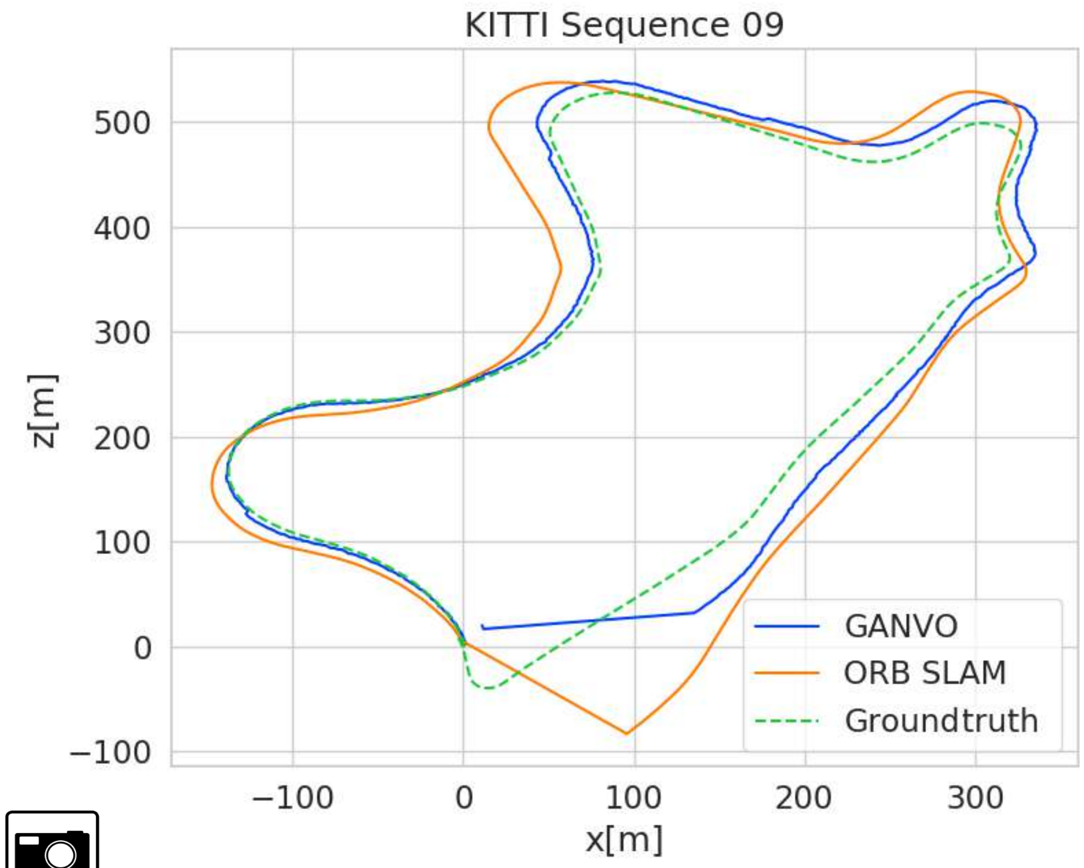
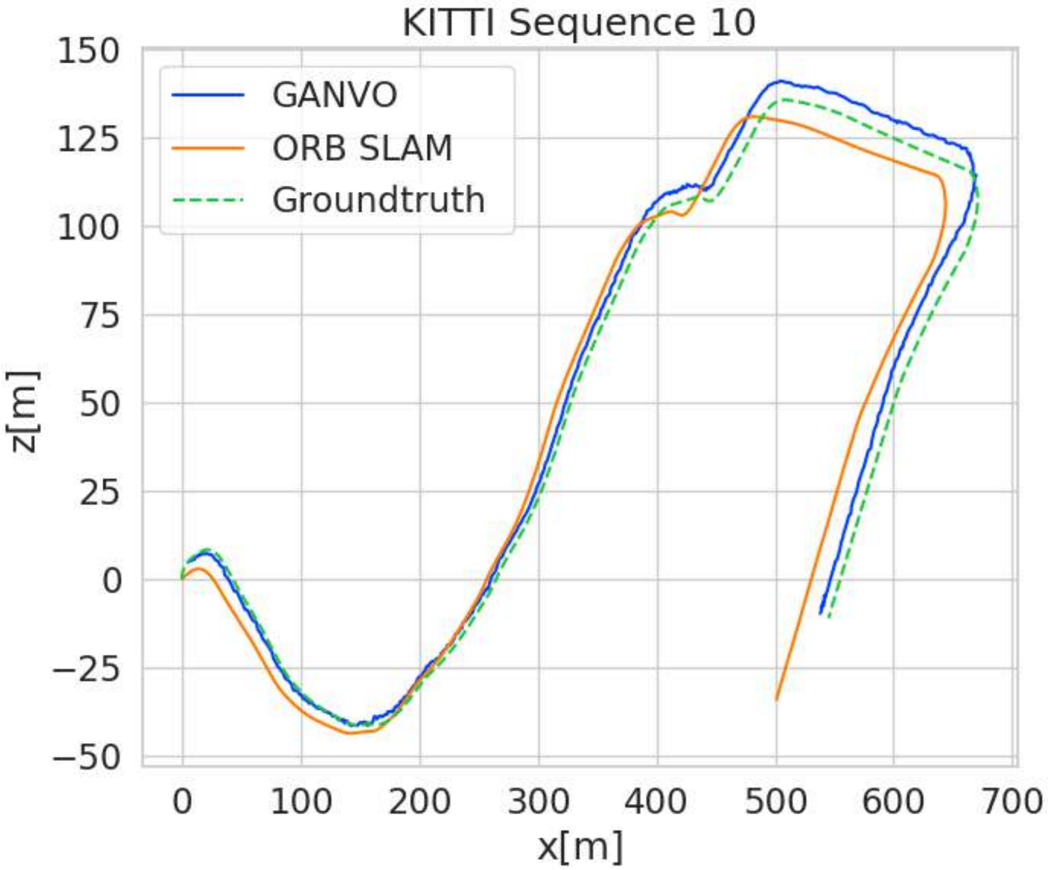
GANVO: Visual Odometry and Depth Estimation Results



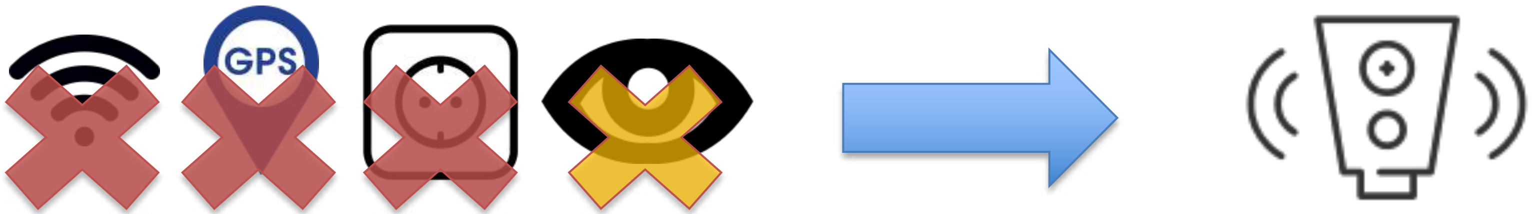


GANVO: Visual Odometry and Depth Estimation

- State of the art tracking results without requiring any training (ground-truth) data
- Allows the tracking technique to adapt to new and unseen environments rapidly

Challenges under constrained visibility

Still no GPS, Wi-Fi, or even electricity is available.



Extra Challenges:

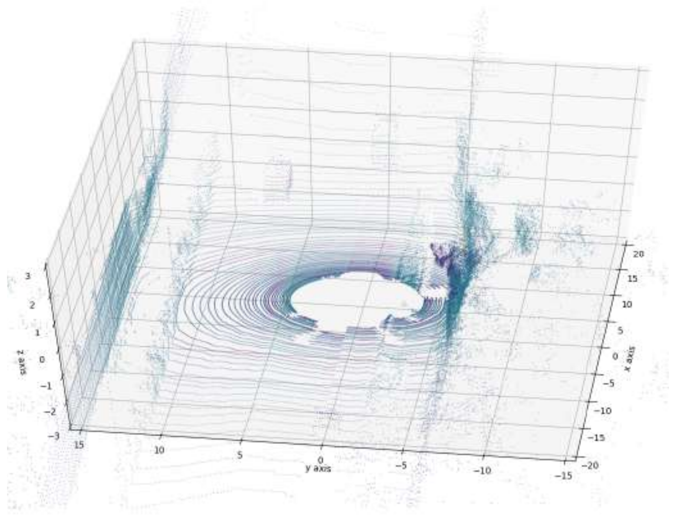
- Vision is compromised. Alternative equipment is required.
- Heat signature might not be enough to use thermal images.

