Robust 3D Sensor Cloud Localization from Ultrasound Range Measurements

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Where innovation starts

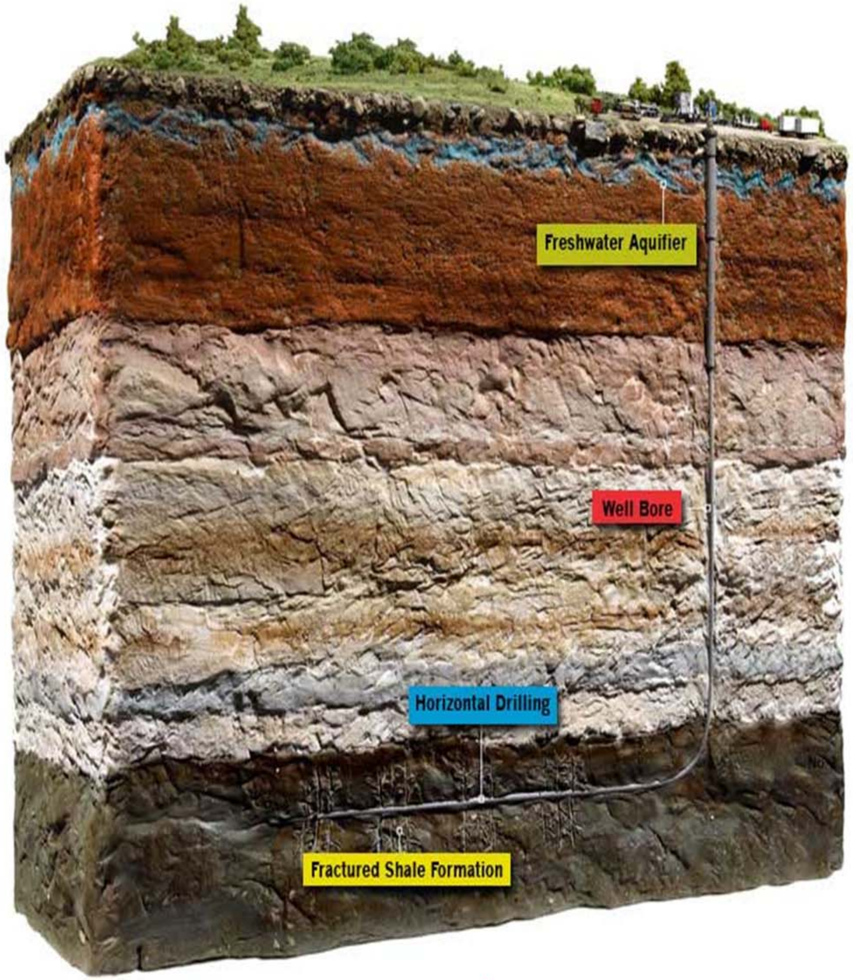
Introduction

- Application context:
  - 3D mapping of underground structures
- Current solutions
- Our approach:
  - Miniaturized sensor clouds
  - Simultaneous Localization And Mapping (SLAM)
- Simulation results
- Future work
- Questions

3D Mapping of Underground Structures

Problem statement:

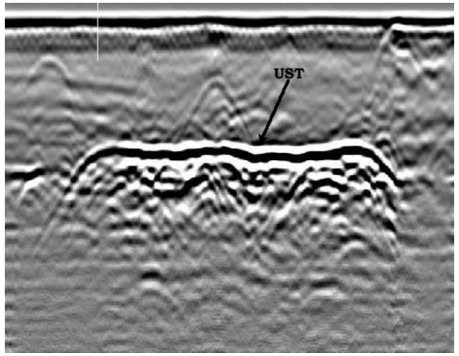
- **3D mapping of underground structures**
  - **oil wells**
  - **pipes**
- **Filled with liquid medium**
- **Globally big but locally small**



Current solutions

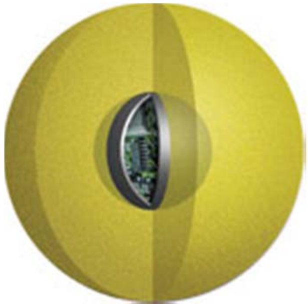
From surface:

- **Reflection seismology**
- **Ground penetrating RADAR**



Underground:

- **Sensor probes**
    - **SmartBall (Pure Technologies)**



- **Robots**
    - **Explorer (CMU-NREC)**

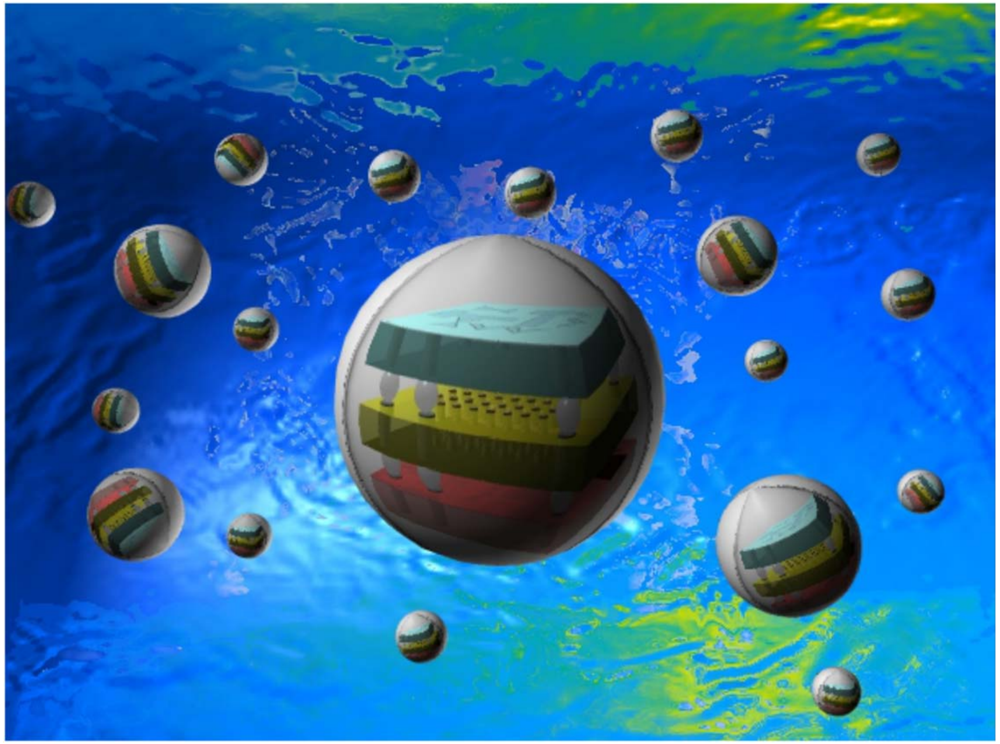
Cloud of miniaturized sensor platforms

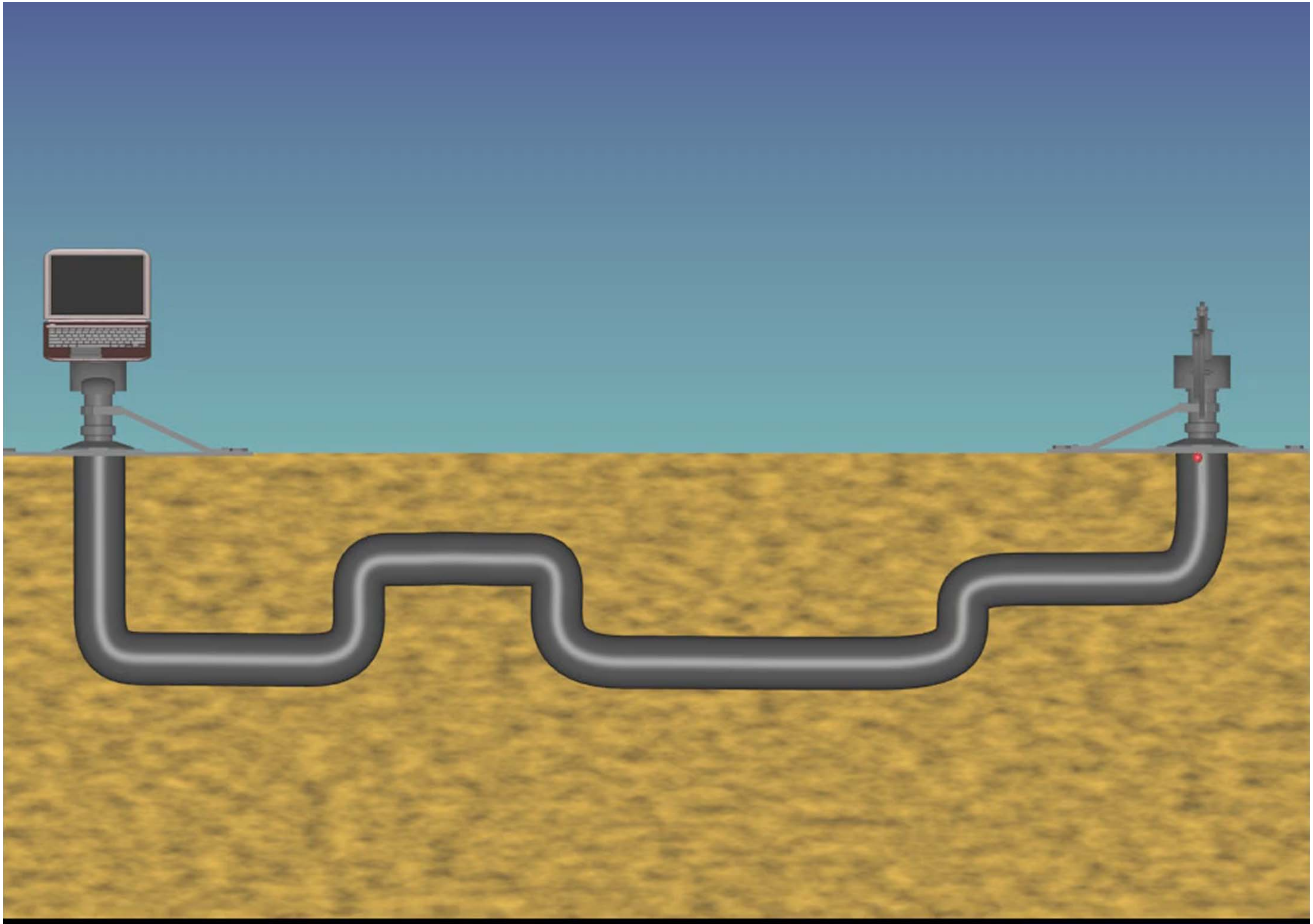
Approach:

- **Massive sensor cloud**
- **Reconstruct sensor cloud shape**

Localization required:

- **No GPS, beacons, etc.**
- **Limited size = limited capabilities**
  - **Ultra-sound ranging**

