Accurate Signal Timing from High Frequency Streaming Data

Jonathan Wang[1], Alex Sim[2], K. John Wu[2], Seongwook Hwangbo[3]

[1]Rice University, [2]Lawrence Berkeley National Laboratory, [3]Hyundai Electric & Energy Systems Co., Ltd.

RESEARCH GOAL

To analyze massive high-frequency streaming data to localize the coordinates of partial discharge events by identifying the signal arrival time in noisy data

BACKGROUND

- Insulation failure is the most common type of transformer breakdown
- **Partial Discharge (PD)**, an internal arcing event, is a symptom of insulation failure
- Induced PD at 2 locations: PD1 and PD2
- Streaming PD signal data
  - Collected by ultra-high frequency (UHF) sensors
  - 300 MHz – 1 GHz frequency
  - 0.4 ns per data point, 12 GB per sec
  - 4 channels per sample (4 sensors)
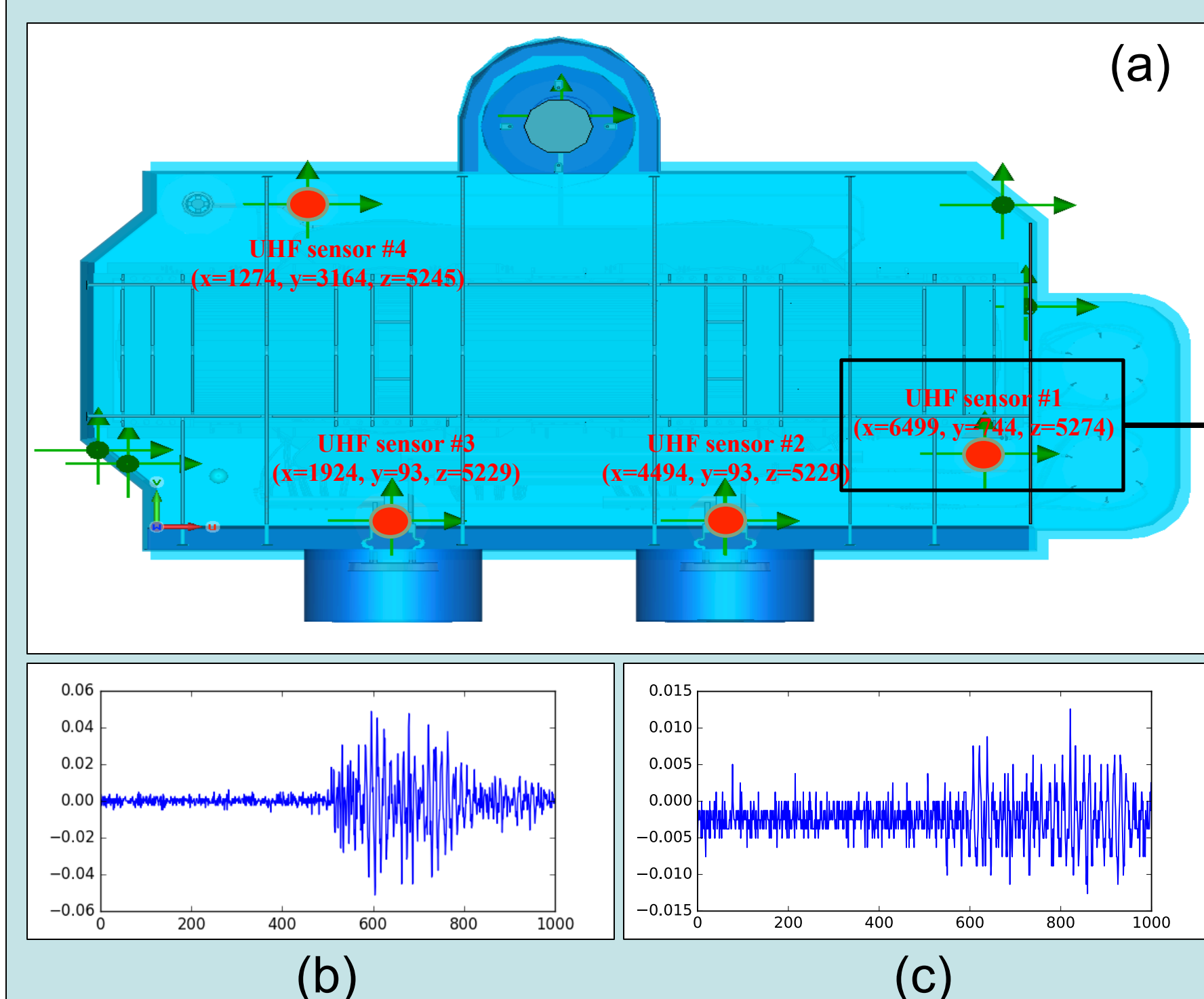- **Challenge: Use PD voltage data to locate source of PD**

Figure 1: (a) Transformer UHF sensor diagram. (b) Relatively easy to distinguish signal arrival in low noise data (c) but much harder in high noise data where signal arrival is obscured by noise.