Lidar

DeepPCO: End-to-End Point Cloud Odometry through Deep Parallel Neural Network

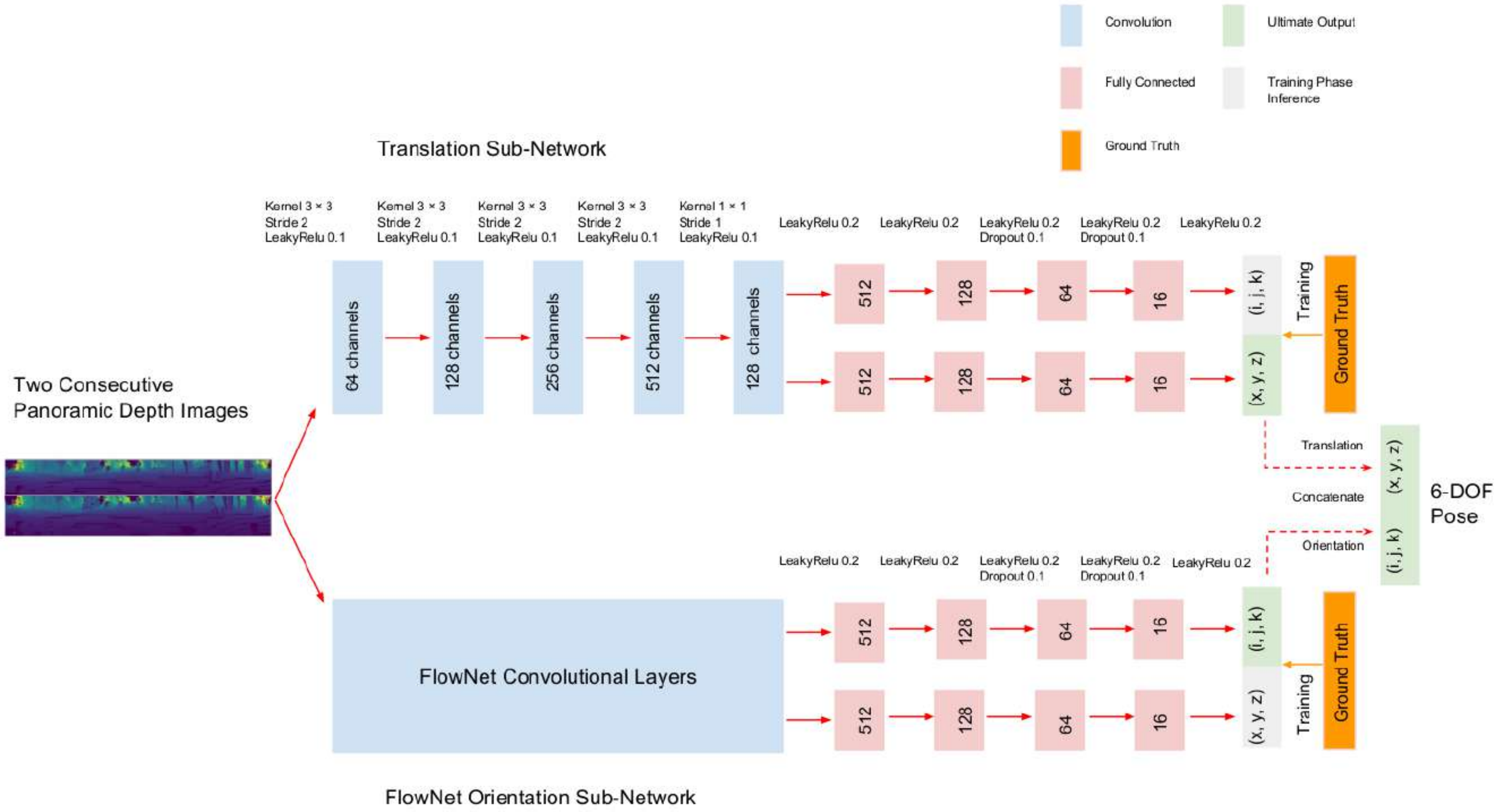
Lidar is a reliable sensor in firefighters' scenario:

- It can perceive environment even in dark or dynamic indoor environment.
- It can create high-quality point cloud map which can assist firefighters.
- It can provide the accurate odometry, which can localize firefighters in real time.



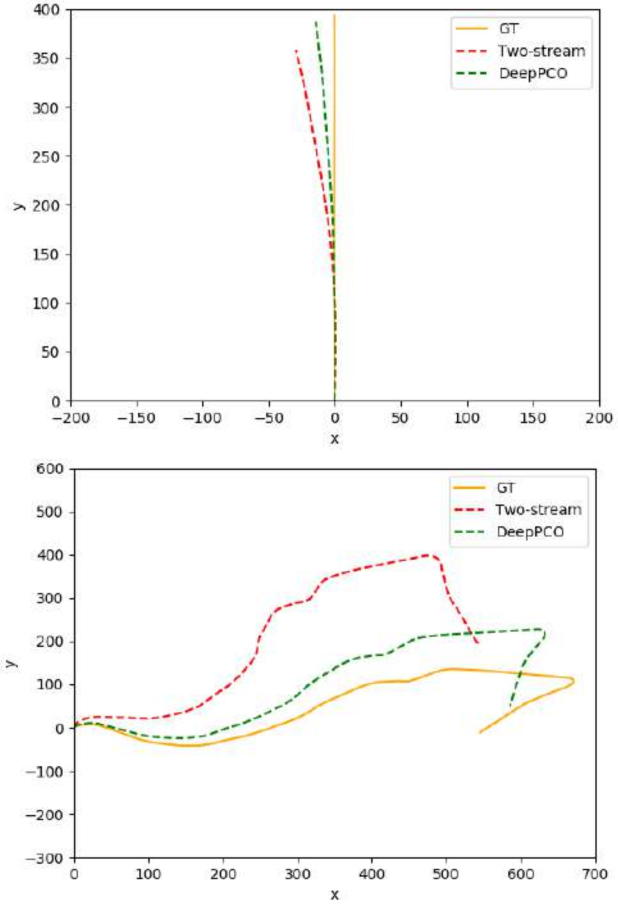
"DeepPCO: End-to-End Point Cloud Odometry through Deep Parallel Neural Network" – IROS 2019
Wei Wang, Muhamad Risqi U. Saputra, Peijun Zhao, Pedro Gusmao, Bo Yang, Changhao Chen, Andrew Markham, and Niki Trigoni

DeepPCO: Architecture



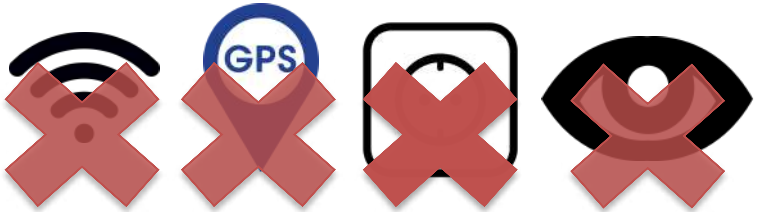
DeepPCO: End-to-End Point Cloud Odometry through Deep Parallel Neural Network

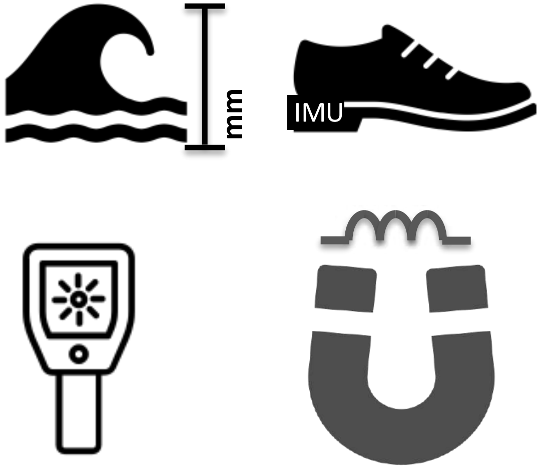
- Position and Orientation estimations are more accurate if estimated separately.
- Also gives you a point cloud map of the environment if needed.



Challenges under NO visibility

Still no GPS, Wi-Fi, or even electricity is available.





Extra Challenges:

- Vision is no longer reliable.
- Lidar no longer works.

Data Collection - Training Facility

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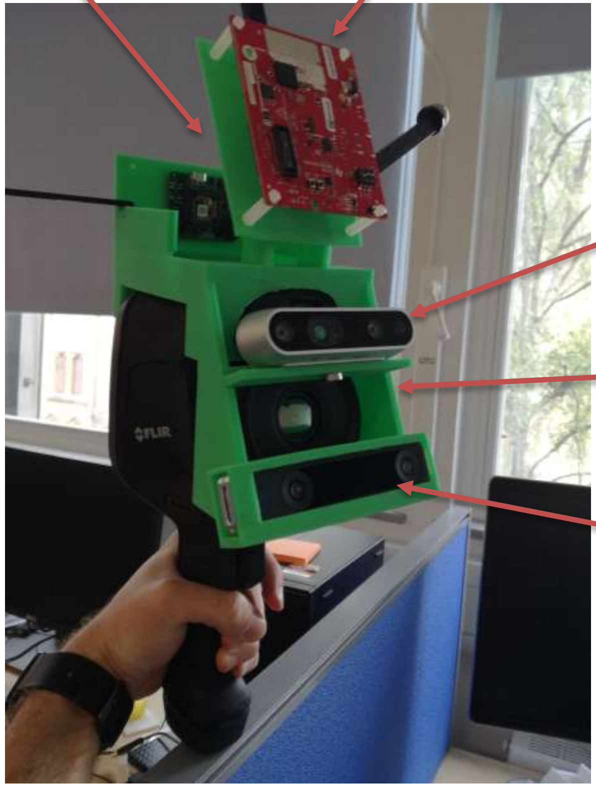
Data Collection - Training Facility



Data Collection - Training Facility

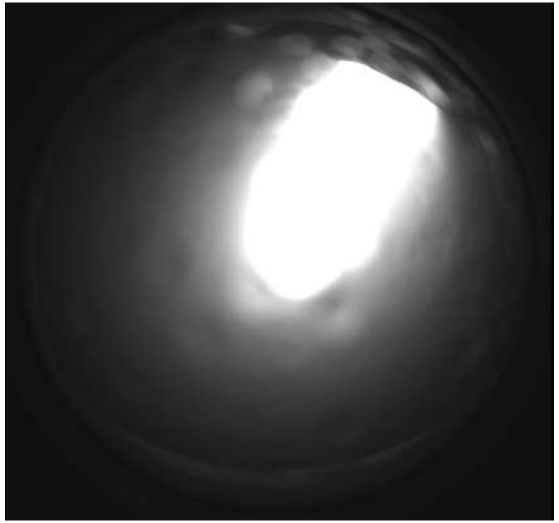
Data Collection - Training Facility

<u>Issues:</u>

- Extremely low visibility.
- Soot could lead to inability use laser/depth.

