ViPER
Vehicle Pose Estimation using UWB Radios

Alireza Ansaripour (University of Houston)

Milad Heydariaan (University of Houston)

Omprakash Gnawali (University of Houston)

Kyungki Kim (University of Nebraska-Lincoln)

DCOSS 2020

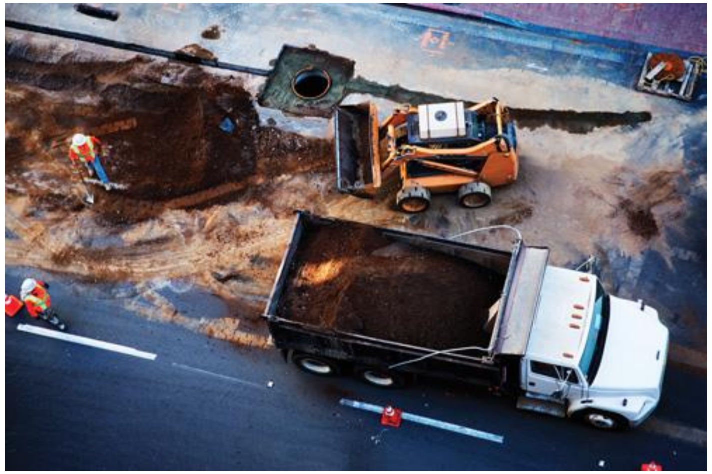
June 2020

ViPER
Vehicle Pose Estimation using UWB Radios

- **Introduction**
- Challenge
- Related work
- Design
- Evaluation
- Conclusion

Road construction safety

- About 773 per year lose their lives in work zone crashes[1].
  - 1982 - 2017
- Some of these can be prevented
  - Monitoring the location
- Pose estimating systems
  - Track the entities



1 https://www.cdc.gov/niosh/topics/highwayworkzones/default.html

Requirements for location system for construction safety

- Consistent location availability
  - All time
  - Real-time
  - Notify the workers quickly as possible
- Low location estimation error
  - Avoid false alarms

Pose estimation technologies

Non-UWB technologies	Multi-sensors technologies	UWB-based technologies

• GPS + IMU
  • Weinstein (2010)
• Multiple-cameras
  • Soltani (2017)
	• IMU + UWB
	  • Strohmeier (2018)
	• GPS + UWB
	  • González (2007)
		• Multiple-UWB
		  • Zhang (2012)

• Low accuracy • High implementation cost	• Data fusion problem	• Non-Line of sight problem

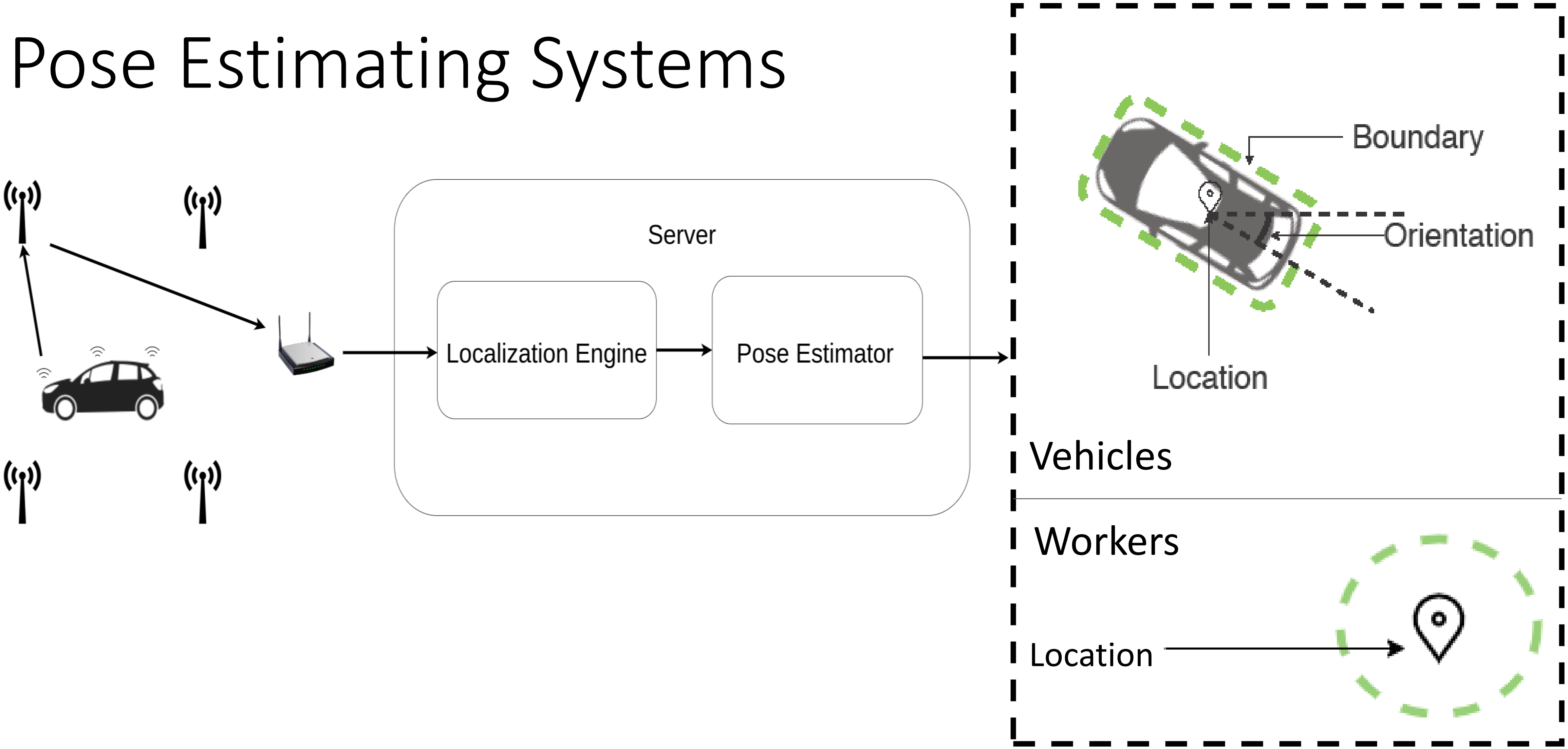
UWB based pose estimation

Data is collected with anchors and tags

Tag

Anchor

Pose Estimating Systems

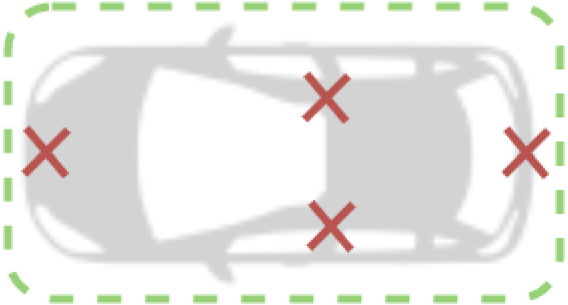


ViPER
Vehicle Pose Estimation using UWB Radios

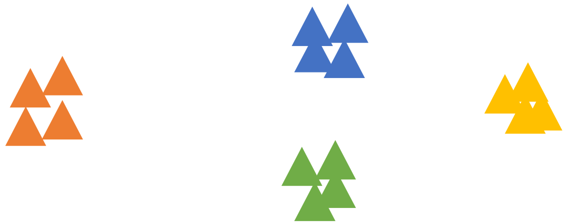
- Introduction
- **Challenge**
- Related work
- Design
- Evaluation
- Conclusion

Boundary estimation (ideal case)

Tag placement on vehicle



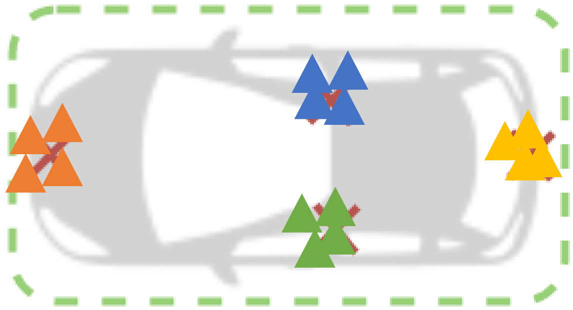
Calculated location of tags



Boundary estimation (ideal case)

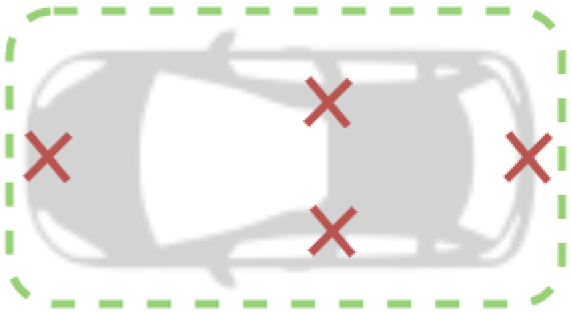
Tag placement on vehicle

Calculated location of tags

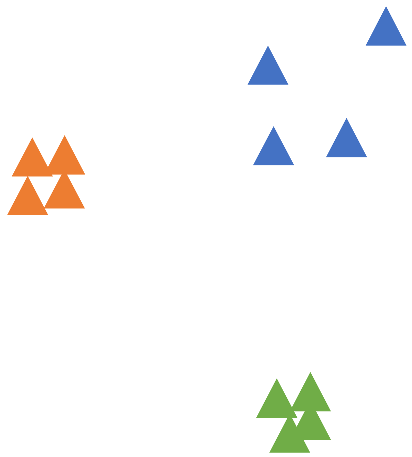


Boundary estimation (real-world scenario)