SIGNAL TIMING

- Distinguish signal from noise
  - Difficult with low signal-to-noise ratio
- **Savitzky-Golay Filter with Refinement**
  - Filter noisy data by convolution to improve signal-to-noise ratio (SNR)
  - Preserves features better than other filters
  - Determine window of signal arrival
  - Refine window with moving average
  - Define threshold based on noise

METHOD OVERVIEW

(a) Detect PD in streaming data from UHF sensors by voltage threshold. Collect 500 points (200 ns) before and after for 1000 point (400 ns) signal sample.

(b) Compute signal timings and predict PD location.

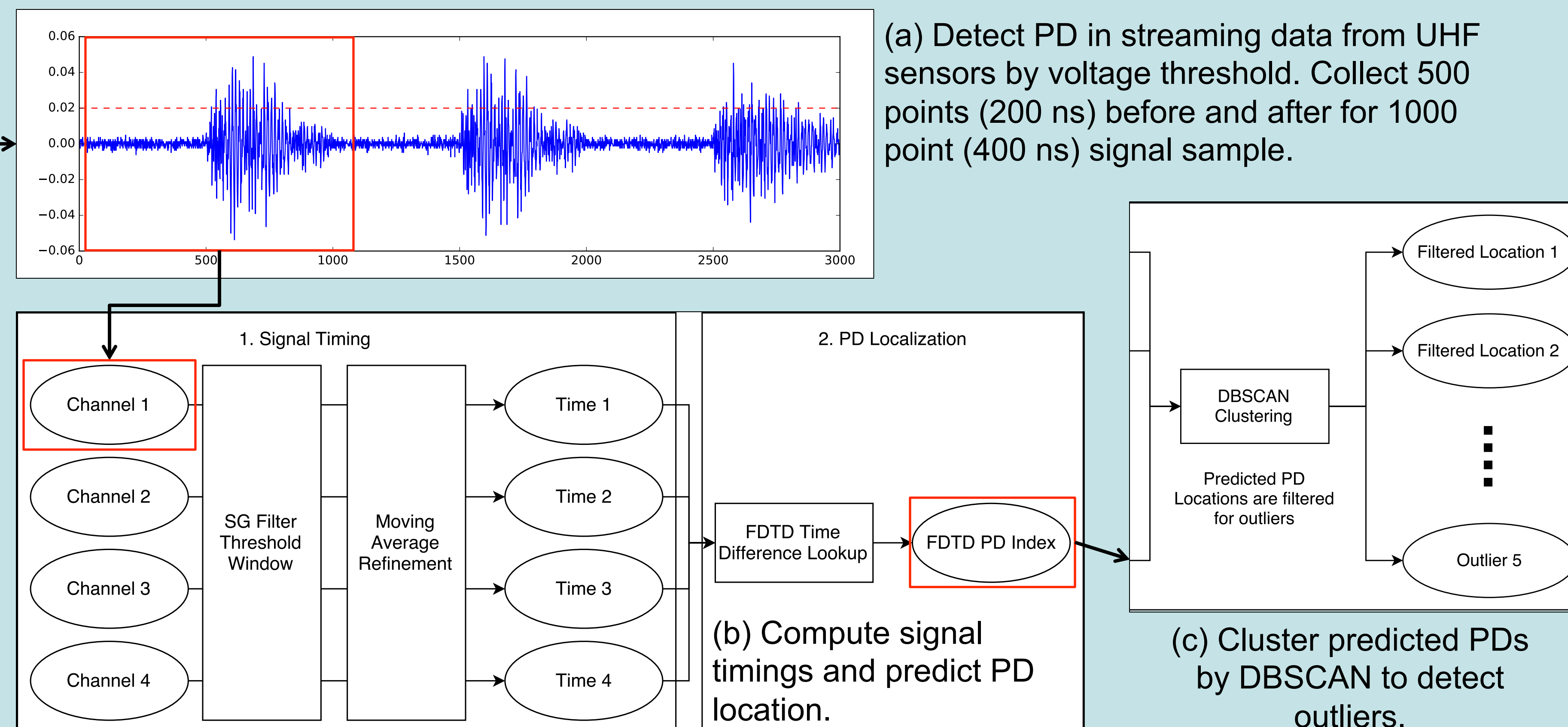(c) Cluster predicted PDs by DBSCAN to detect outliers.