Issues:

- Temperature is controlled by watering the ceiling, which required sensor protection.
- Due to unpredicted motions, some sensors were disconnected.
- Flashlights caused white balancing to overcompensate

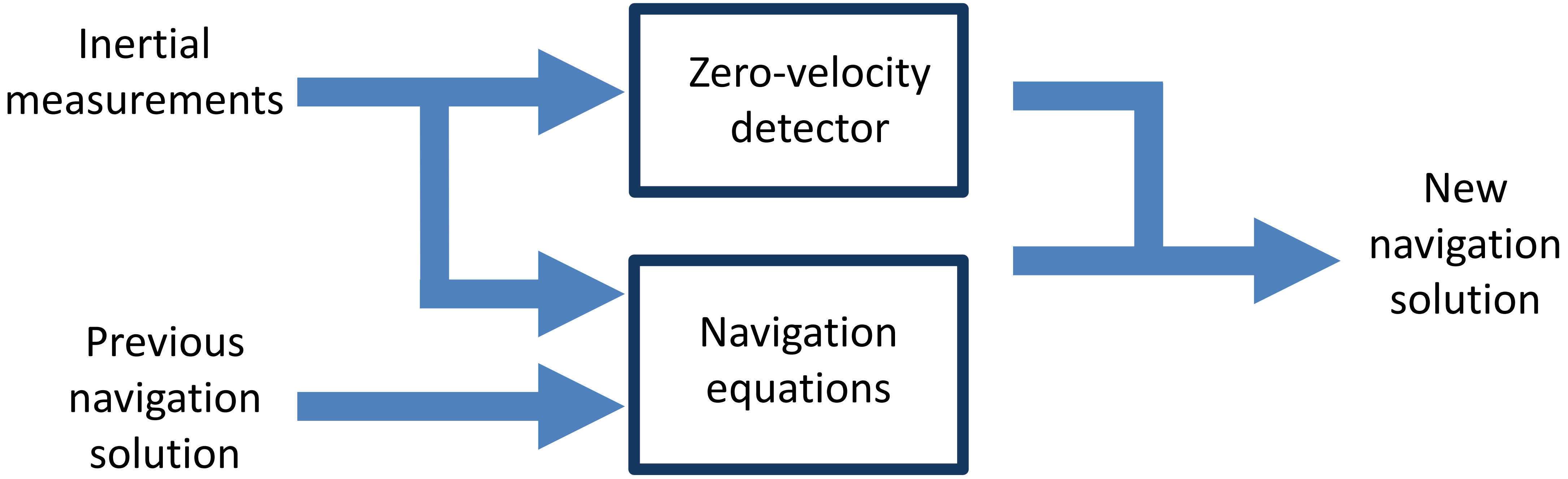


Foot-mounted inertial navigation

Odometry from foot-mounted inertial sensors

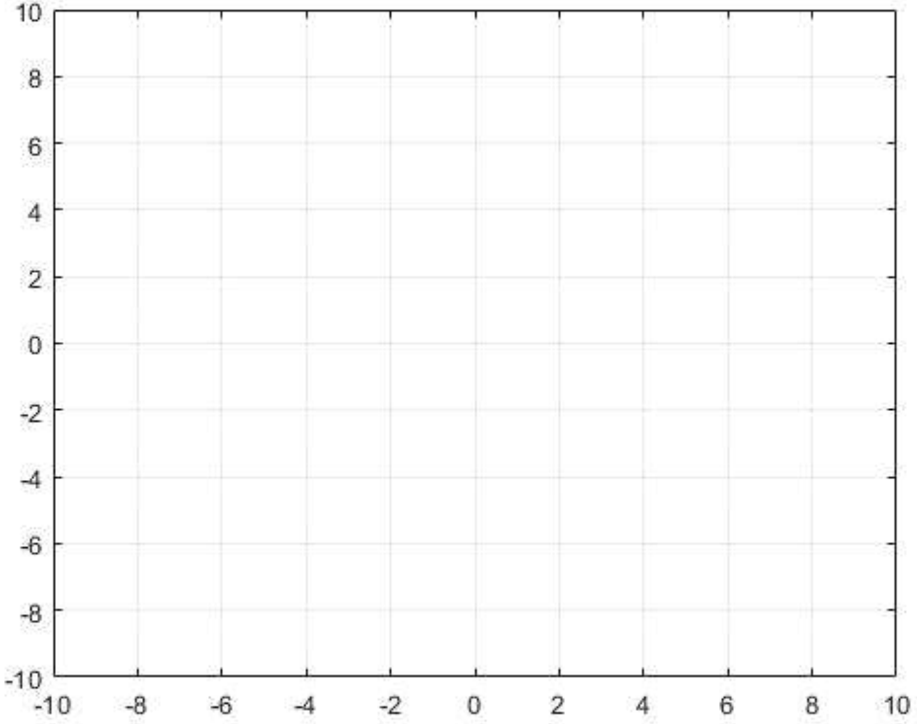
- Not dependent on environmental conditions
- Does not require external infrastructure
- Low-cost technology

Zero-velocity-aided inertial navigation

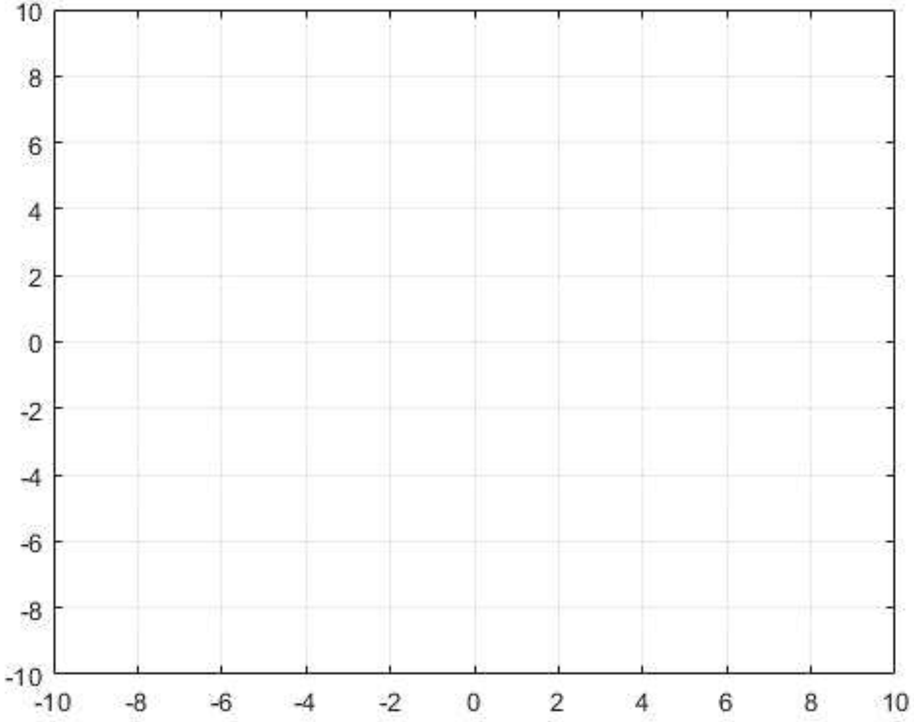


The effect of zero-velocity updates

<u>With</u> zero-velocity updates



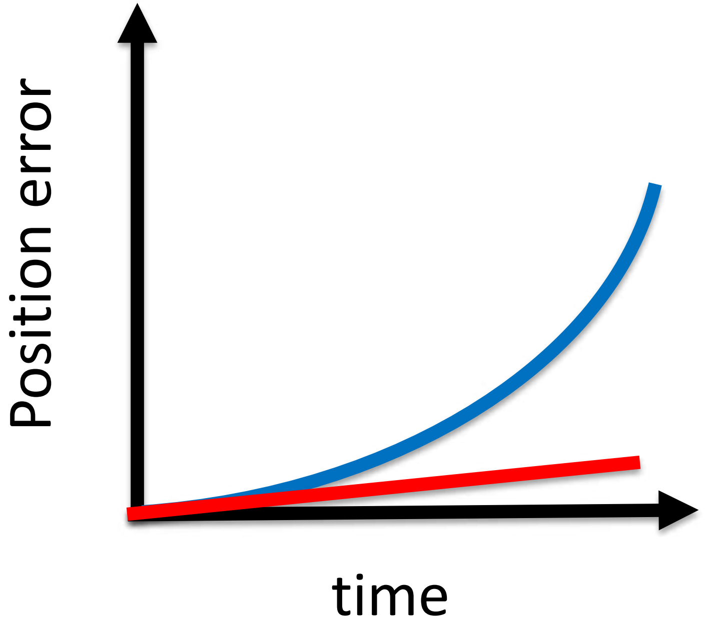
<u>Without</u> zero-velocity updates



Position error growth

Without zero-velocity updates: **Cubic** position error growth.

With zero-velocity updates: **Linear** position error growth.



Navigation	Navigation time
Stand-alone inertial navigation	A few seconds
Zero-velocity-aided inertial navigation	Several minutes

Zero-velocity Detection

Compute likelihood ratio: $L(\mathbf{z}_n) = \frac{p(\mathbf{z}_n|H_1)}{p(\mathbf{z}_n|H_0)}$

$L(\mathbf{z}_n) < \gamma$

The foot is moving

γ

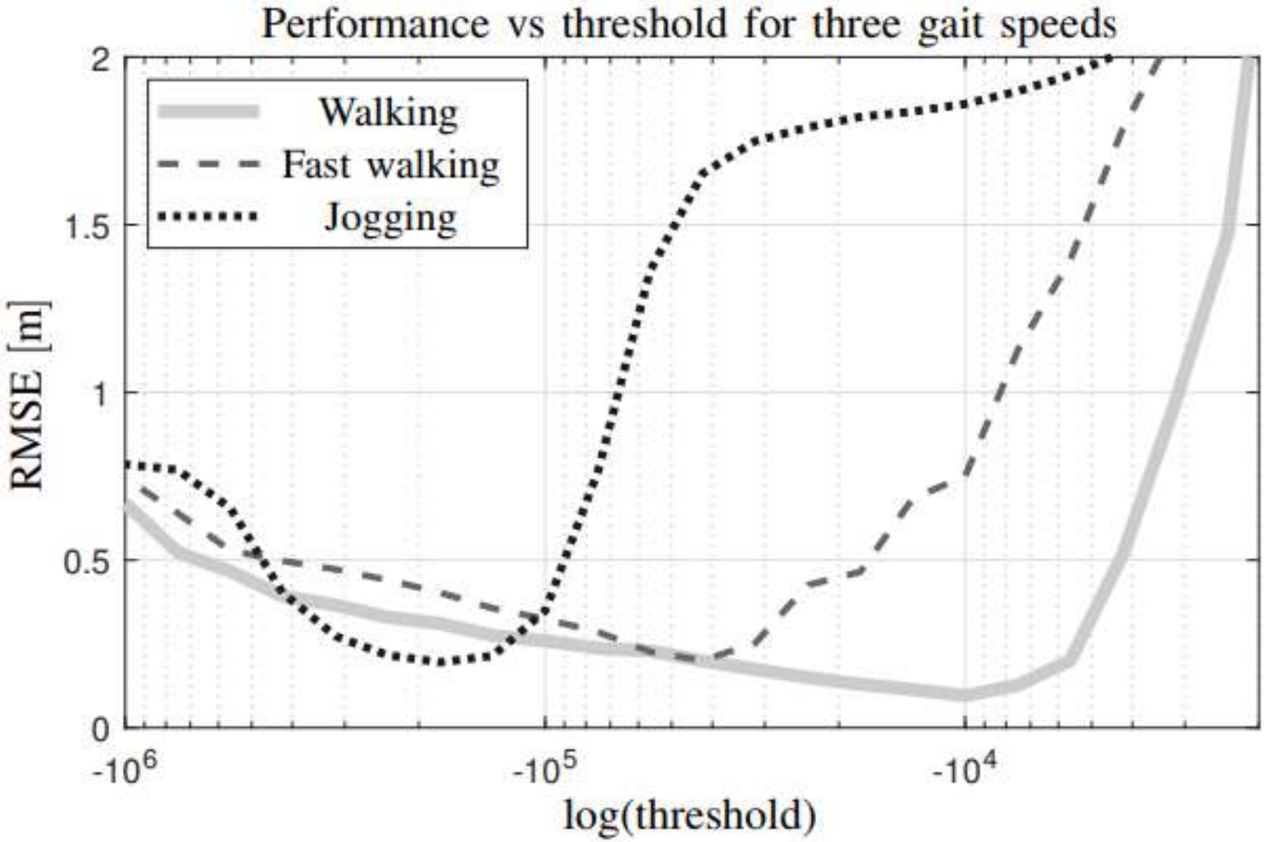
$L(\mathbf{z}_n) \geq \gamma$

The foot is stationary

How set γ? The optimal fixed γ depends on the velocity.