Tag placement on vehicle



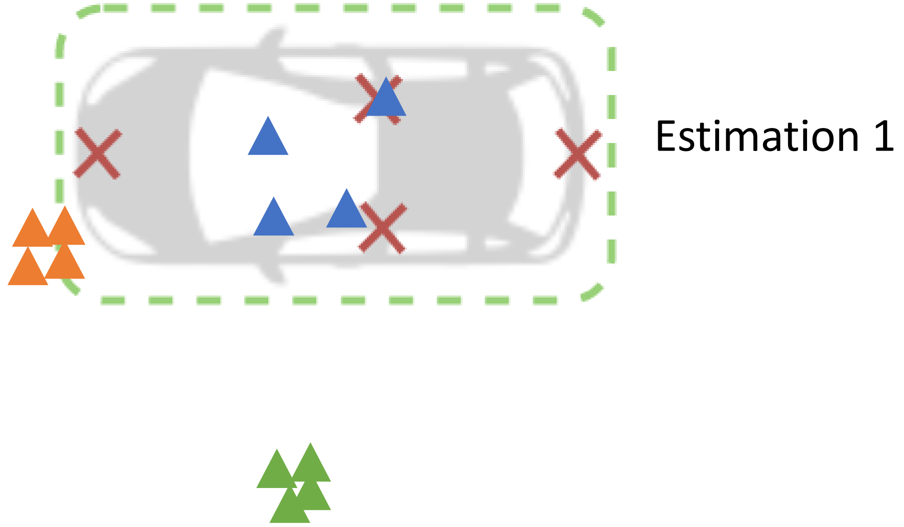
Calculated Locations



Boundary estimation (real-world scenario)

Calculated Locations

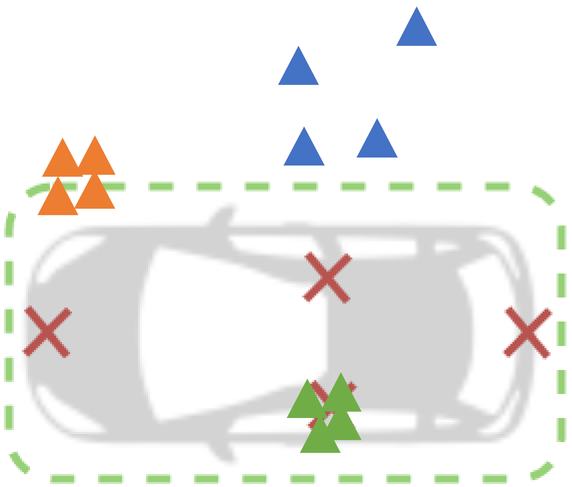
Tag placement on vehicle



Boundary estimation (real-world scenario)

Calculated Locations

Tag placement on vehicle

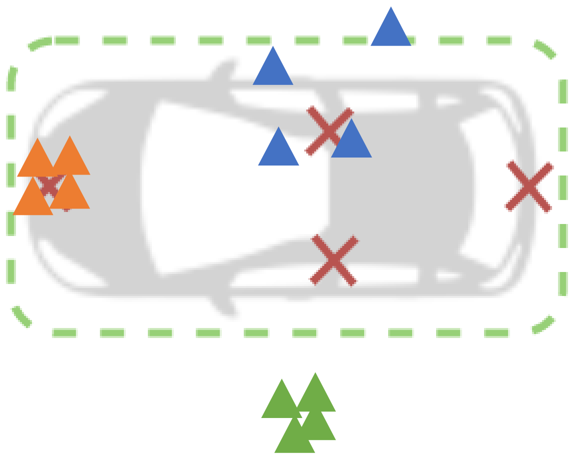


Estimation 2

Boundary estimation (real-world scenario)

Calculated Locations

Tag placement on vehicle



Boundary estimation

- Inaccurate localization
  - Non-line of sight (NLoS) condition
- Different possibilities for boundary
  - When using mapping method (trivial method for mapping)

ViPER
Vehicle Pose Estimation using UWB Radios

- Introduction
- Challenge
- **Related work**
- Design
- Evaluation
- Conclusion

Related work

- Averaging methods (Zhang C. (2012))
  - Reduce the error in estimating the pose
  - Not effective in construction site environments
- Optimization method (Vahdatikhaki F. (2015))
  - Specific type of vehicles
  - Limited type of movements
- Data fusion (Strohmeier M. (2018))
  - Sophisticated
  - Limited to simple environments

ViPER
Vehicle Pose Estimation using UWB Radios

- Introduction
- Challenges
- Related work
- **Design**
- Evaluation
- Conclusion

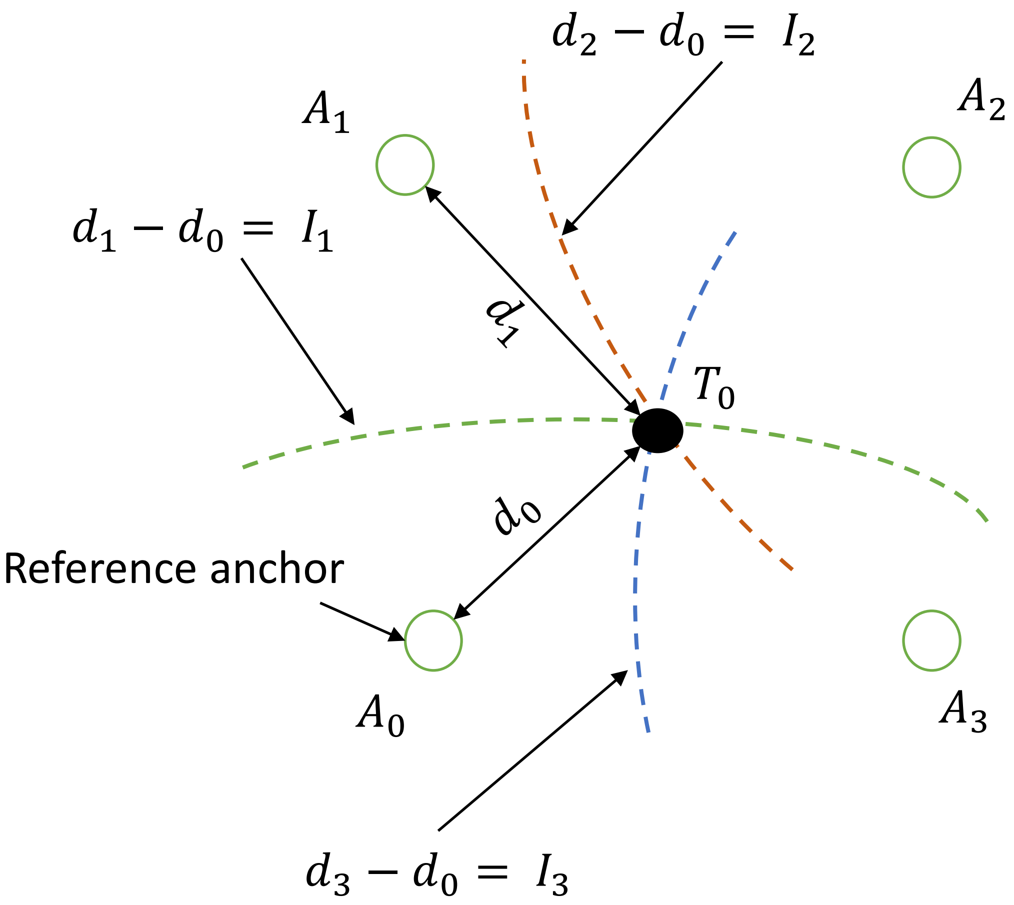
Design overview

- Localization engine
  - TDoA localization
  - Low-pass filter
  - Anchor and reference selection
- Pose estimator
  - Removing inaccurate estimates
  - Rectangle optimizer

TDoA Localization

- Used in our localization engine

1. Collects the received timestamp of the signal from anchors
2. If more than 4 anchors reported timestamp for a tag
    1. One anchor is chosen to be reference
    2. TDoA inputs are calculated
    $$I_i = c * (t_i - t_{ref})$$
    3. Calculates the location of the tag
    $F([I_1, \ldots, I_n]) \rightarrow (X, Y, residual\_error)$