Figure 2: (a) Obtain PD signal sample from streaming data. (b) *For Signal Timing*: de-noise data with Savitzky-Golay Filter and find arrival window using threshold. Refine window with moving average and threshold to obtain arrival time. *For PD Localization*: use 4 signal arrival times to lookup closest FDTD index. (c) Remove outliers from set of all samples.
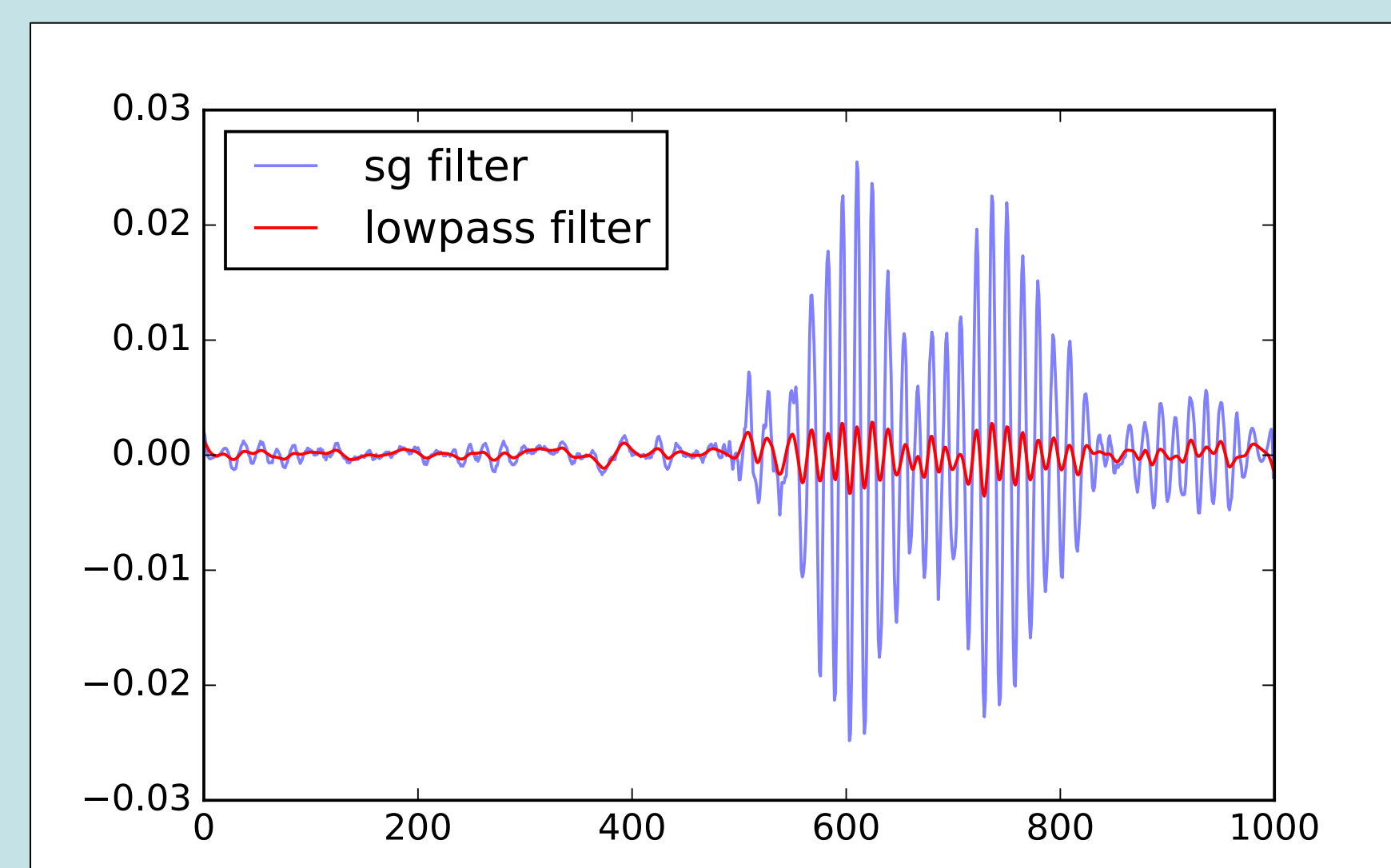
RESULTS