Challenges with zero-velocity-aided inertial navigation

- Position drift
- The optimal implementation is dependent on factors such as
  - gait speed
  - the walking surface



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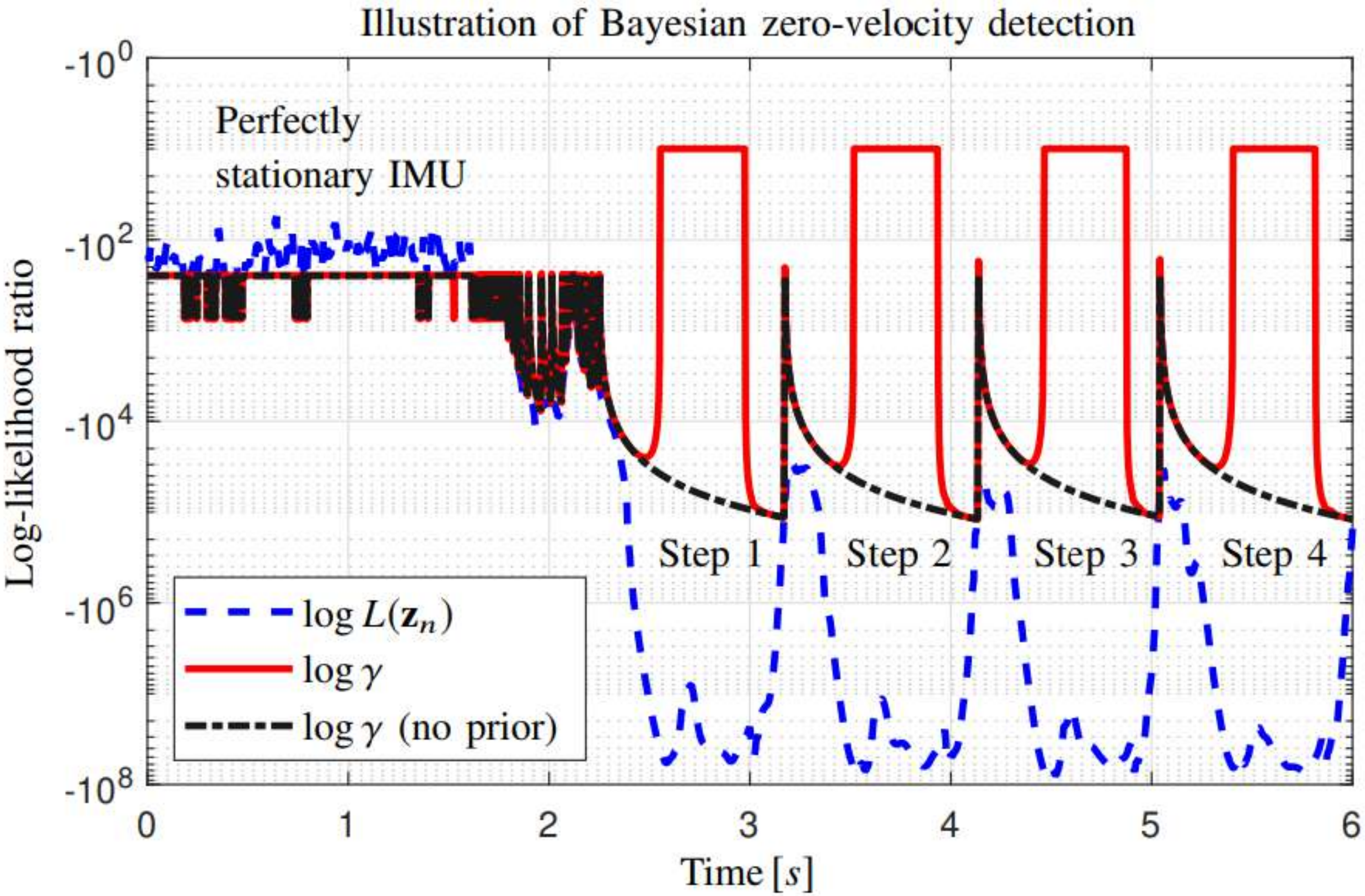
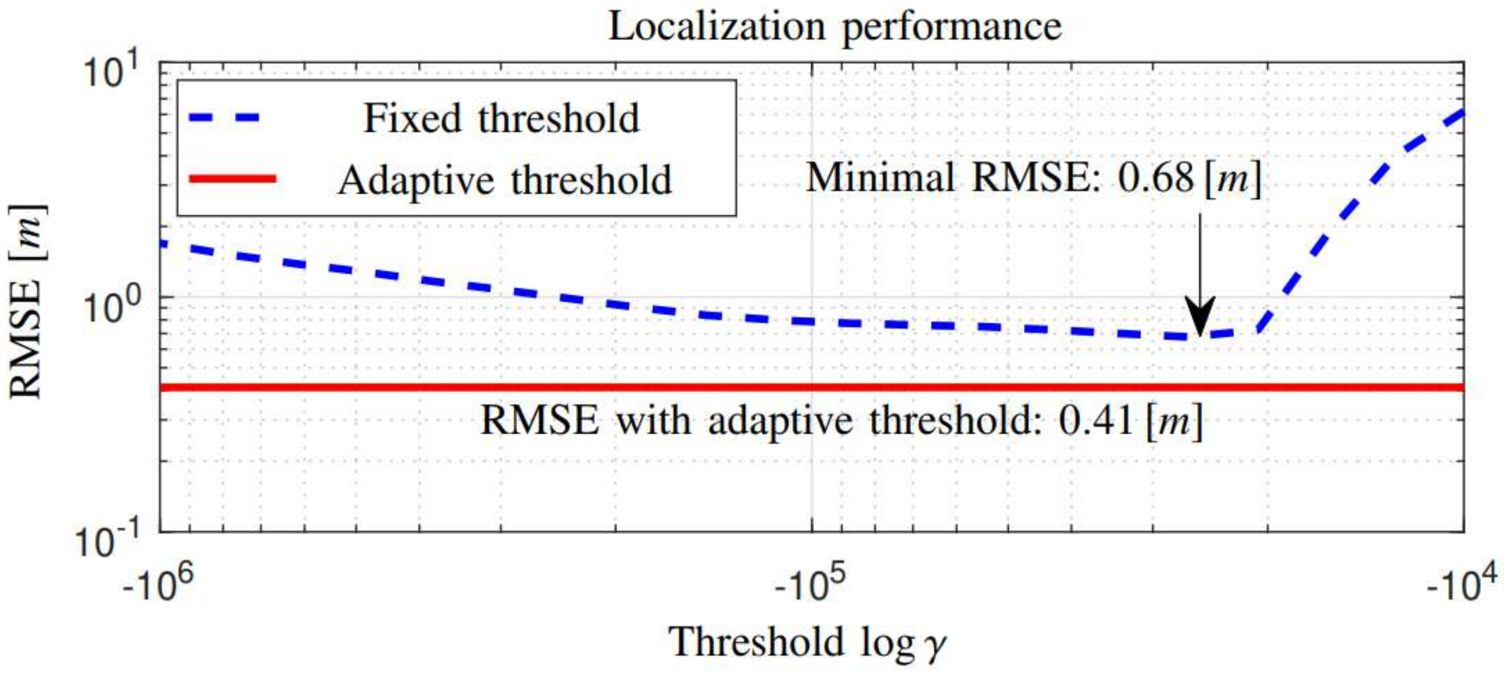
Adaptive Thresholding



Performance Evaluation

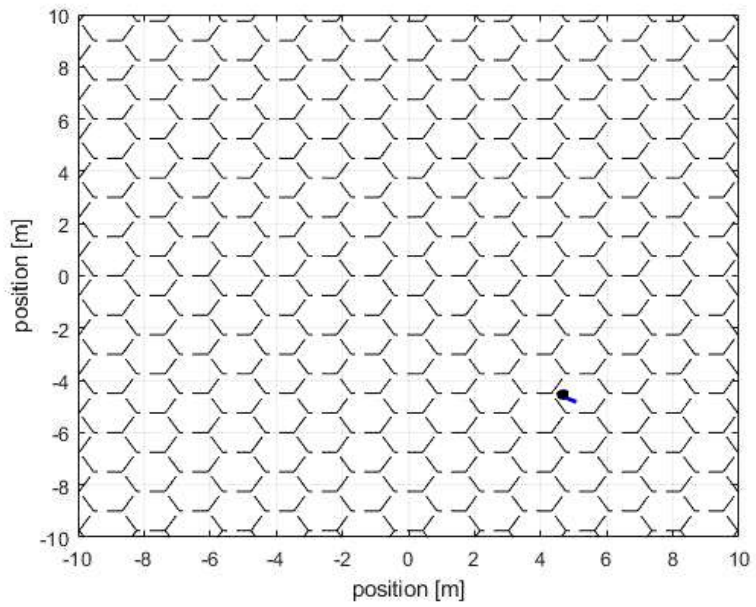
After walking along a closed-loop trajectory with an approximate length of 84 meter:



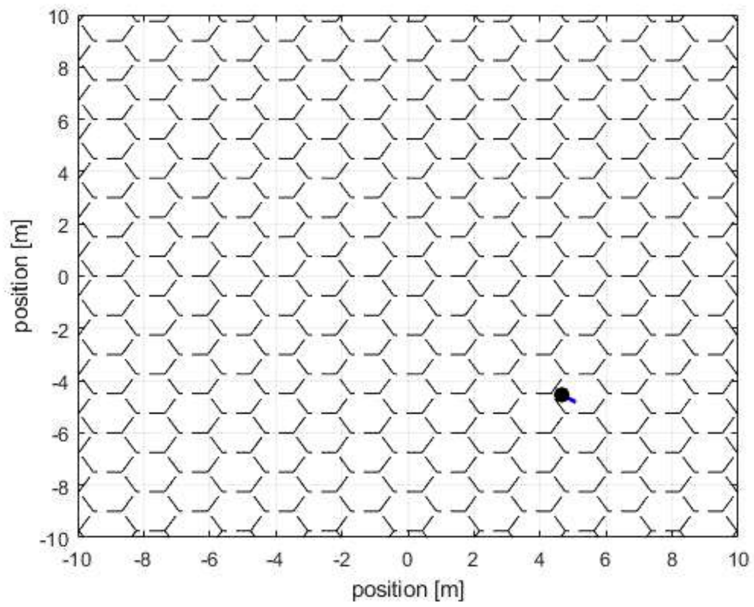
J. Wahlström, I. Skog, F. Gustafsson, A. Markham, and N. Trigoni, "Zero-Velocity Detection - A Bayesian Approach to Adaptive Thresholding," IEEE Sensors Letters, vol. 3, no. 6, Jun. 2019.

FootSLAM

<u>FootSLAM</u>

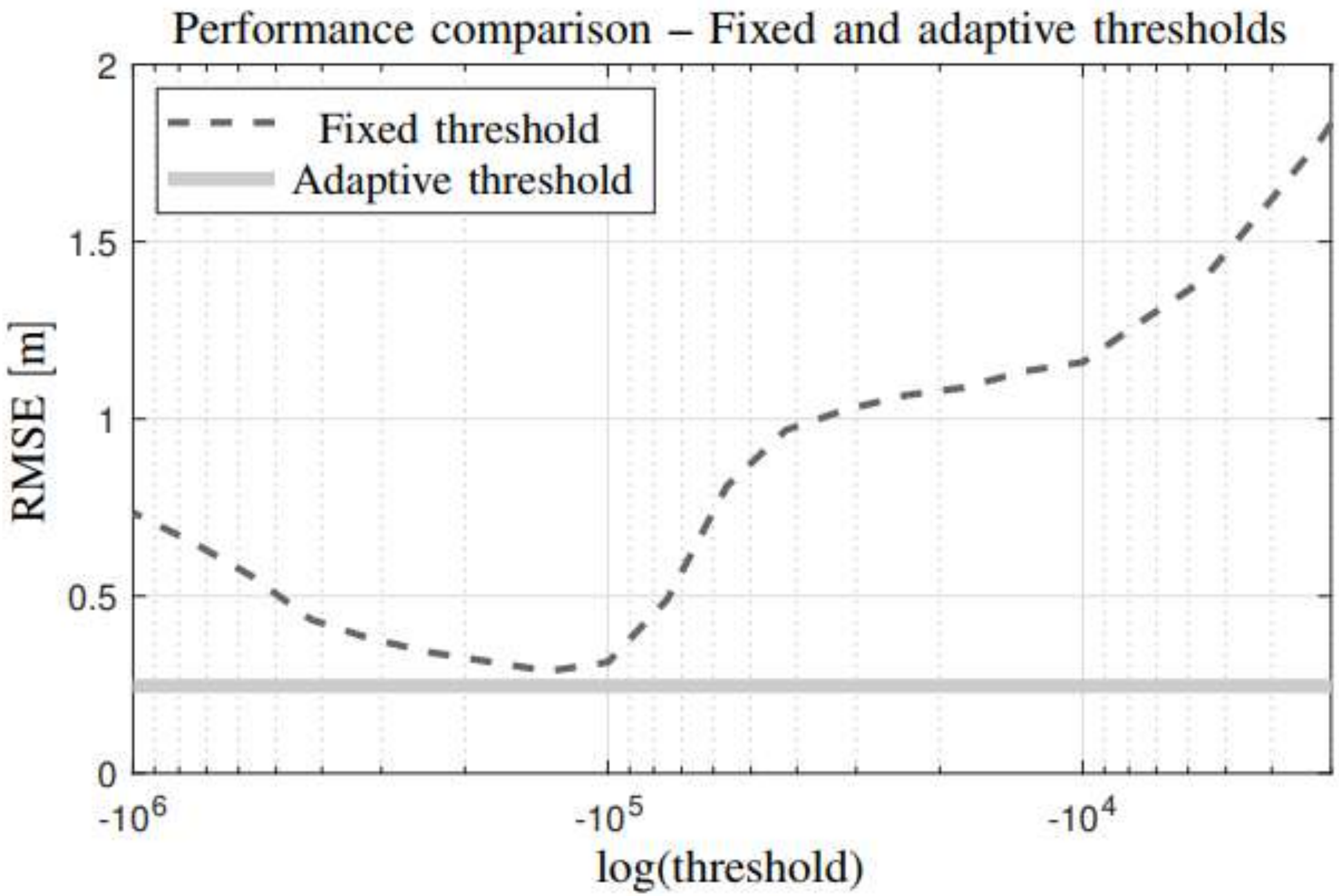


<u>Inertial odometry</u>



- Divide the navigation area into a grid of hexagons
- Learn the probability of moving from one hexagon to an adjacent one.

Calibration using FootSLAM



Foot-mounted inertial navigation

- Foot-mounted inertial navigation is a reliable navigation technology with no dependence on visibility, line-of-sight, or pre-deployed infrastructure.
- By adapting the zero-velocity-detection threshold it is possible to reach excellent performance despite variations in gait speed and environment conditions.

Magneto Inductive

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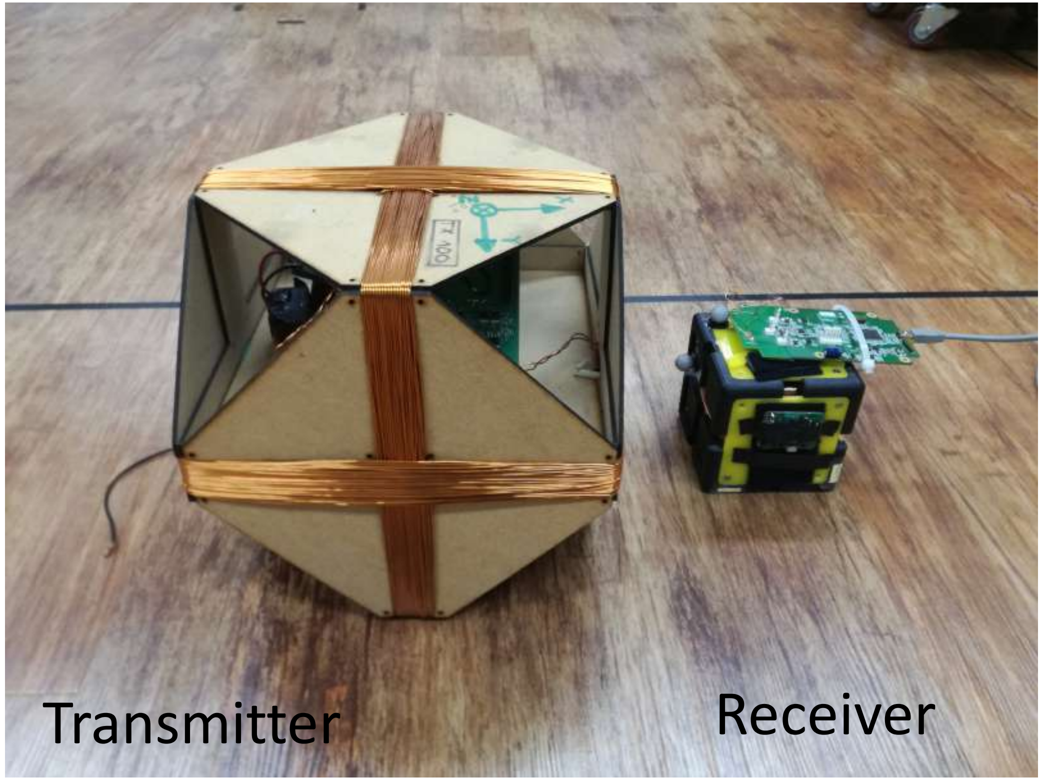
Magneto Inductive

Advantages:

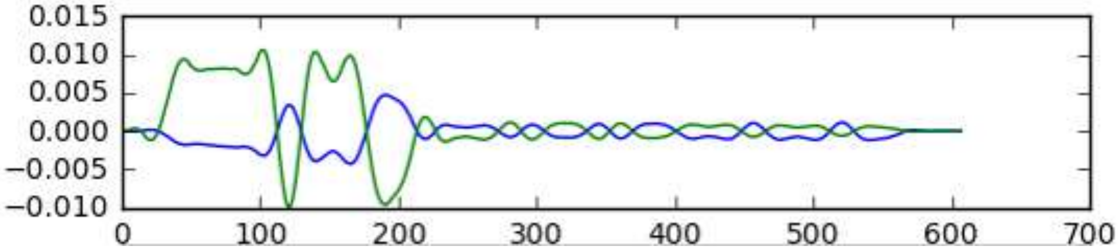
- Low frequency modulated magnetic fields provide accurate 3-D positioning
- MI does not suffer from multipath
- Penetrates the majority of materials (concrete, soil, people, water, vegetation) without loss
- Single transmitter provides 3-D positioning

Disadvantages:

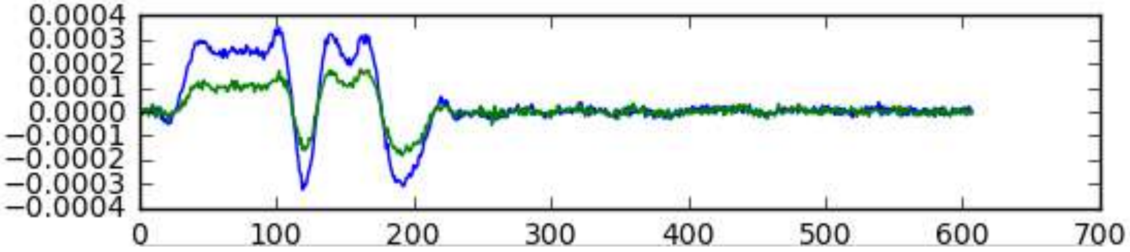
The signal amplitude decays quickly with distance, so that the signal received rapidly fades into noise with increasing distance