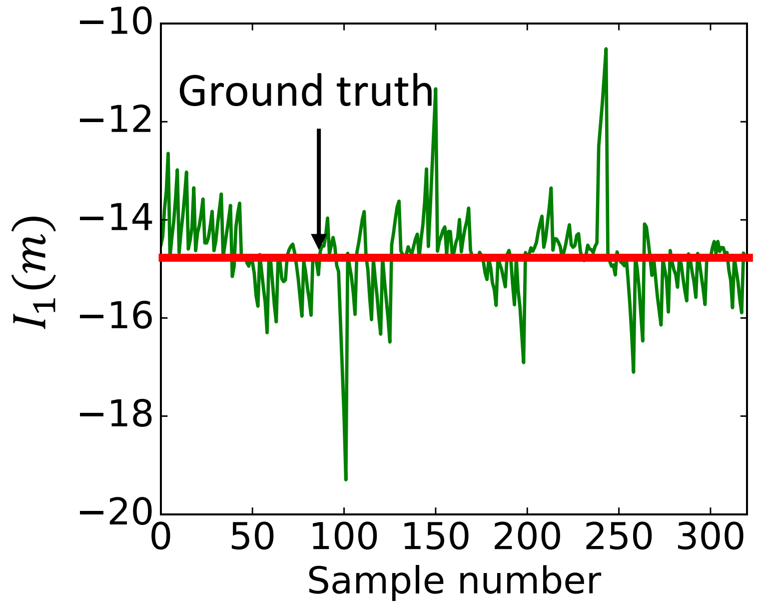


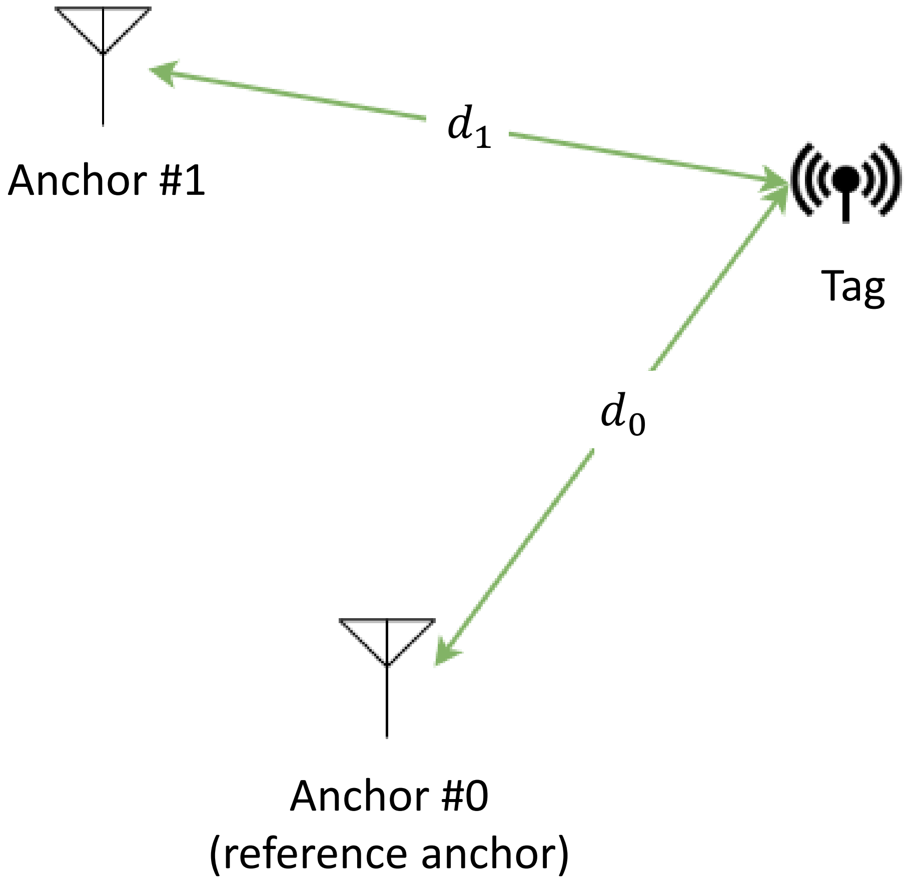
Correcting TDoA input

1. Low-pass filter
2. Anchor selection
3. Reference selection

TDoA input observation

- TDoA input for static tag
- Expected result to be static
  - $I_1 = d_1 - d_0$
- Plenty of fluctuations in observation



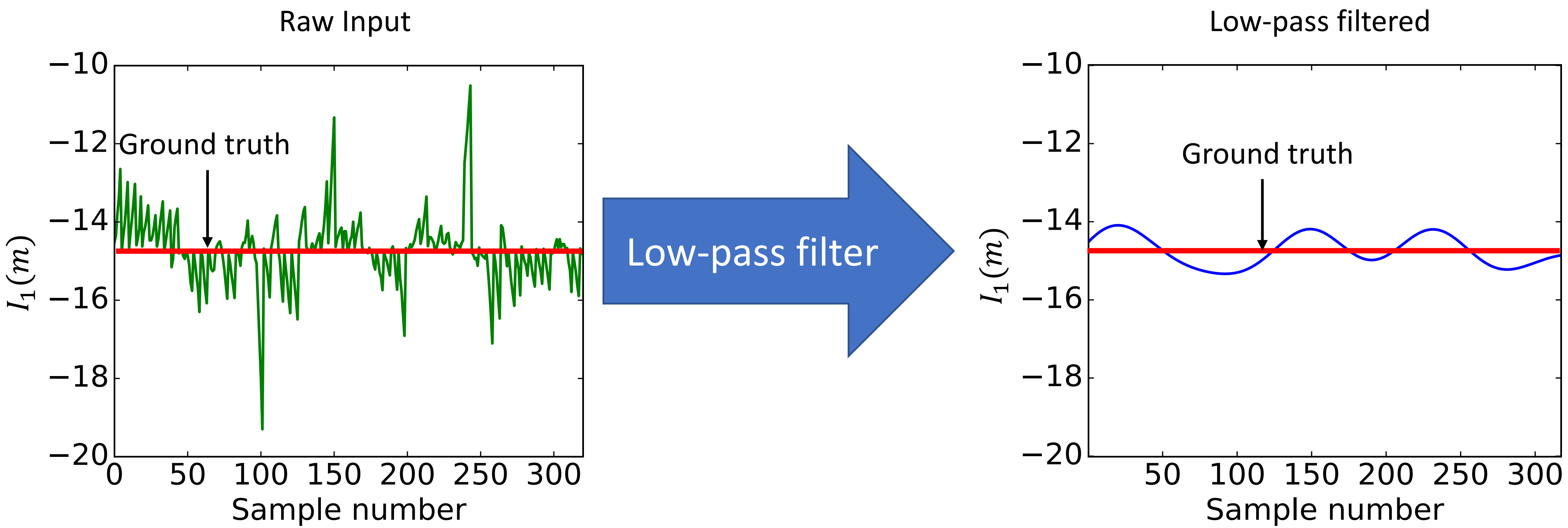


Correction 1: Low-pass filter

- Remove the noise in TDoA input
- Designed a low-pass filter
- Parameters
  - Cut-off frequency : 5 Hz
  - Order : 5