Figure 3: In low noise data, the Savitzky-Golay Filter (SG Filter) results in a significantly higher signal-to-noise ratio (SNR) than the lowpass filter, making signal detection trivial.
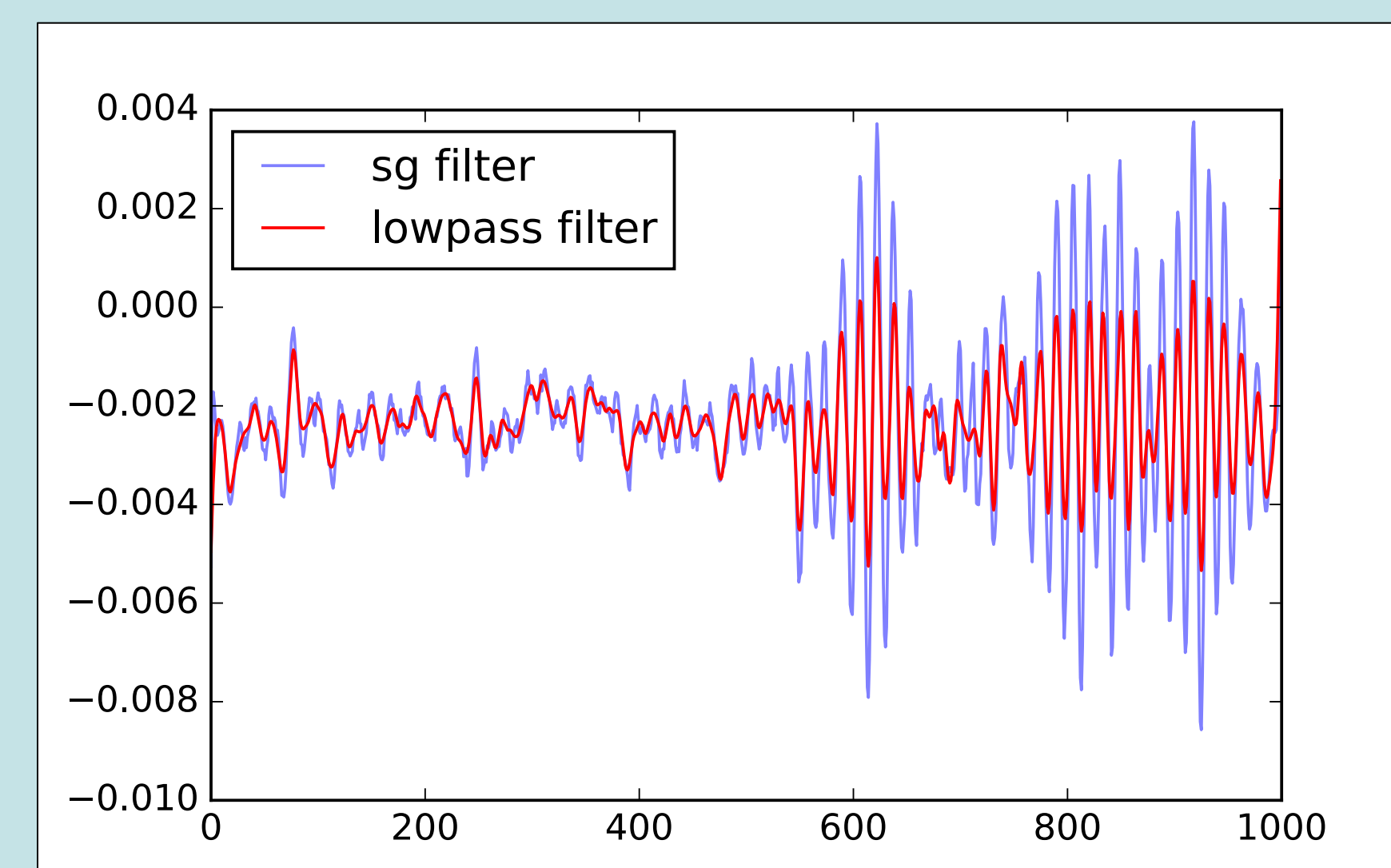