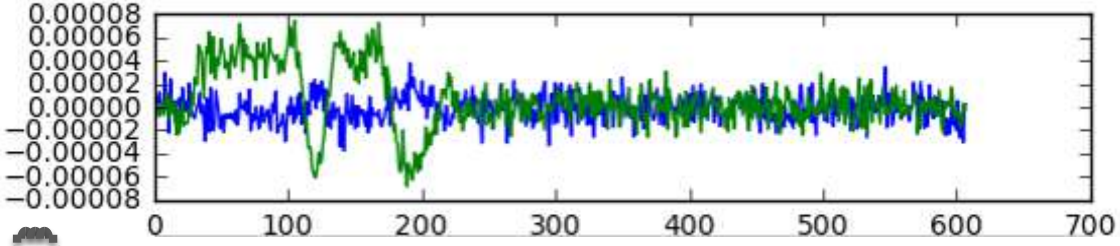
Rx at 3 m



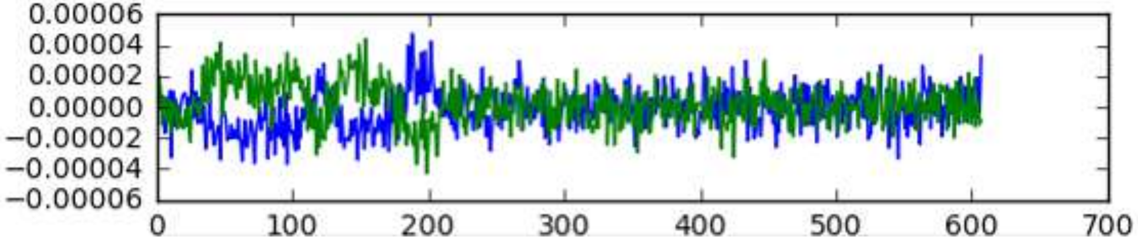
Rx at 10 m



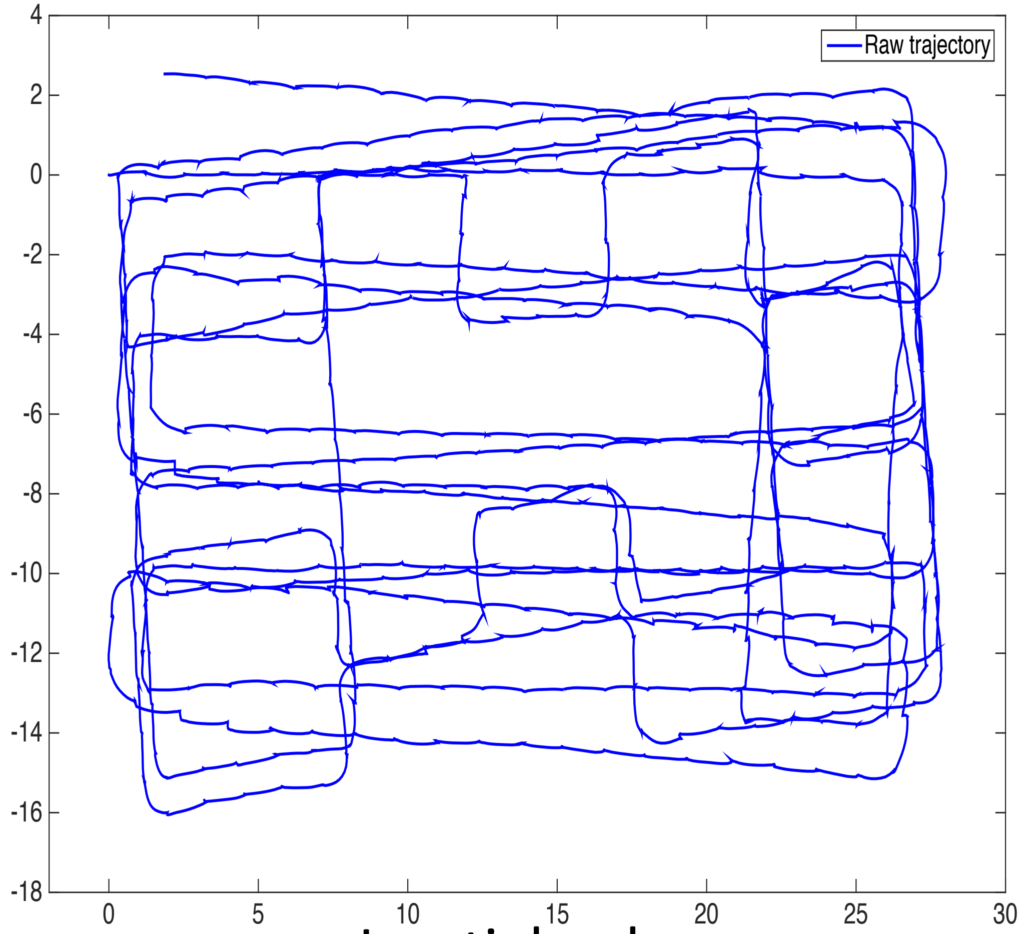
Rx at 20 m



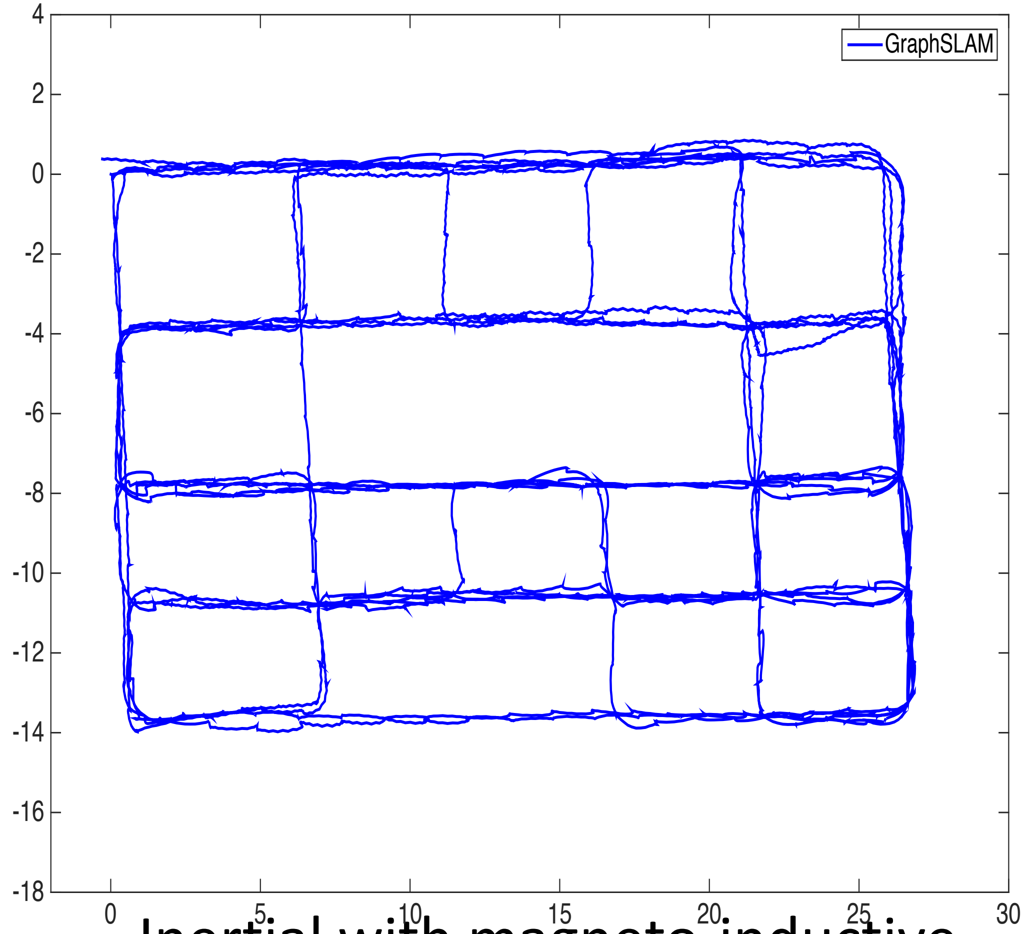
Rx at 30 m



Position Estimates



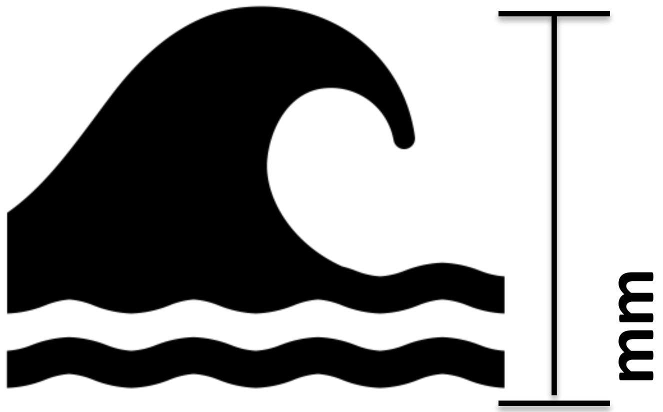
Inertial only



Inertial with magneto-inductive

Magneto Inductive

- Rapid amplitude decay also means higher accuracy within a specific range.
- Magneto Inductive can be coupled with Inertial Sensors to allow for graph optimization.