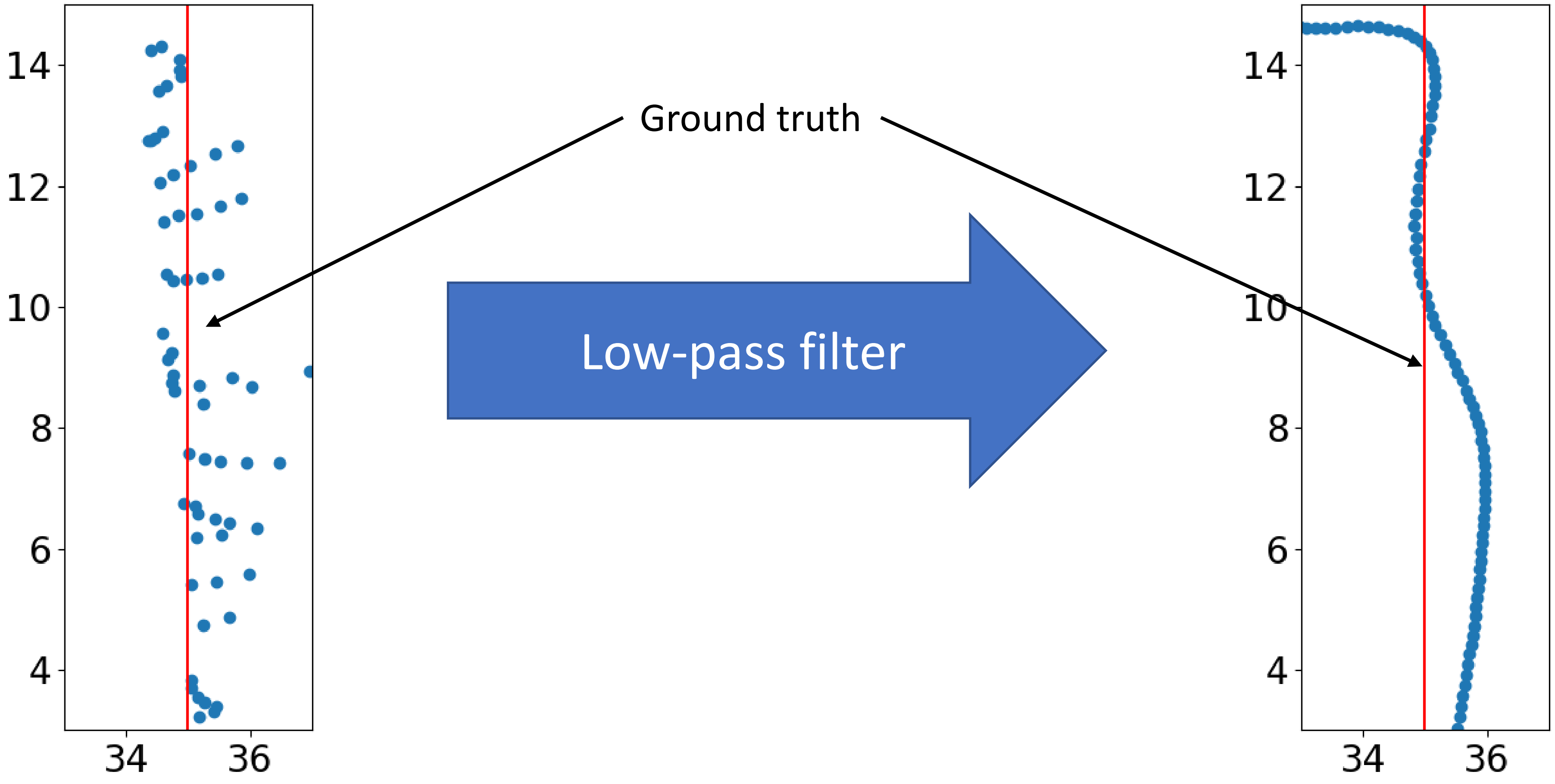
Correction 1: Low-pass filter

Some of the noises were removed by applying low-pass filter on TDoA input



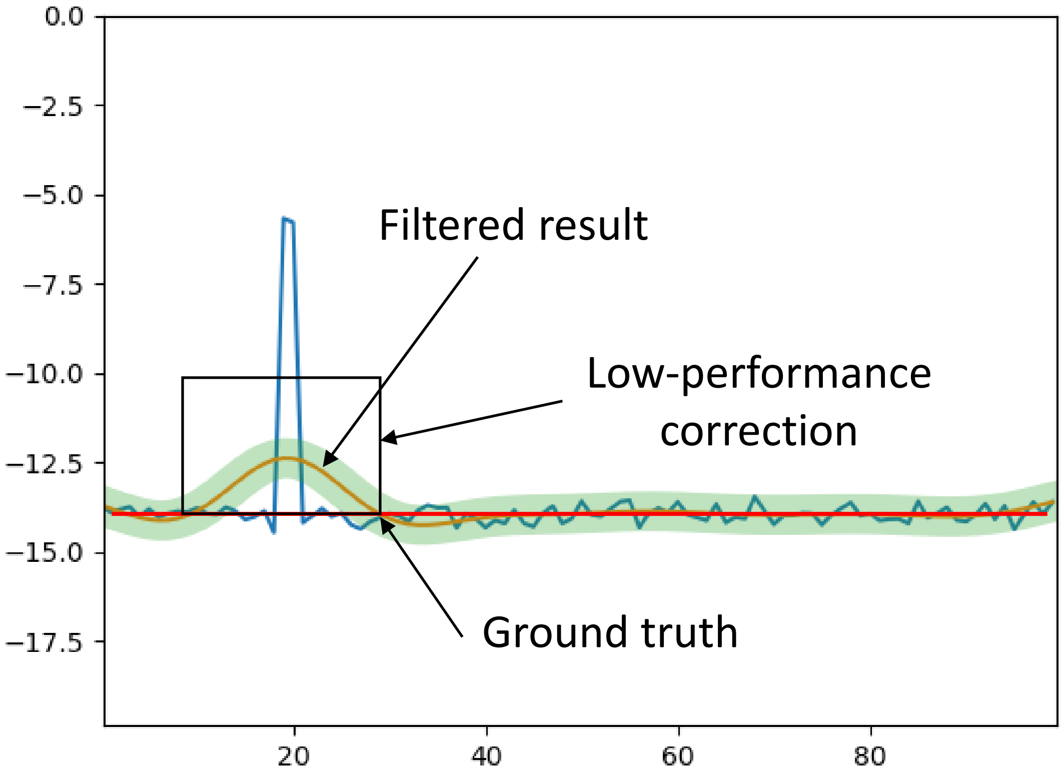
Results for a moving tag

Low-pass filter was able to reduce the number of missing points

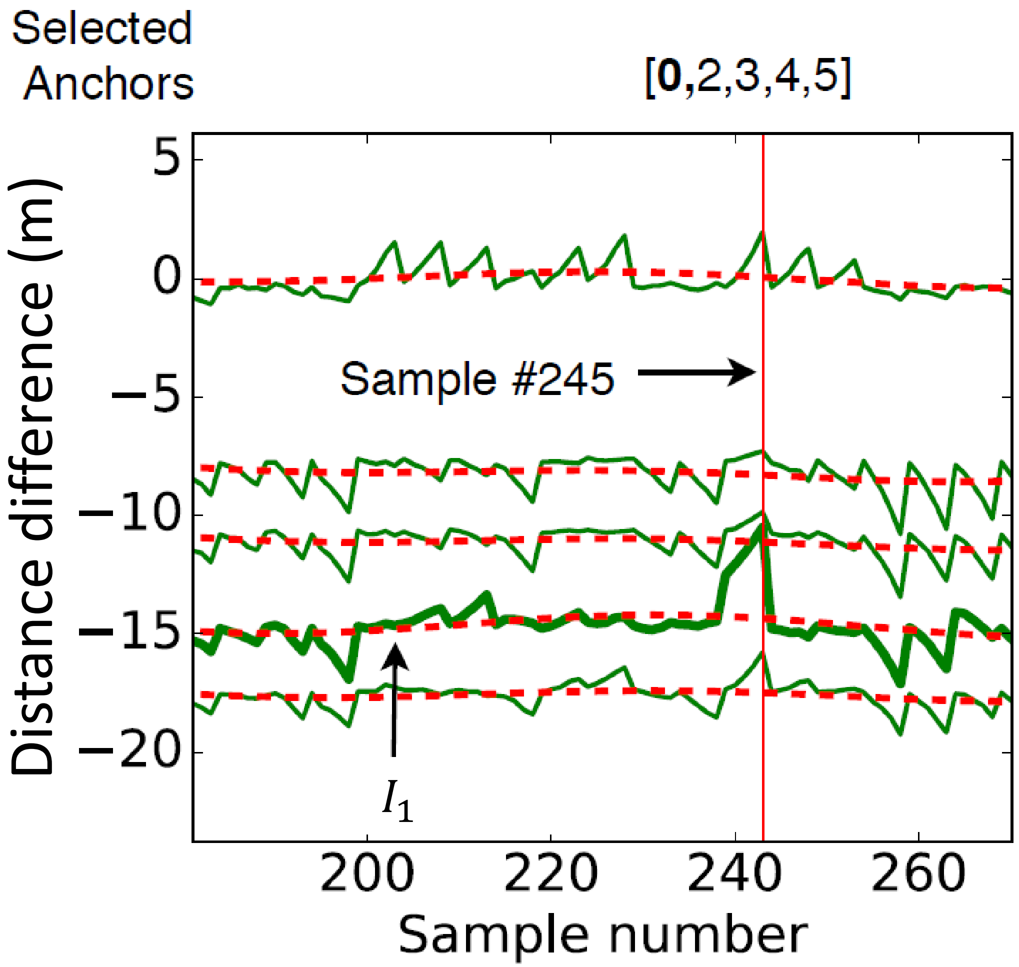


Correction 2: Anchor selection

- Feed the optimizer with more validated data
- Removing inaccurate measurements
- More than 4 anchors reporting
- Gap between actual and filtered value
  - Gap threshold: 2 meters