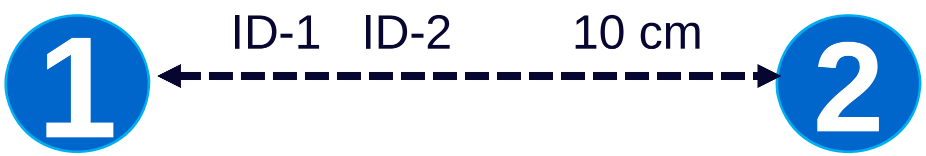




Ultrasound range measurements

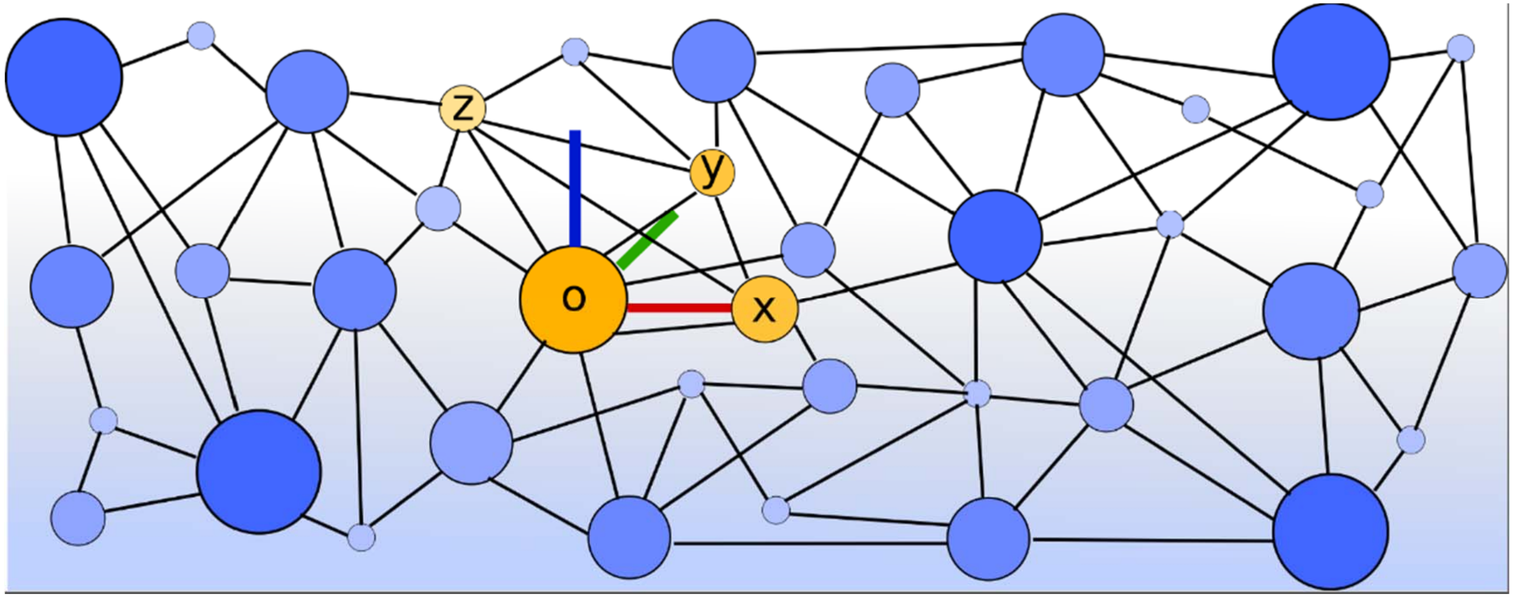
- **Goal**
  - **visualize application specific sensor data in 3D**
  - **estimate 3D shape of environment**
  - **estimate 3D locations of motes**

- **Mote-to-mote ultrasound range measurements**
- **ID of motes encoded in ultrasound signal**
- **After retrieving the motes:**
  - **ID ID Range**
  - **ID ID Range**
  - **ID ID Range**



Simultaneous localization and mapping

- **Pose-graph simultaneous localization and mapping**



- **Challenges**
  - **obtaining an initial solution**
  - **be robust to corrupted data**