Millimeter wave

Millimeter Wave Radar

- Independent of illumination condition and infrastructure (e.g. GPS or Wi-Fi)
- Functional under poor visual conditions due to
  - thick smoke
  - heavy fog
  - high temperatures and
  - falling debris

Millimeter Wave Radar

Advantages:

- Provides accurate range-measurement
- Gathers readings at close range, and
- Operates at low peak power

Challenges:

- Sidelobes—radiation sent in unintended directions and
- Multipath reflections that occur when a wave encounters additional reflection points before returning to the receiver antenna

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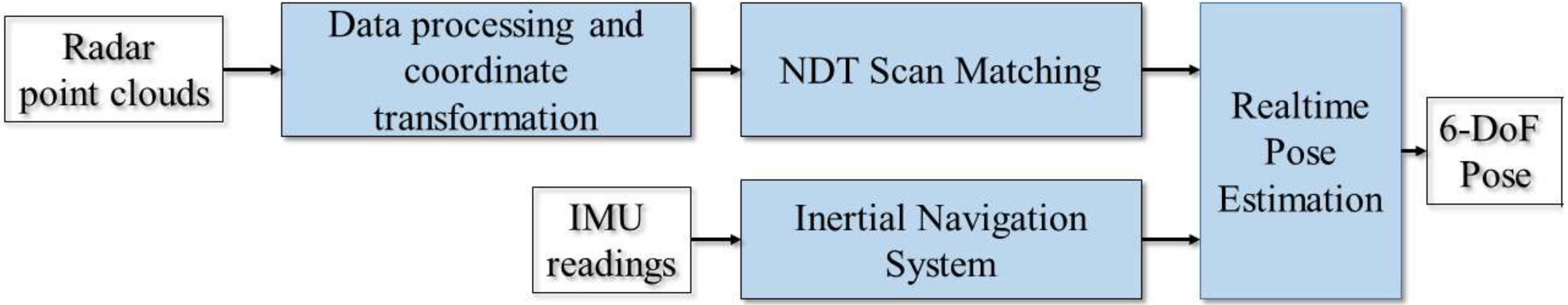
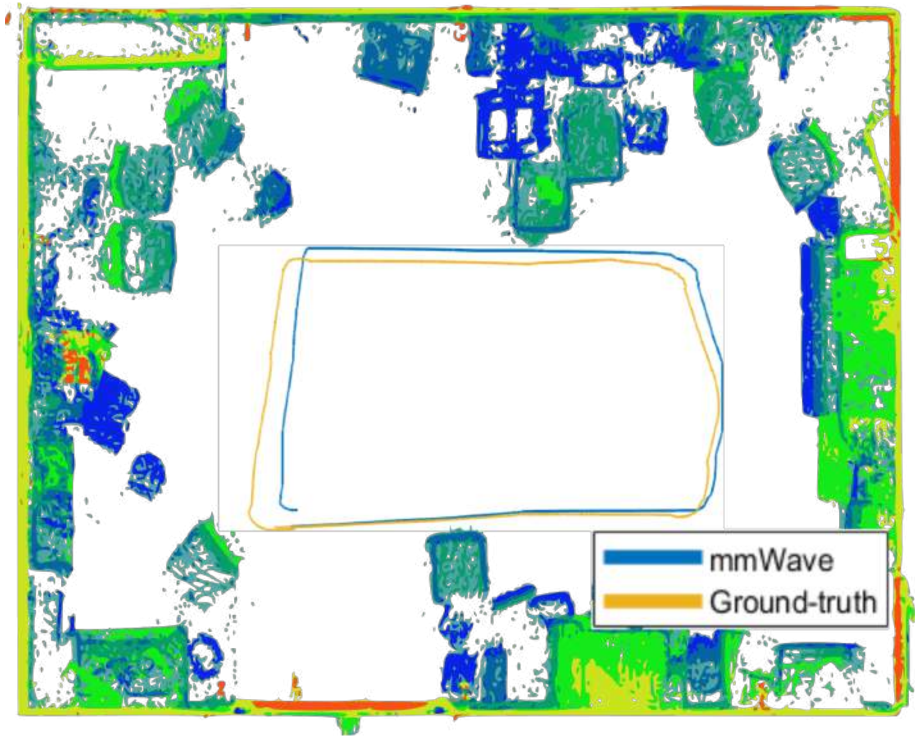
Millimeter Wave Radar-Our Approach



- **Idea:** To use MM-Wave short range radars as the main means for pose perception to improve the precision of pose estimates and map reconstruction
- Radar odometry based on the normal distributions transform (NDT) scan matching approach aided by IMU

Millimeter Wave Radar Odometry

- Estimated trajectory compared with ground-truth trajectory



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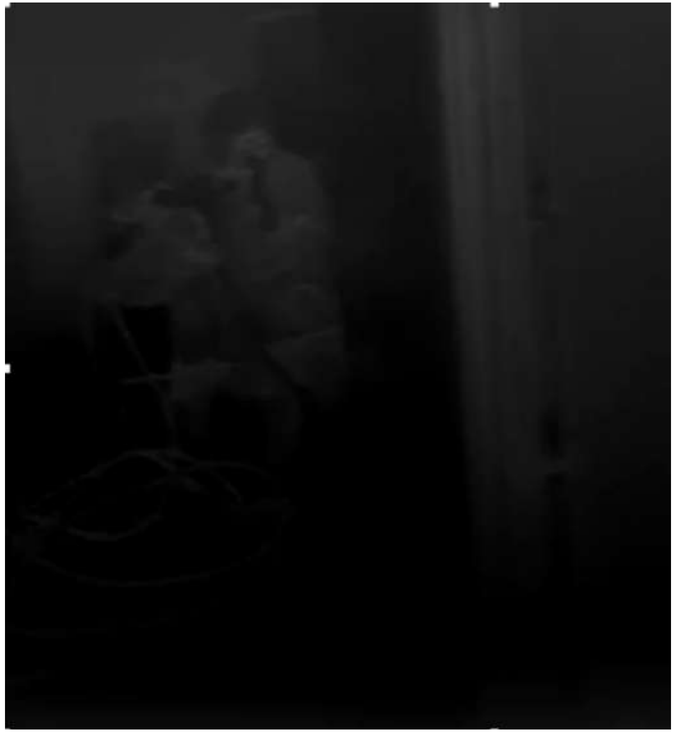
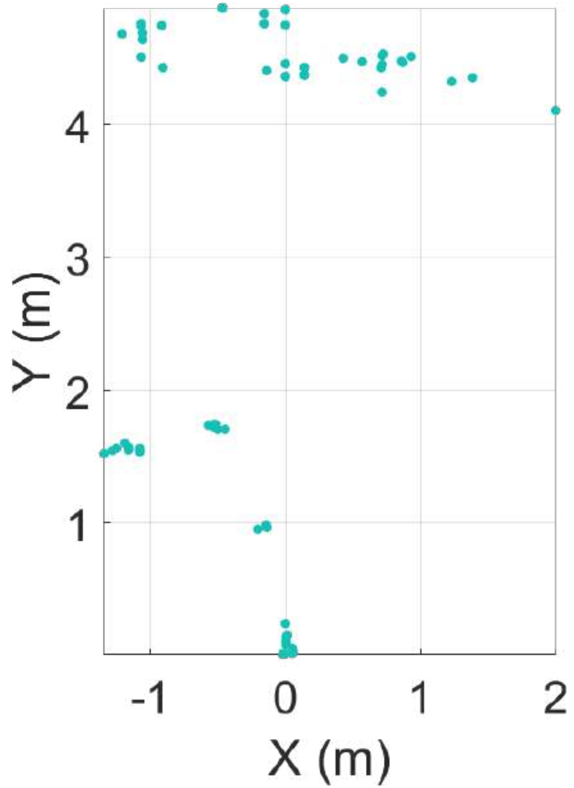
Millimeter Wave Radar

- Sparse measurements from radar scan in smoke-filled environment

Thermal data



Radar data



Millimeter Wave Radar

- Millimeter wave radar is a promising sensing technology capable of penetrating smoke.
- When compared to Lidar, Millimeter Wave radar produces fewer points, which in turn leads to faster processing.

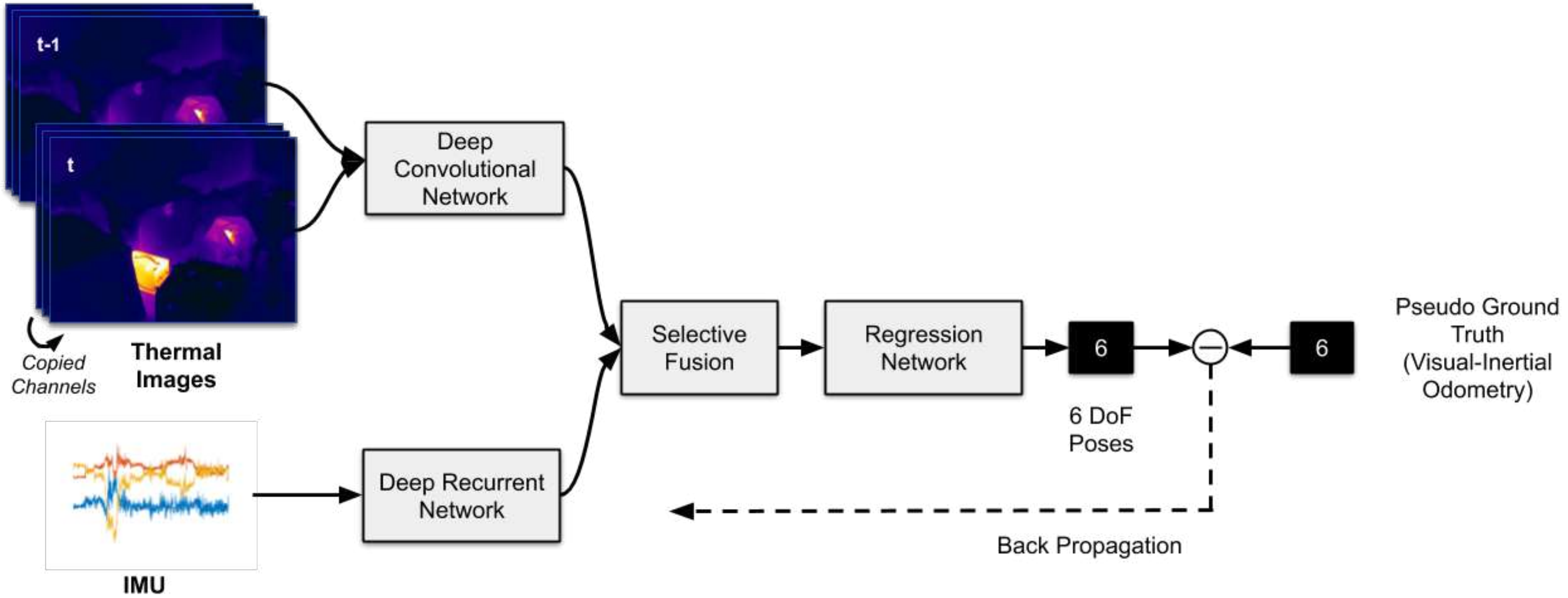
Thermal

Thermal

Advantages:
- Functional under heavy smoke, etc.
- Enough information to identify object’ s shape
- Ideally compatible with state-of-the-art algorithms for vision