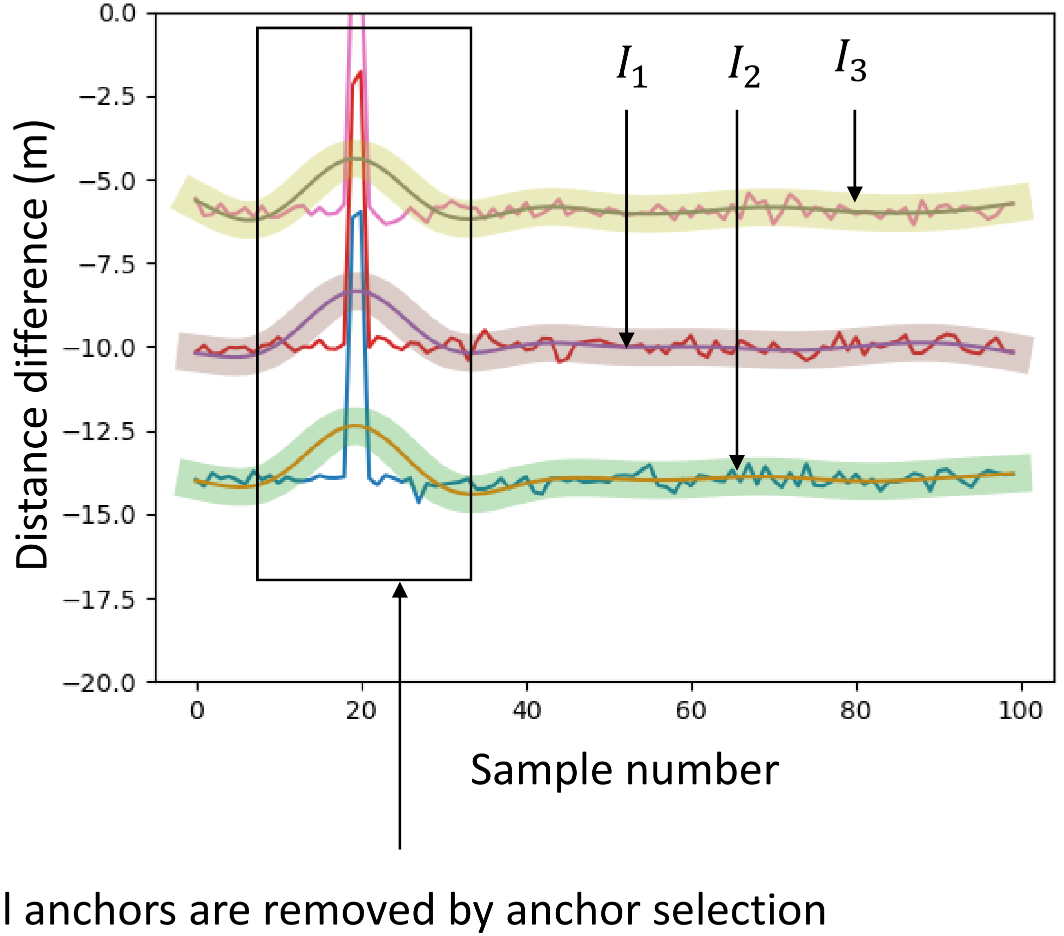


Anchor Selection (real-world results)



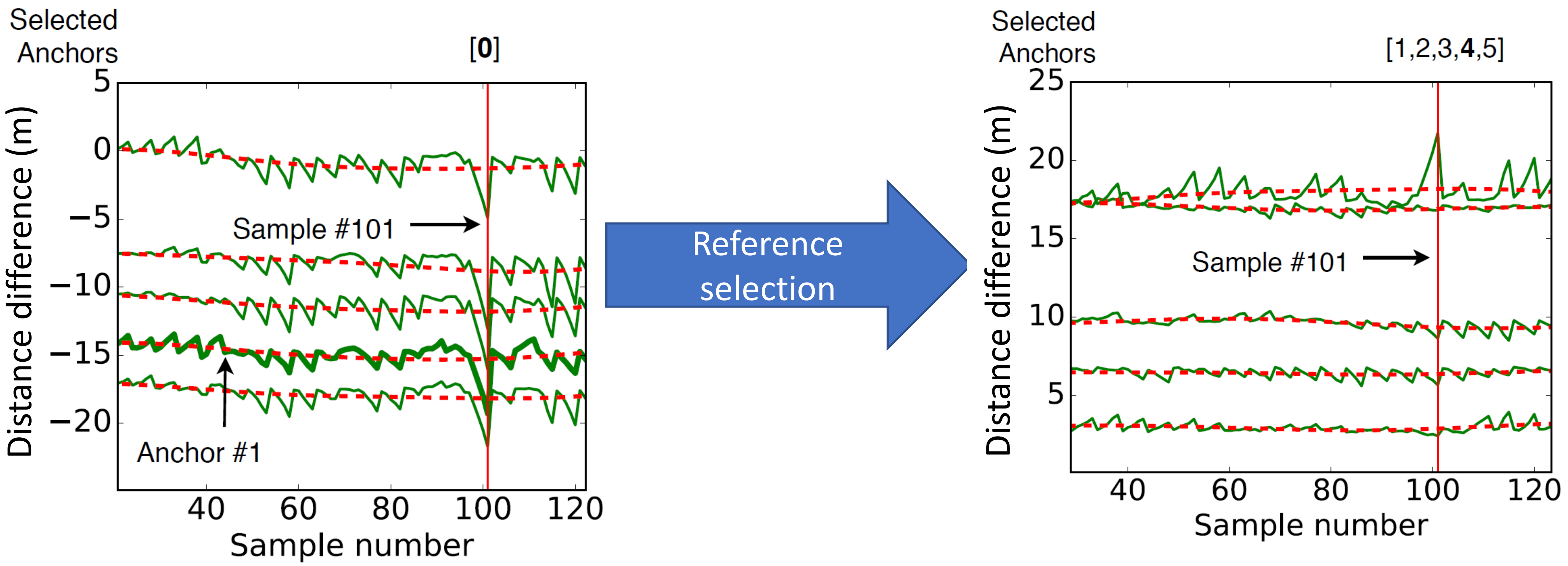
Correction 3: Reference selection

- Large number of anchors were removed by Anchor Selection
- Error in the time stamp of the reference
  - Propagate to all TDoA inputs
  - $I_i = c * (t_i - t_{ref})$
- Modify the reference anchor
  - One with least number of removed anchors

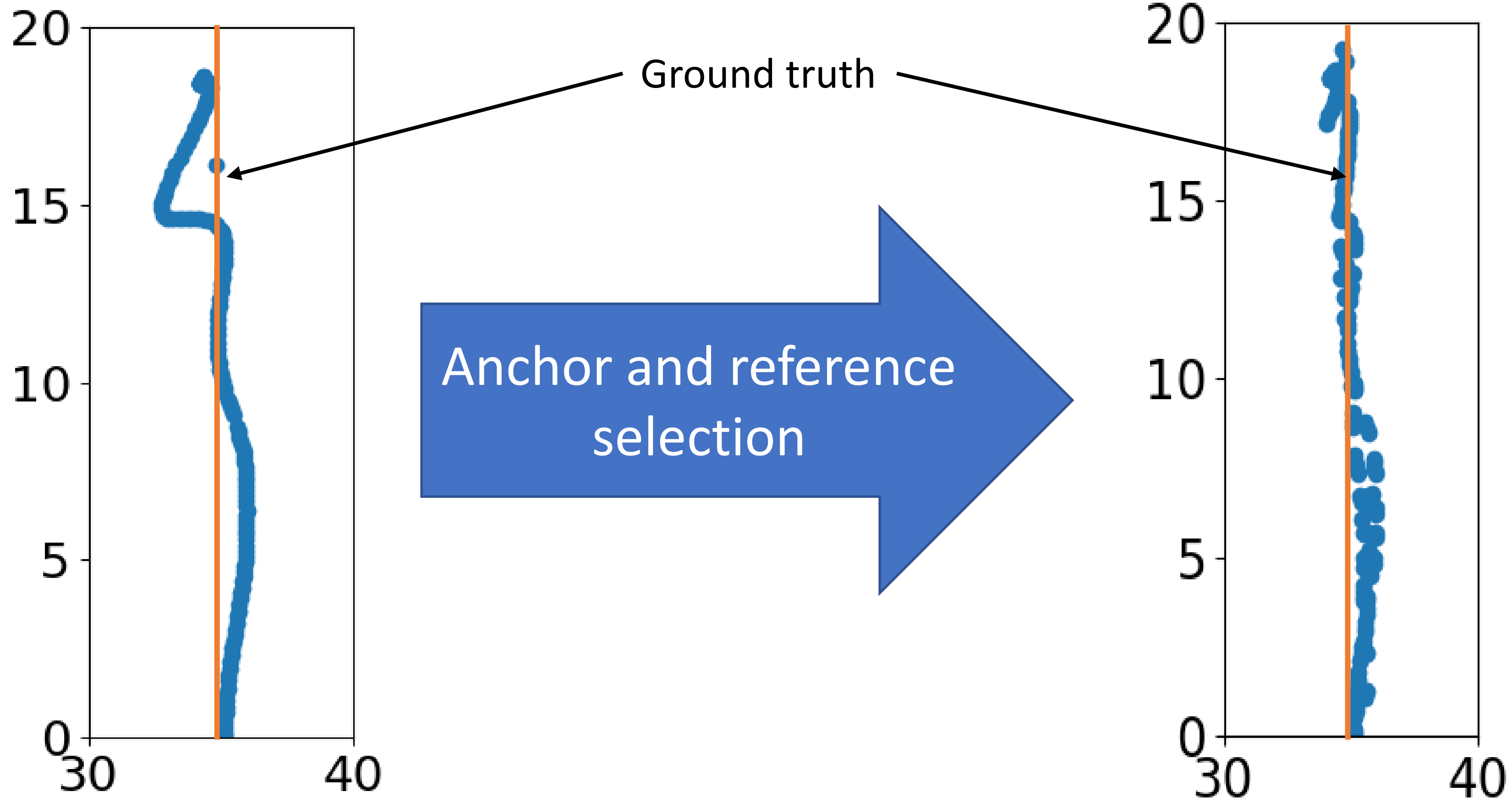


Reference Selection (real-world results)