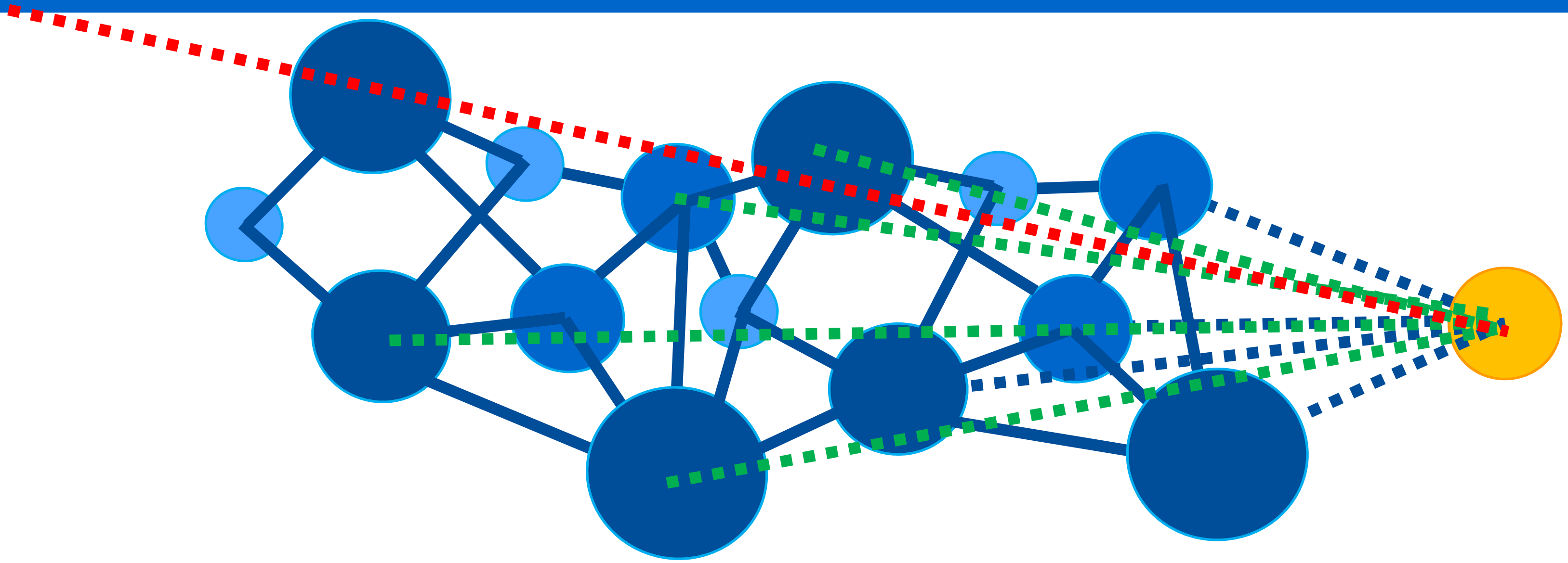
Estimating 3D locations of motes

- **Select stable seed of 4 motes**
  - **construct 3D coordinate system**

- **Non-alternating approach**
  1. **try to add all motes with Random Sample Consensus**
  2. **globally optimize graph using Gauss-Newton**

- **Alternating approach**
  1. **locally add *N* motes with Random Sample Consensus**
  2. **globally optimize graph using Gauss-Newton**
  3. **Go back to 1**

RANdom Sample Consensus (RANSAC)



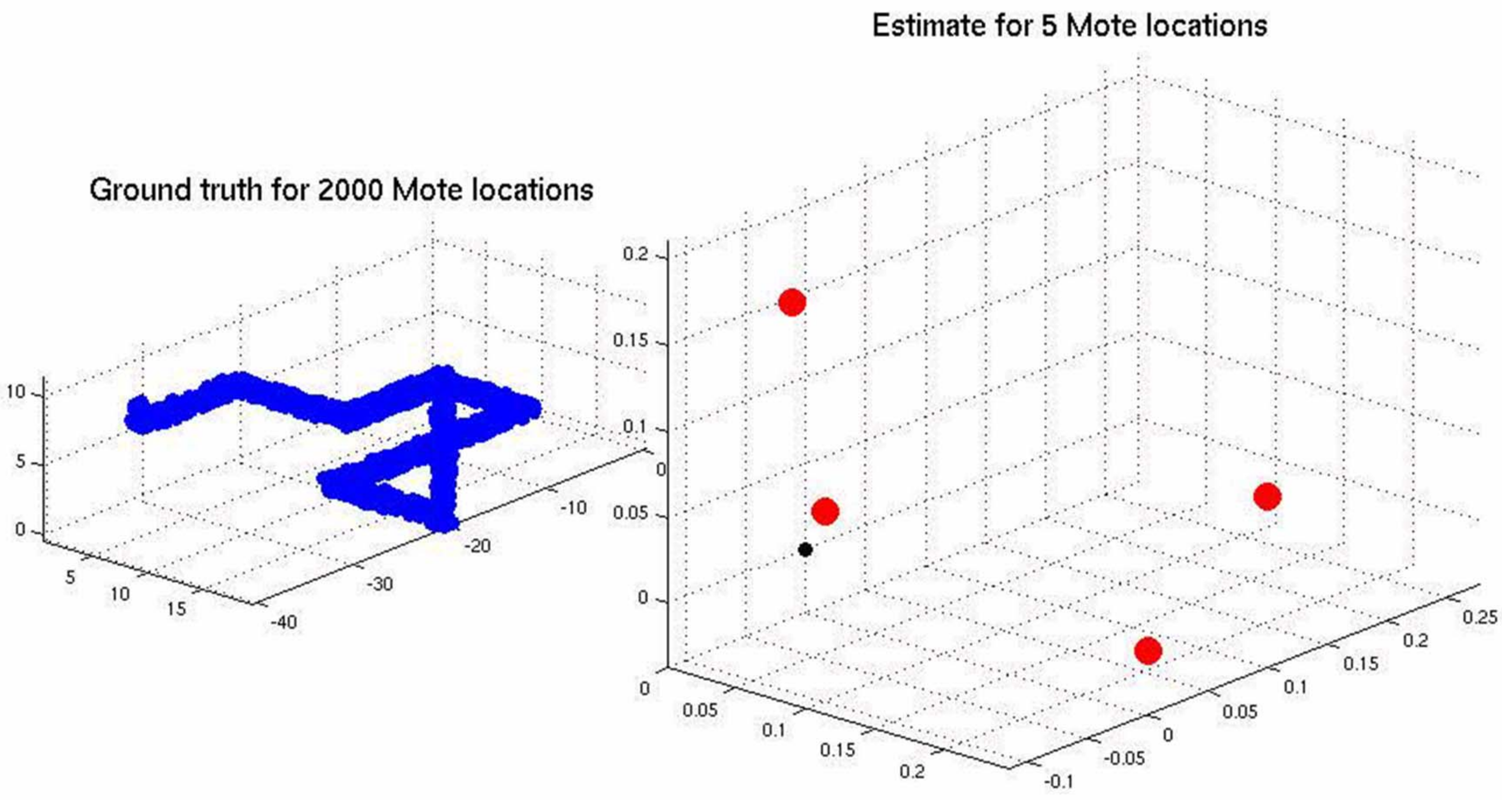
RANSAC

1. **Randomly select new mote that sees cloud**
2. **Reconstruct mote location using 4 random measurements**
3. **Determine *inliers*/*outliers* using all other measurements**
4. **Go back to 1 for *N* times**
5. **Select mote that has most *inliers***