Figure 4: SG Filter results in 2x the SNR of lowpass filter even in high noise data, making thresholds viable for signal detection.
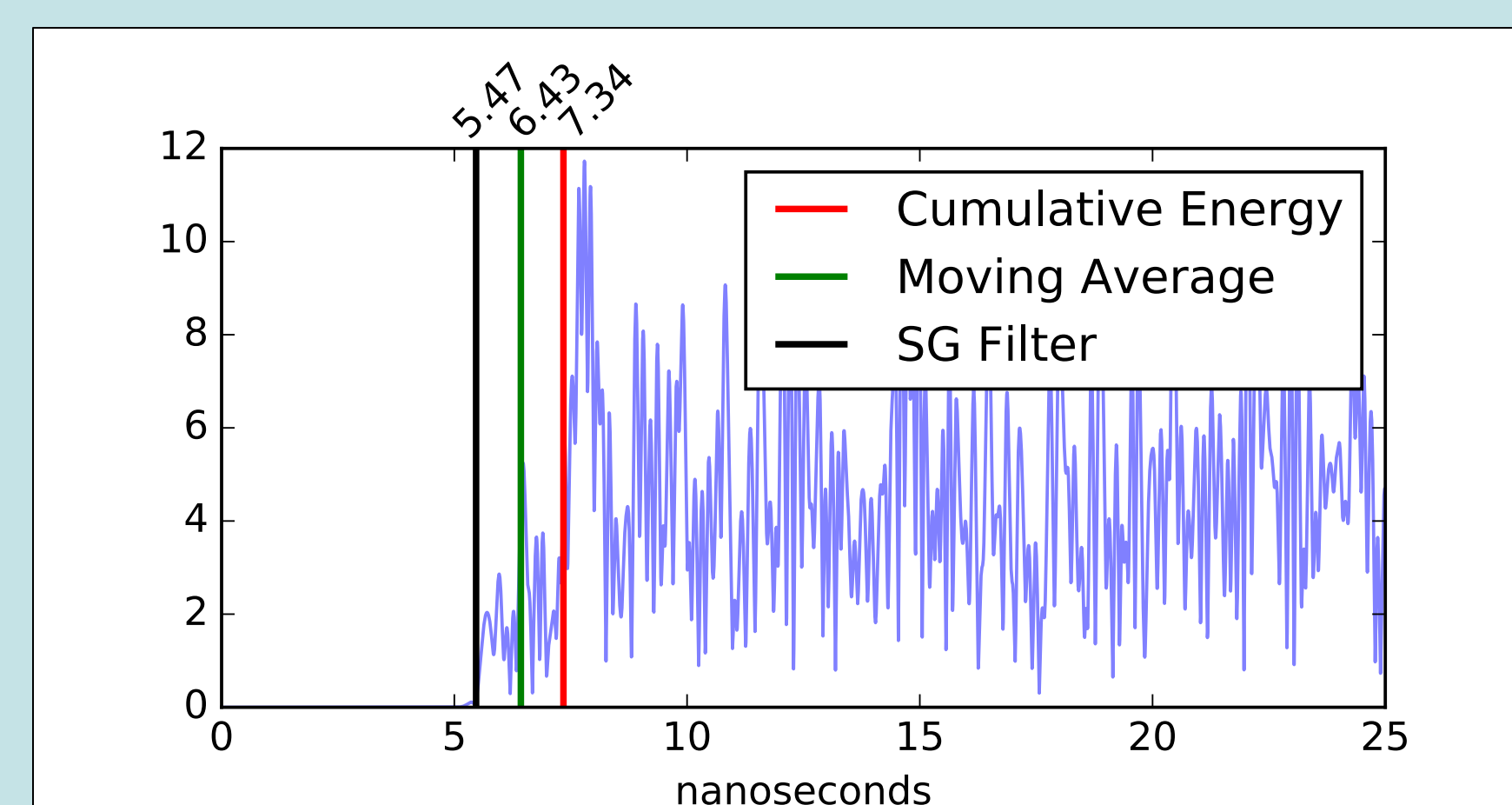