The number of removed anchors decreased as we changed the reference anchor



Results for a moving tag



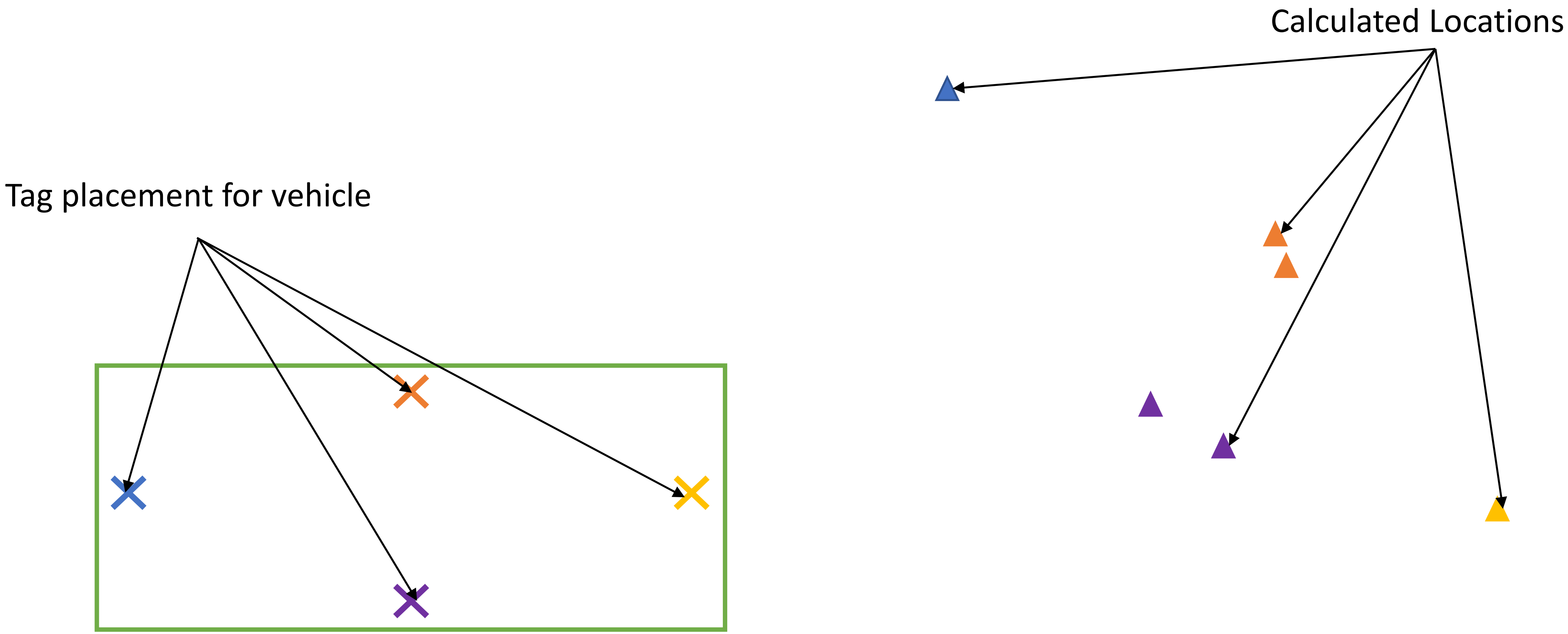
Pose estimation

- Removing erroneous location
- Rectangle optimization method

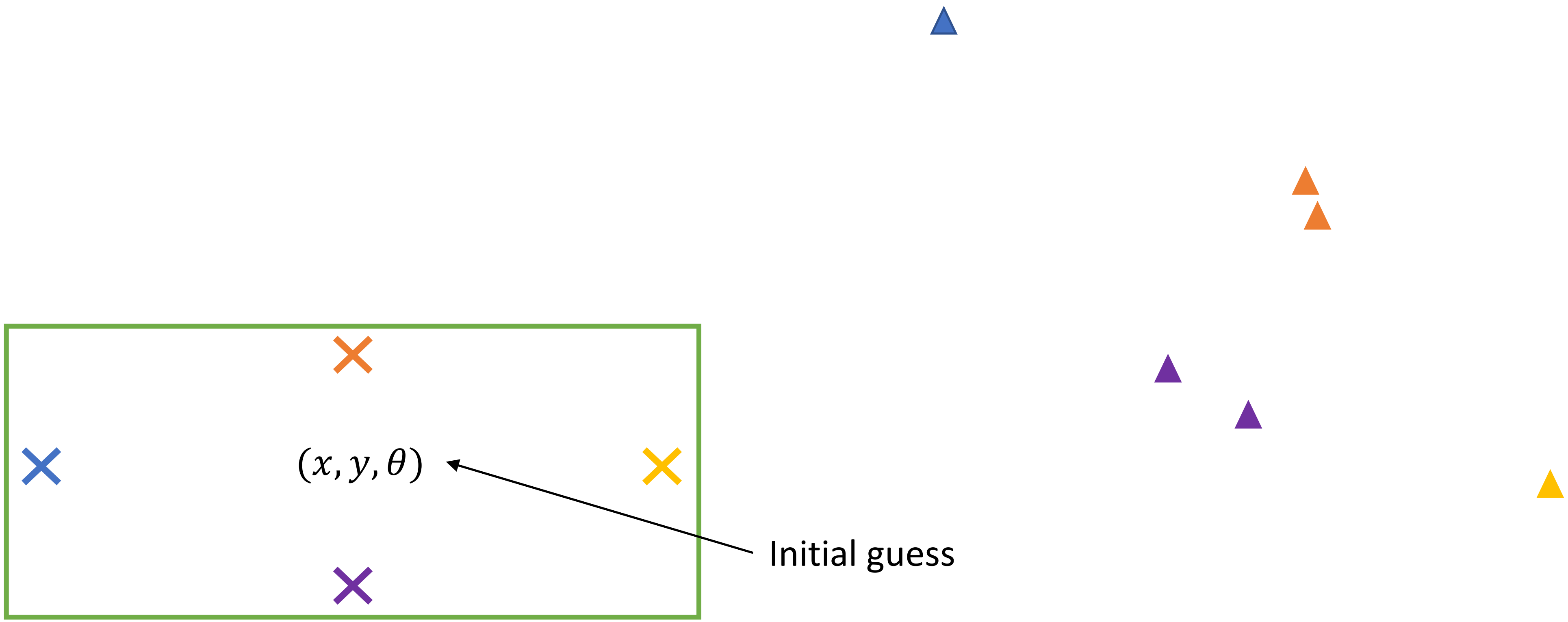
Correction 4: Removing Erroneous Locations

- Estimate the error of the location
  - Value of the TDoA optimization
  - Residual value
- Remove the locations
  - High residual value
  - Threshold = 5