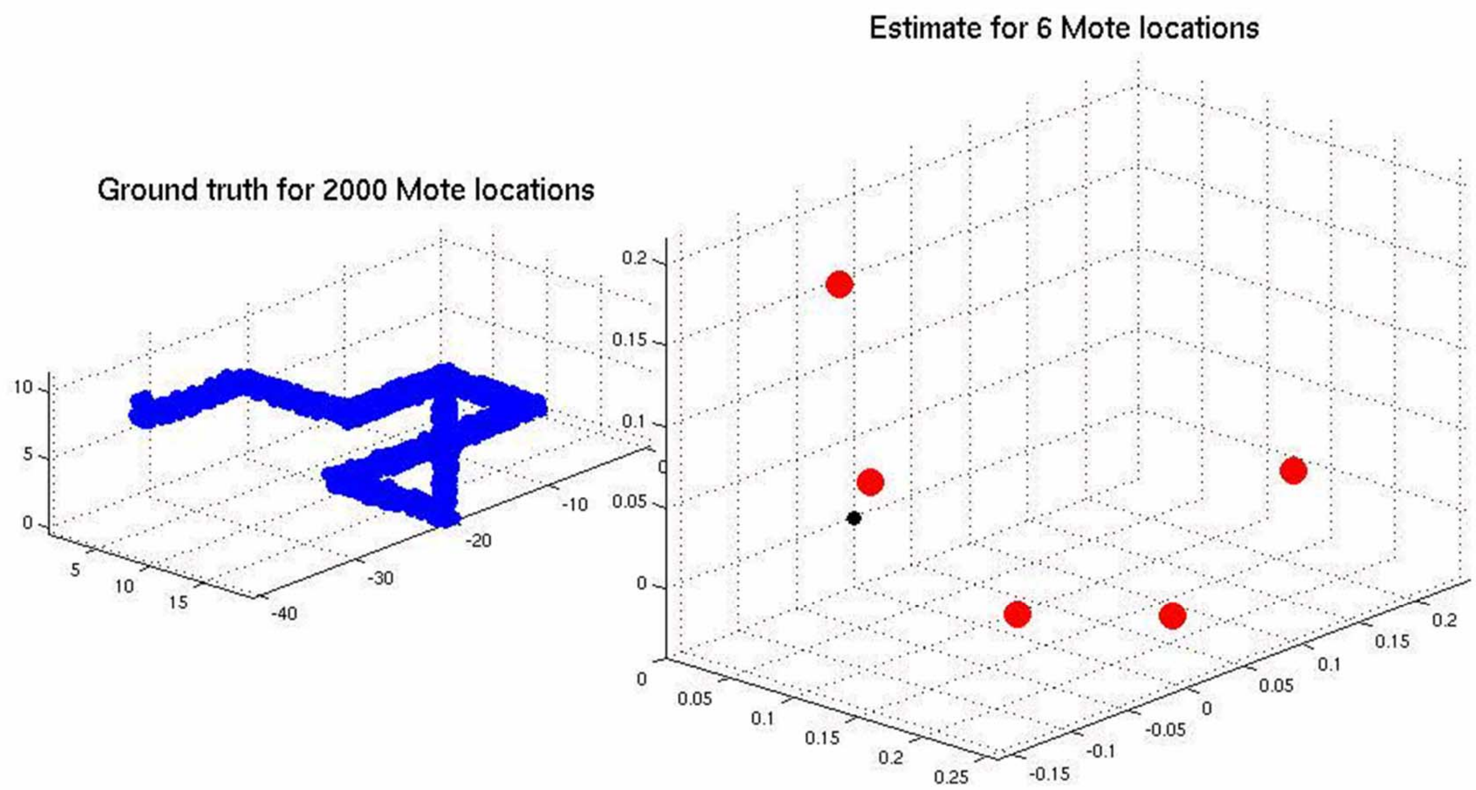
Experiments

- **Simulation of 2000 motes (100X)**
- **Parameters**
  - **mote density**
  - **sensor range of motes**
  - **range-dependent Gaussian noise**
  - **percentage of outliers, i.e. corrupted measurements**
- **Goal**
  - **derive minimal requirements on mote density and sensor range given noise and outliers characteristics**
  - **guide hardware development of mote prototypes**