Figure 5: SG Filter signal timing method identifies signal arrival time 2 ns (0.5 m) closer than cumulative energy, the current timing method. The signal arrival is where the signal becomes non-zero.
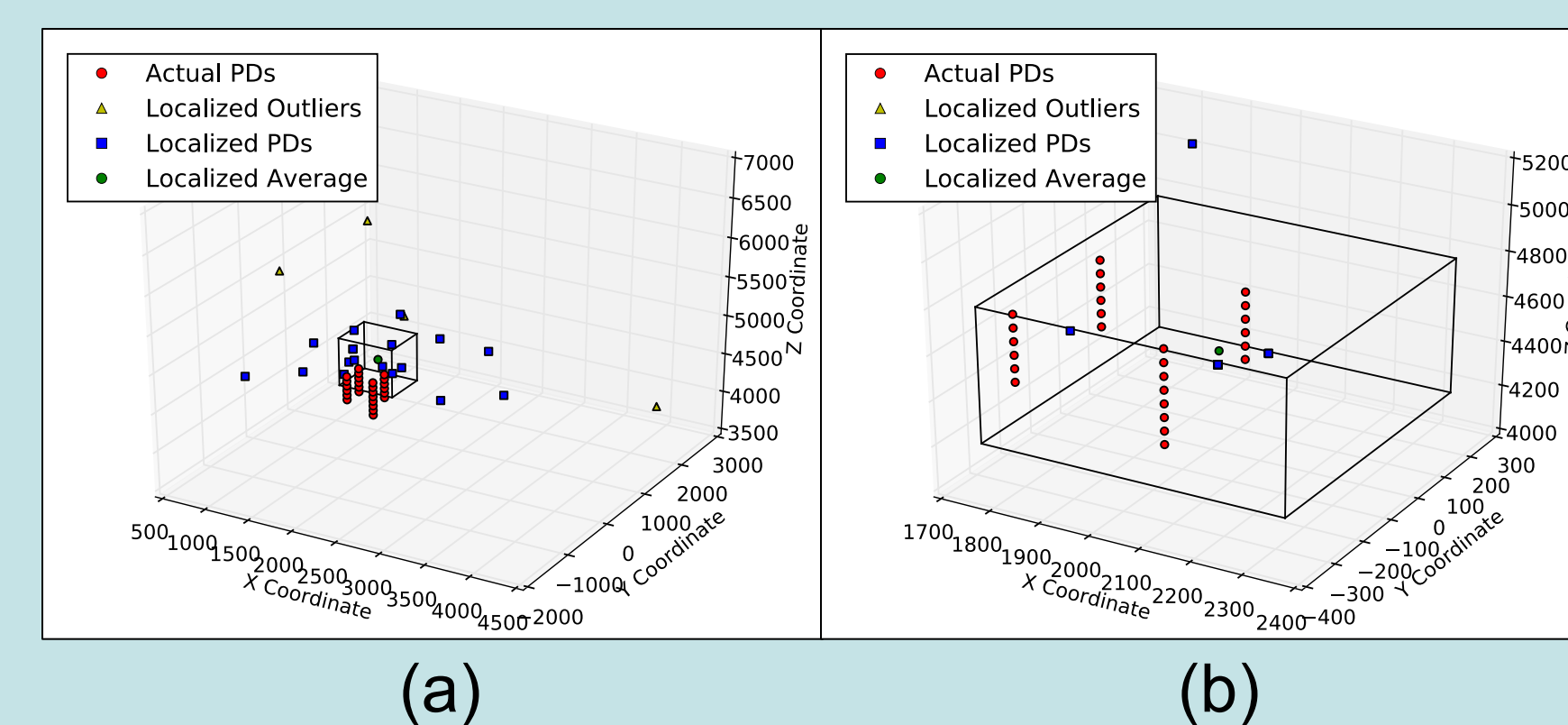

Figure 6: Using SG Filter signal timing method, (a) localization results with multilateration are scattered and far from actual PDs with only 33% accuracy for the above case. (b) Localization with FDTD has 95% accuracy and is much more consistent.