Challenges:
- Lack of visual features
- Dynamic range depends on temperature
- Require Non-uniform Correction (NUC)

Deep Thermal-Inertial Odometry

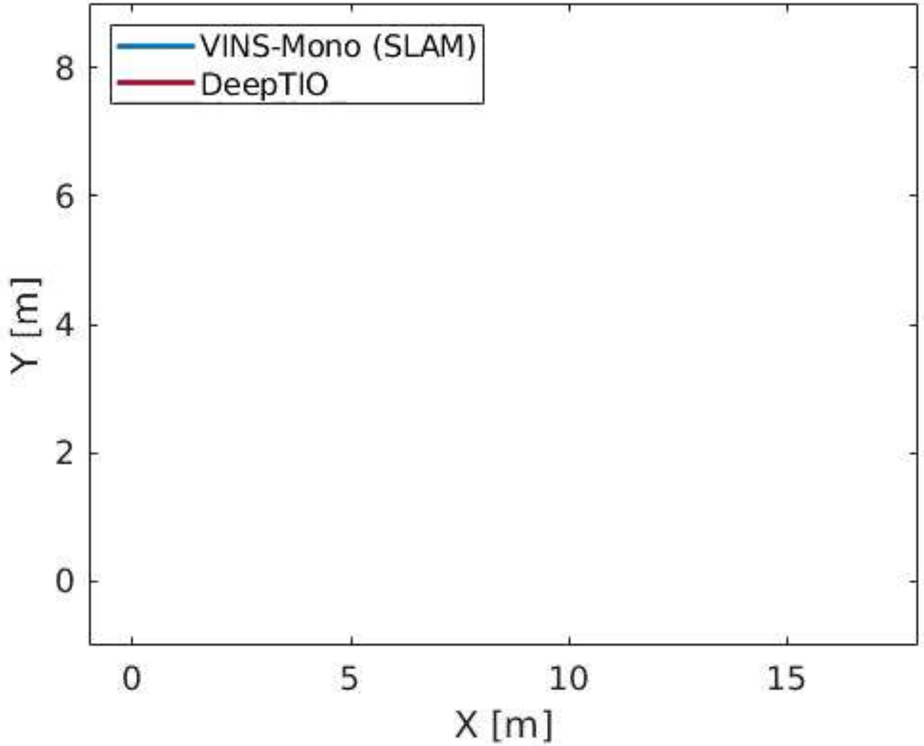


- Train end-to-end with **raw thermal radiometric data** + **IMU**
- Augmentation
  - Random trajectory splitting
  - Mean shifting on radiometric data

Deep Thermal-Inertial Odometry

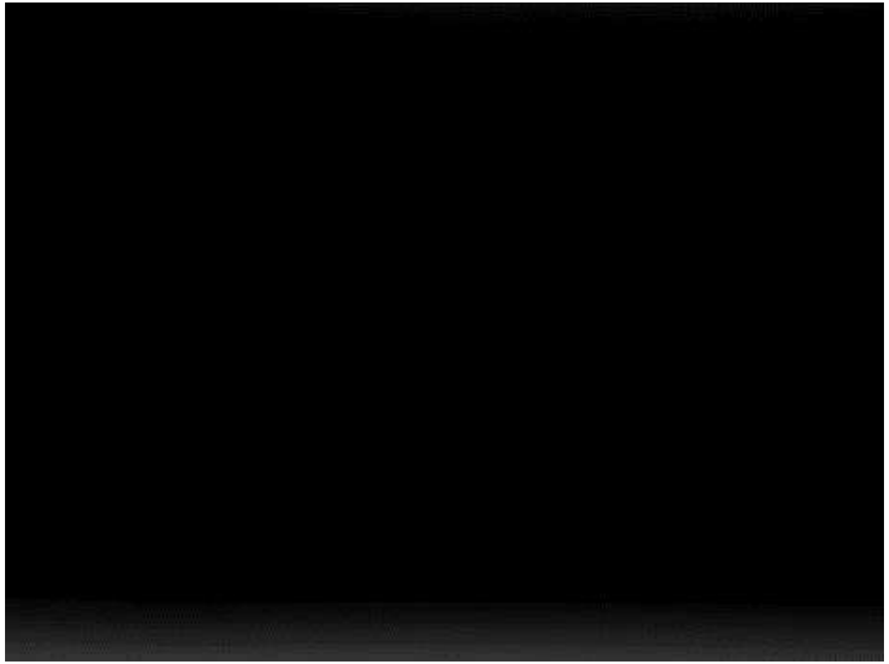
Test in Oxford College Building

Radiometric data normalized to grayscale

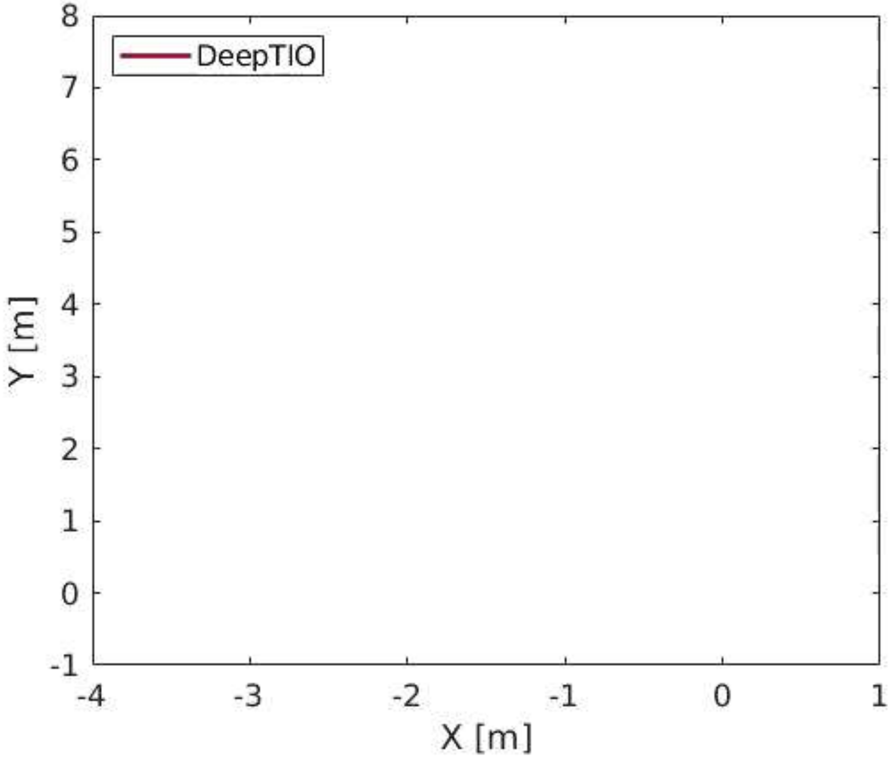


Deep Thermal-Inertial Odometry

Test in firefighter training facility with smoke-filled environment



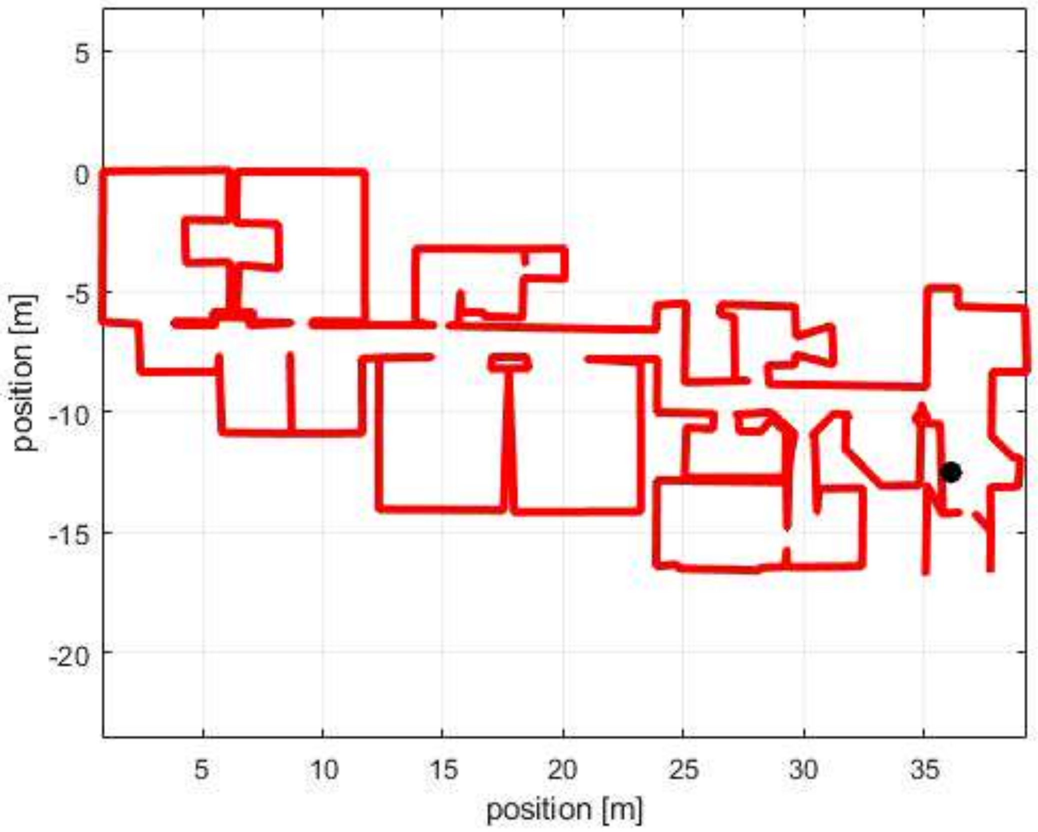
Radiometric data normalized to grayscale



Deep Thermal-Inertial Odometry

- Thermal imaging is a common tool in firefighting
- This is the first work to consider using it to accurately track location

Foot-mounted inertial navigation



Summary

- Multi-sensor approach derisks the failure of a single sensor e.g. due to thick smoke or occlusions
- Individual components for odometry are progressing well
- Iterative approach of testing in the lab and in the wild is yielding benefits in balancing complexity and reality
- Next steps are selective sensor fusion and system integration
- One step closer to the goal of robust first responder tracking

Thank you

Contacts:

niki.trigoni@cs.ox.ac.uk

andrew.markham@cs.ox.ac.uk

#PSCR2019

Come back for the

Next Session

2:40 PM