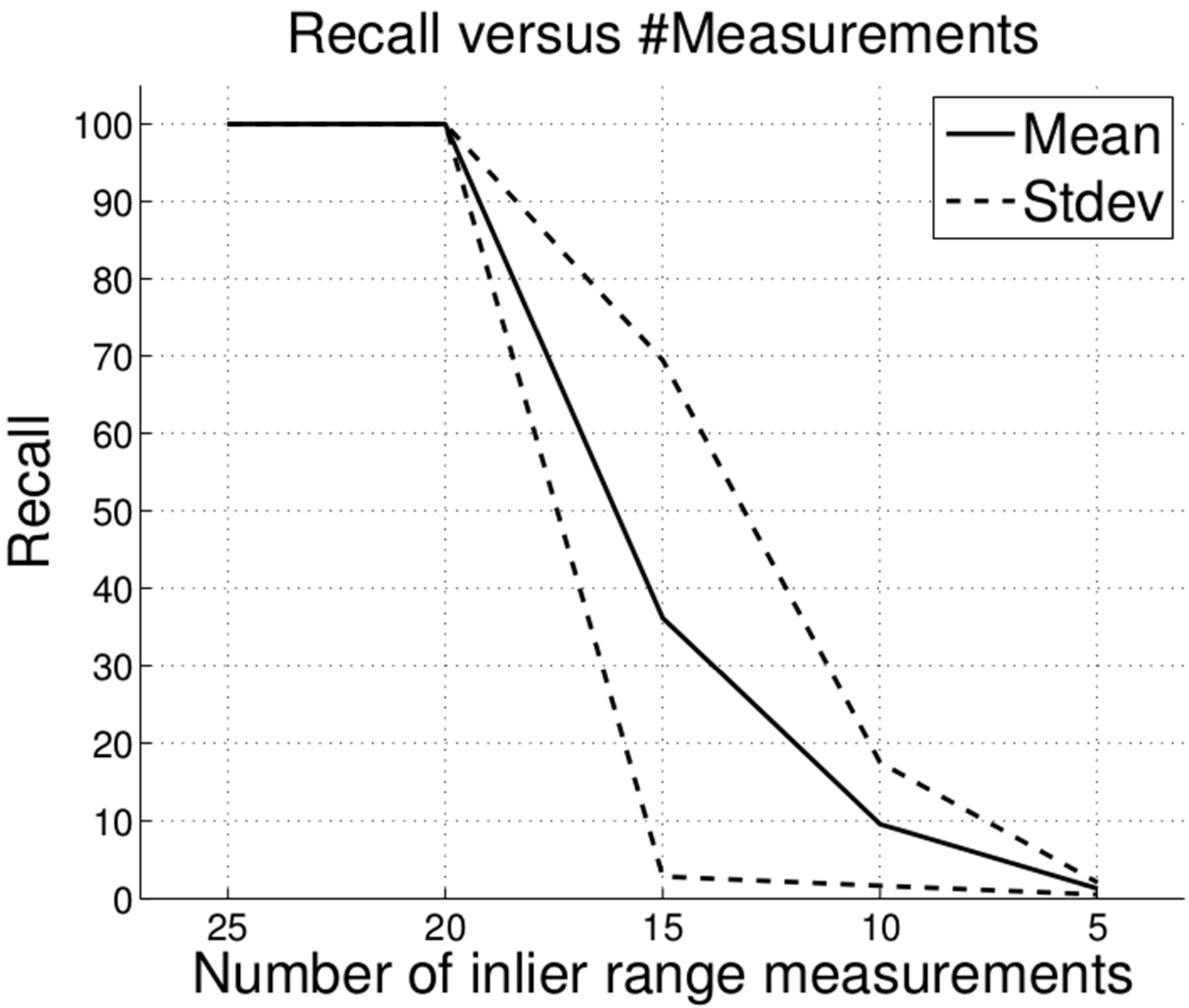
Results non-alternating



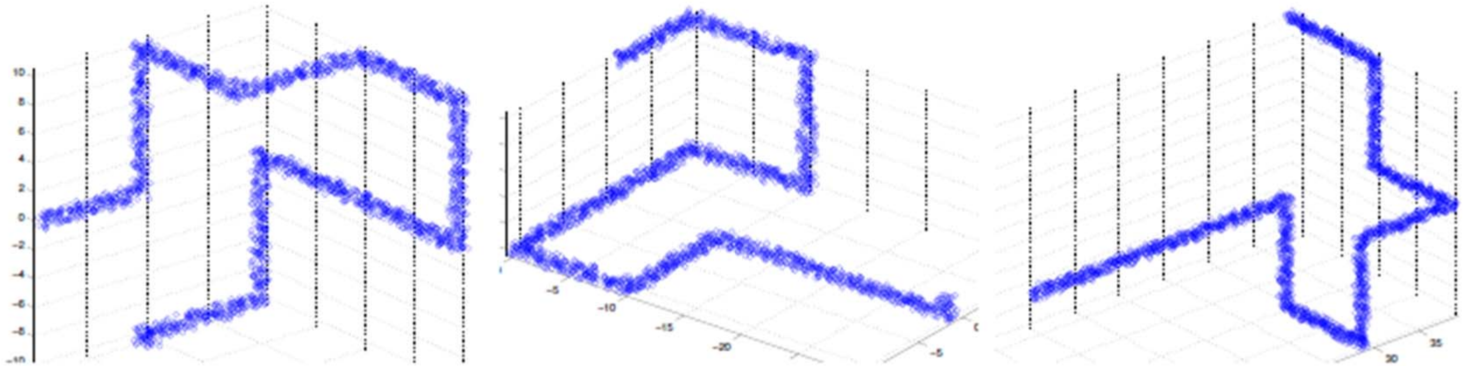
Results alternating