PD LOCALIZATION

- Use signal arrival times to find PD location
- Multilateration
  - Solve 4 quadratic equations for x, y, z, t
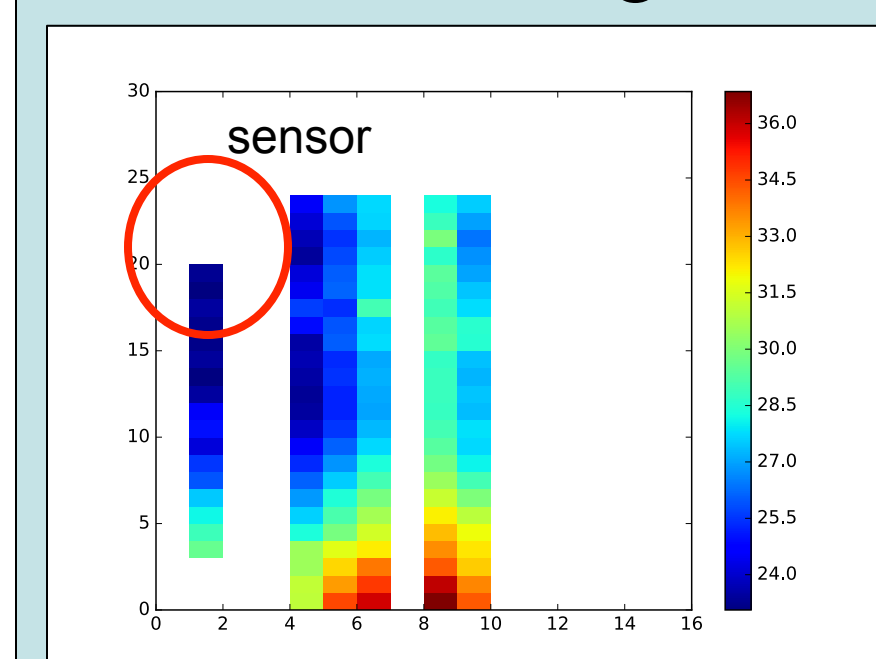 - Assumes signals travel in straight line

Figure 7: Times for signal to reach sensor (in upper left corner). PD signals do not travel in straight lines due to transformer internal structure.

- FDTD Lookup
  - Divide transformer into 30 cm cubes
  - Simulate propagation of PD signal from each index to each sensor
  - Record timings in lookup table
  - Find FDTD index with minimum time error

$$\arg\min_k \sqrt{\sum_{i\in\{1,3,4\}} (TD_{i,2} - PD_{i,2}^{(k)})^2}$$

- Validation: Simulate PD at each FDTD index
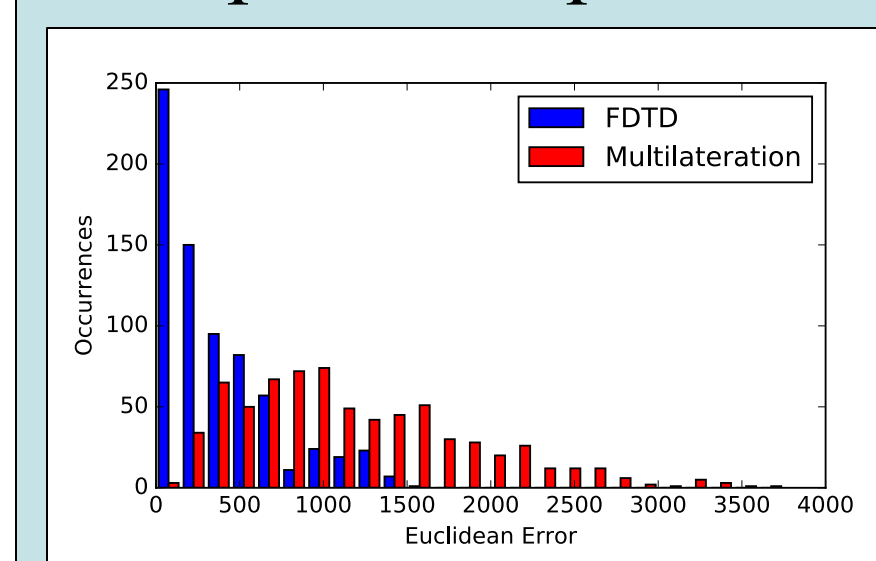 - Find distance between simulated point and predicted point

Figure 8: FDTD lookup has a much lower error distribution than multilateration indicating closer predicted PDs.

CONCLUSION

- Savitzky-Golay filter method with refinement + FDTD lookup
- **2 ns** timing improvement ≈ **0.5 m**
- Localization improvement with SG Filter (using FDTD)
  - From **91% to 95%** in PD1 case (high signal-to-noise ratio)
  - From **13% to 48%** in PD2 case (low signal-to-noise ratio)

ACKNOWLEDGMENTS

CONTACT

- Jonathan Wang
- Rice University
- Email: jw96@rice.edu