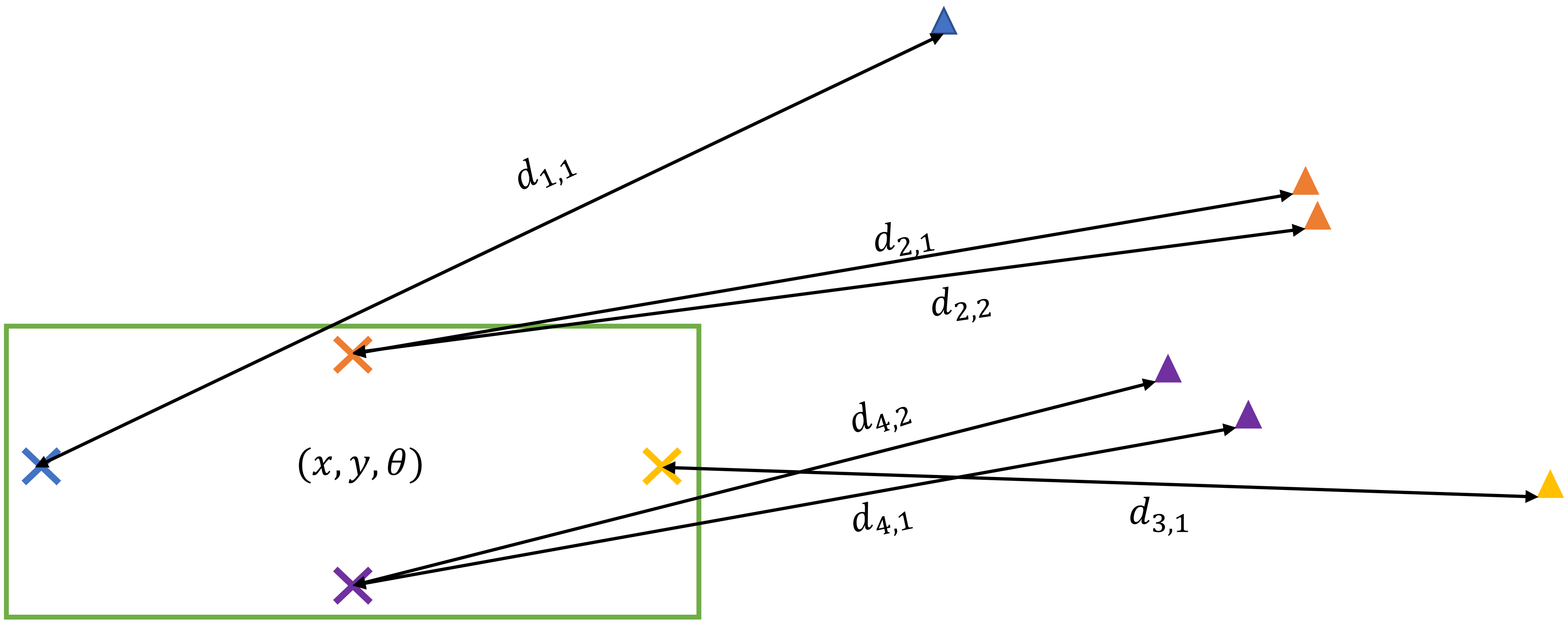
Correction 5: Rectangle Optimizer



Correction 5: Rectangle Optimizer



Correction 5: Rectangle Optimizer



Rectangle Optimizer

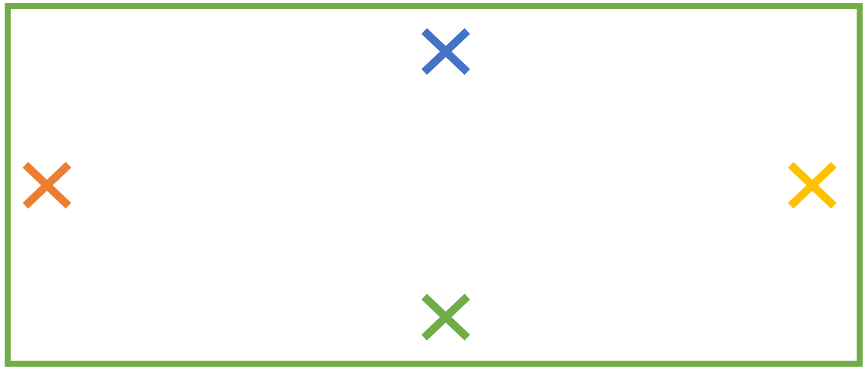
- Objective function

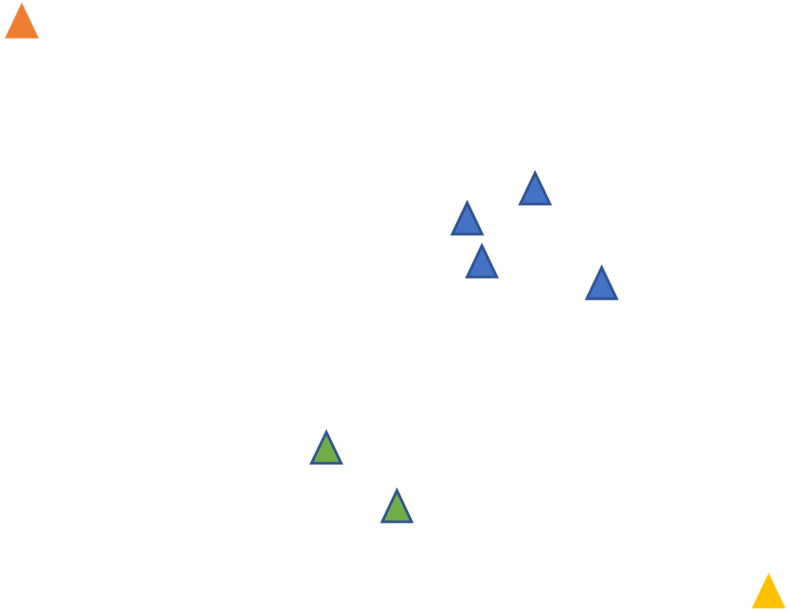
$$f(x, y, \theta) = \sum_{i=1}^{N} \sum_{j=1}^{size(i)} d_{i,j}^2$$