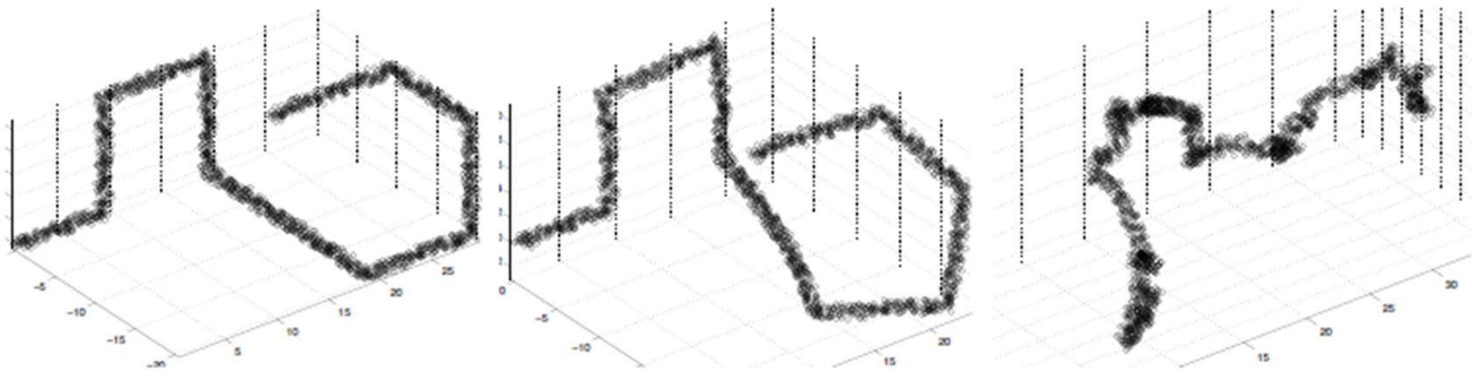
Results *Recall*



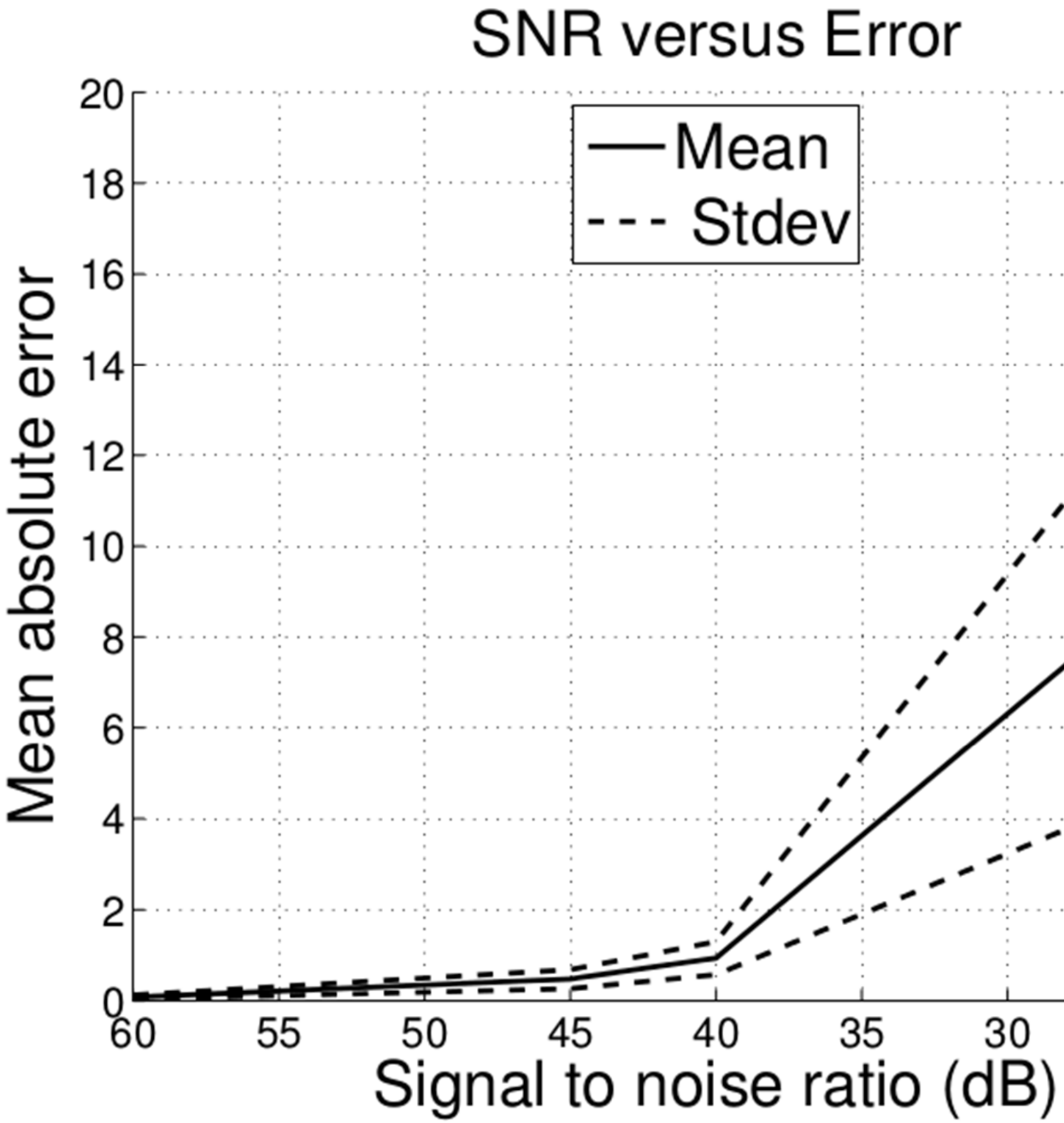
Results *Precision qualitative*



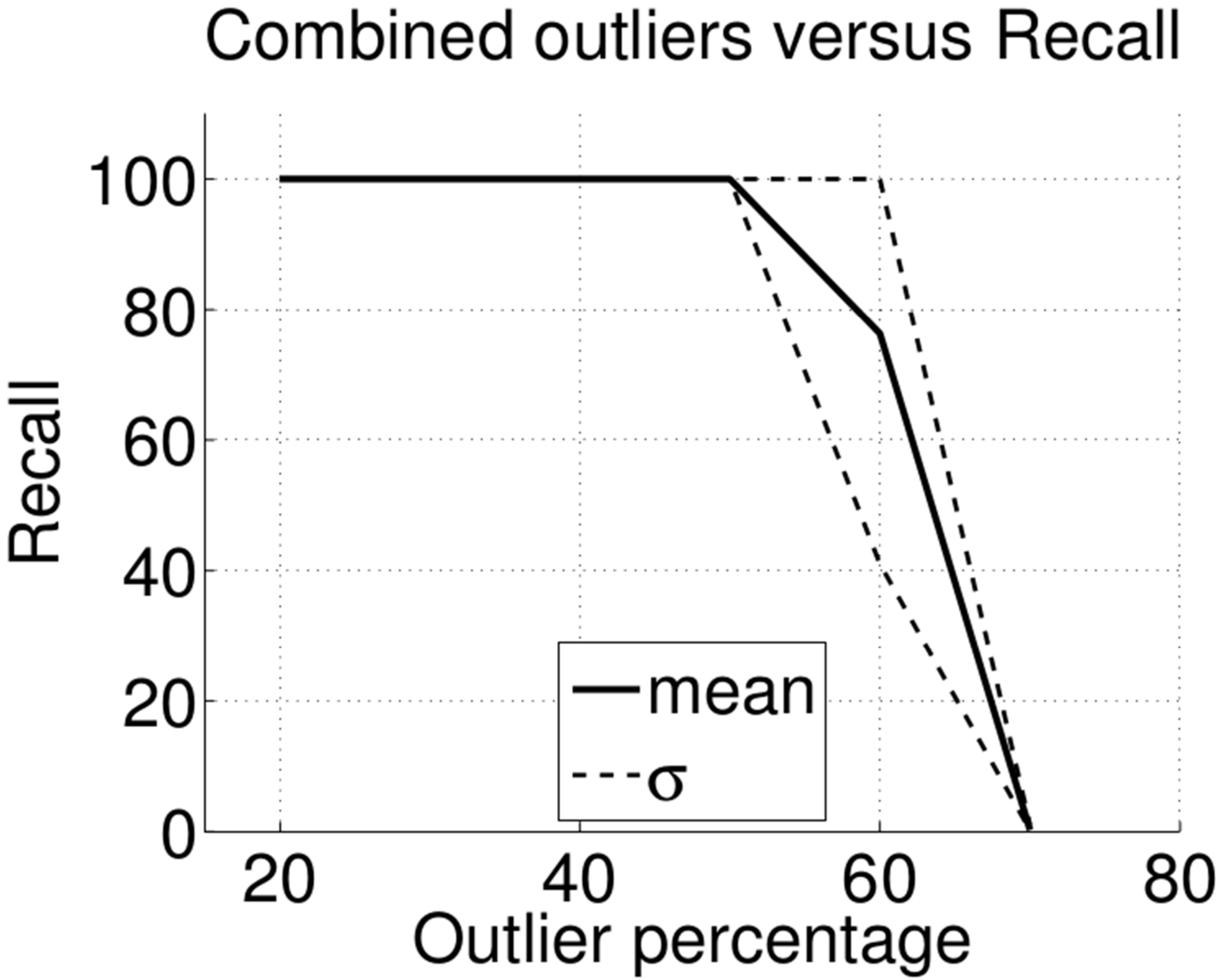