- Finds the location and orientation of the vehicle by

$$\hat{T} = \underset{x,y,\theta}{argmin}\, f(x, y, \theta)$$

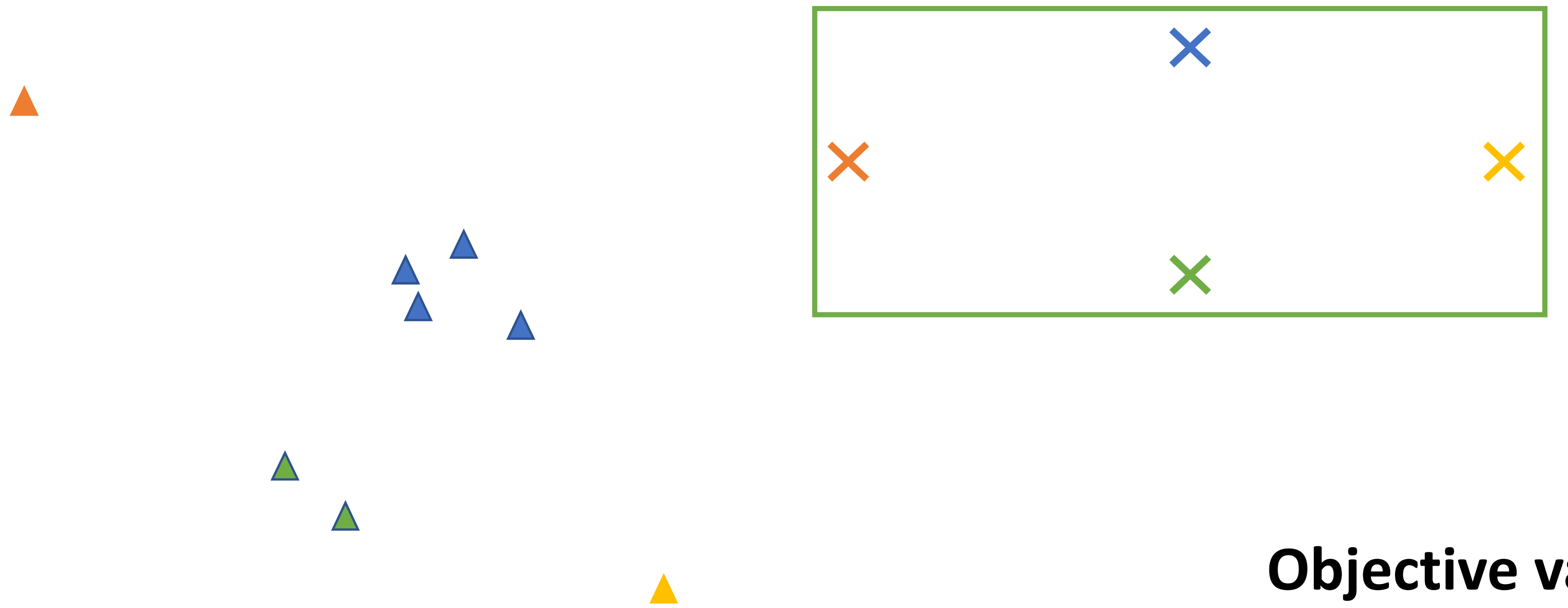
Correction 5: Rectangle Optimizer





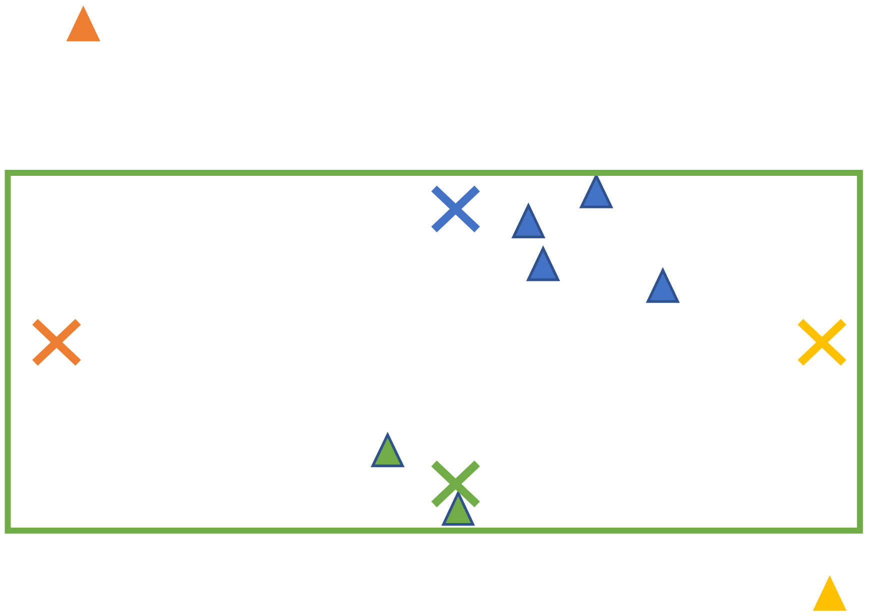
Objective value = 1000

Correction 5: Rectangle Optimizer



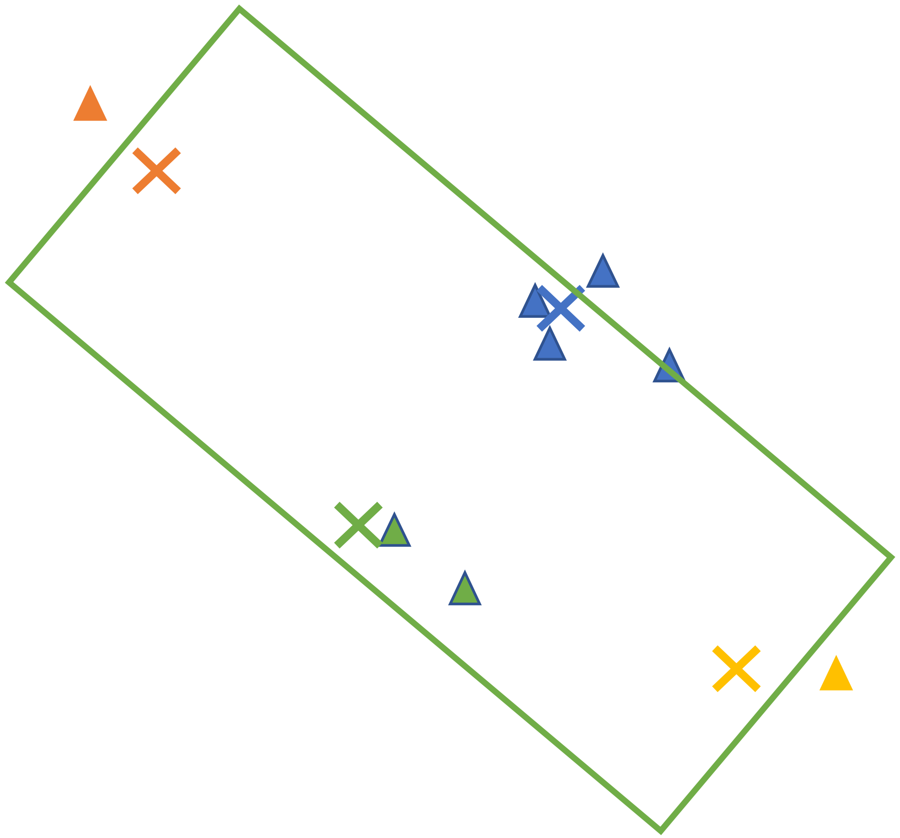
Objective value = 10

Correction 5: Rectangle Optimizer



Objective value = 1

Correction 5: Rectangle Optimizer



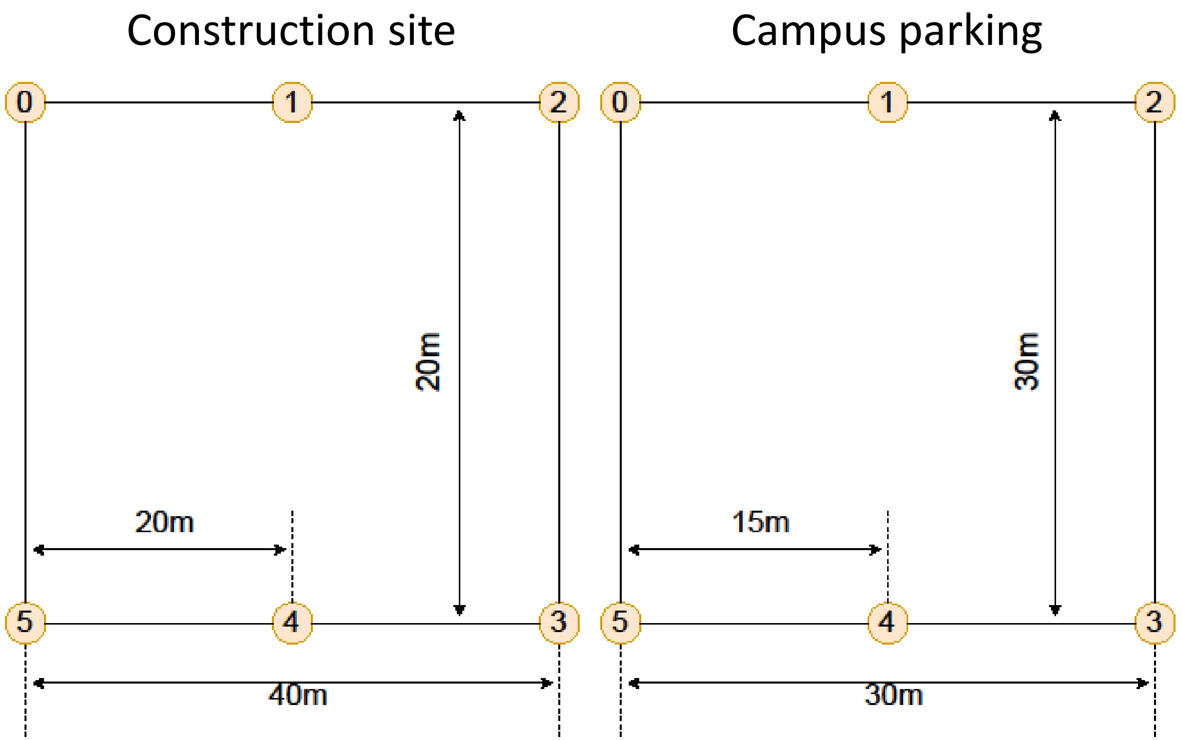
Objective value = 0.05
Residual value = 0.05

ViPER
Vehicle Pose Estimation using UWB Radios

- Introduction
- Challenges
- Related work
- Design
- **Evaluation**
- Conclusion

Evaluation setup and metrics

- Environment setup
  - Campus parking lot
    - Line of sight environment
    - No object blocking the signal
  - Road construction site
    - Objects causing NLoS conditions
- Evaluation metrics
  - Location availability
  - Error rate



Anchor placement

Results (location availability)

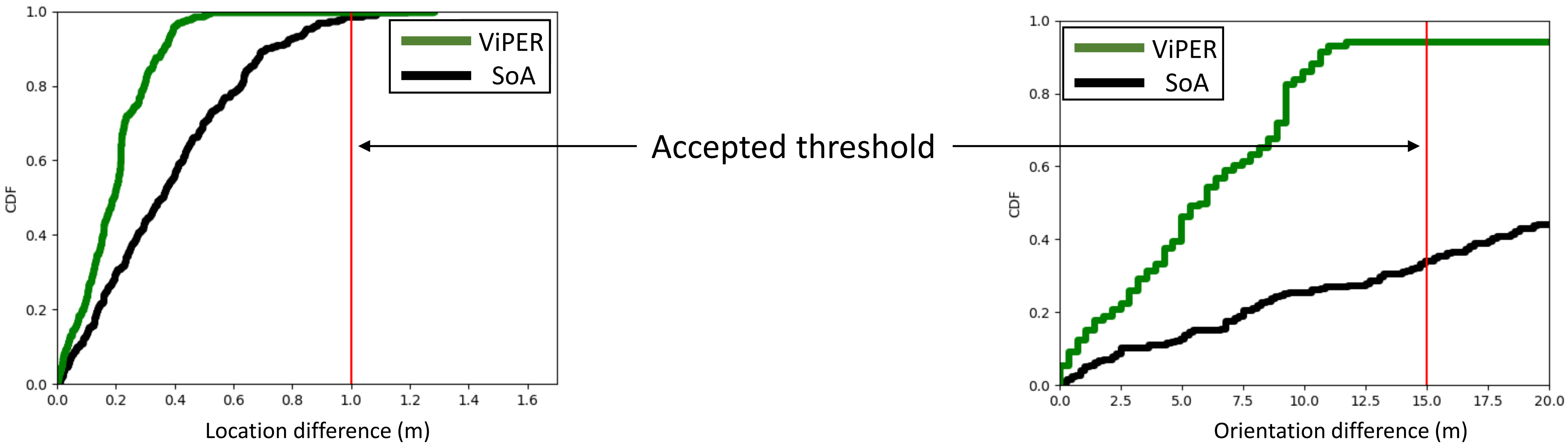
	SOA	ViPER
Construction site	46%	100%
Parking lot	94%	98%

Anchor and reference selection increased the location availability by 117%

Results (error rate)

CDF of difference in location and orientation estimate compared to the ground truth

Differences higher than the accepted threshold is considered as error in our application



Rectangle optimization was able to reduce the error rate by 90%

Limitations

- Number of tags
  - Time division medium access approach
  - Based on the update rate of the tag
    - $Num\ of\ slots = Update\ rate\ * Num\ of\ tags$
  - Currently supports 40 tags with update rate of 4
- Robustness
  - Decrease in accuracy
  - One or more anchors stop sending signal for a long time
  - Average 2-10% drop in accuracy for each tag removed

ViPER
Vehicle Pose Estimation using UWB Radios

- Introduction
- Challenges
- Design
- Evaluation
- **Conclusion**

Conclusions

- Pose estimation system
  - Monitor the safety in construction site environment more accurately
- Improvements
  - Location reception ratio and error rate
- Methods
  - Correcting or removing inaccuracy in TDoA inputs
  - Rectangle optimization to enhance boundary estimation

Contact: aansarip@cougarnet.uh.edu