SNR 40 dB SNR 30 dB SNR 20 dB



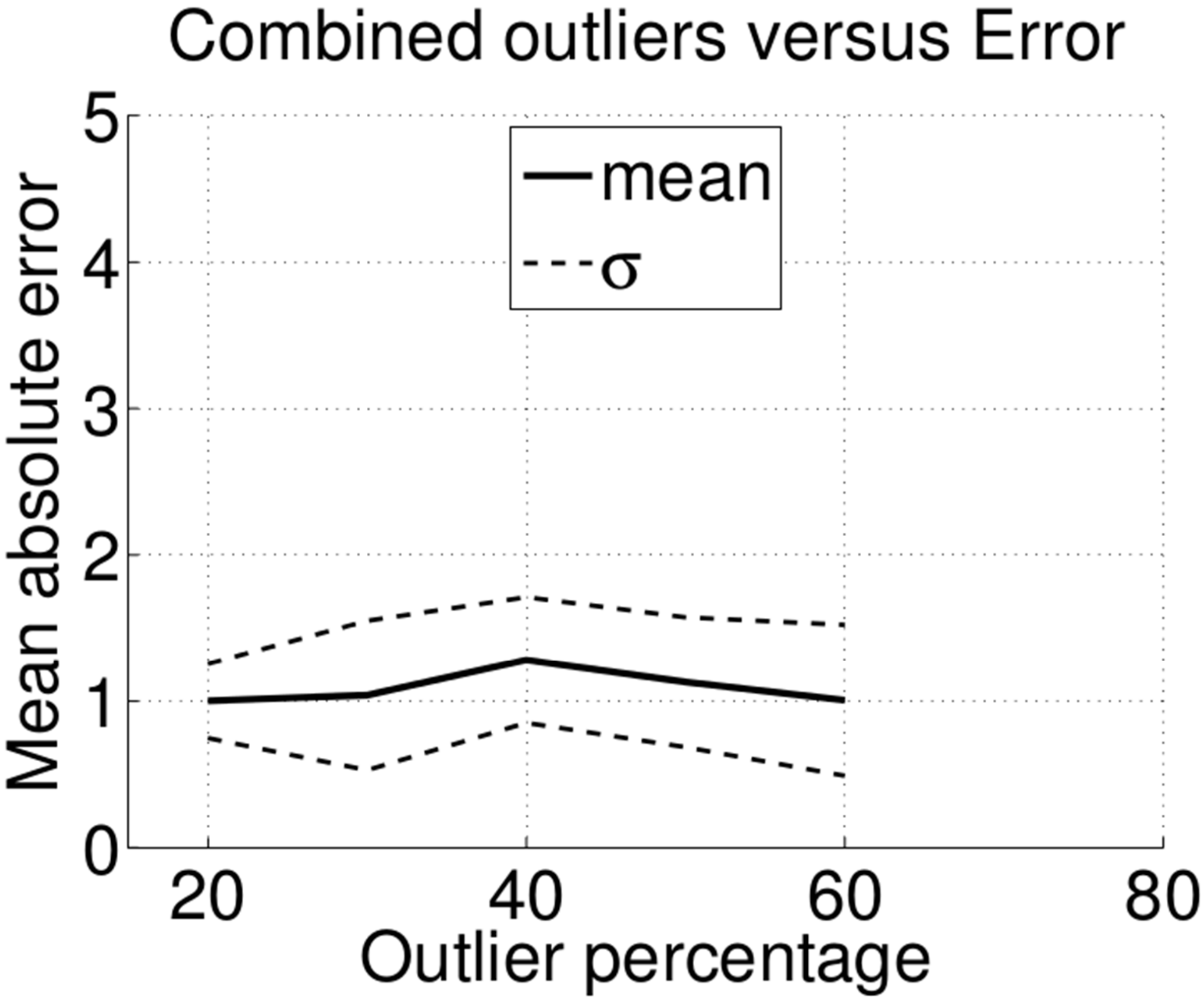
Results *Precision quantitative*



Results *Robustness recall*

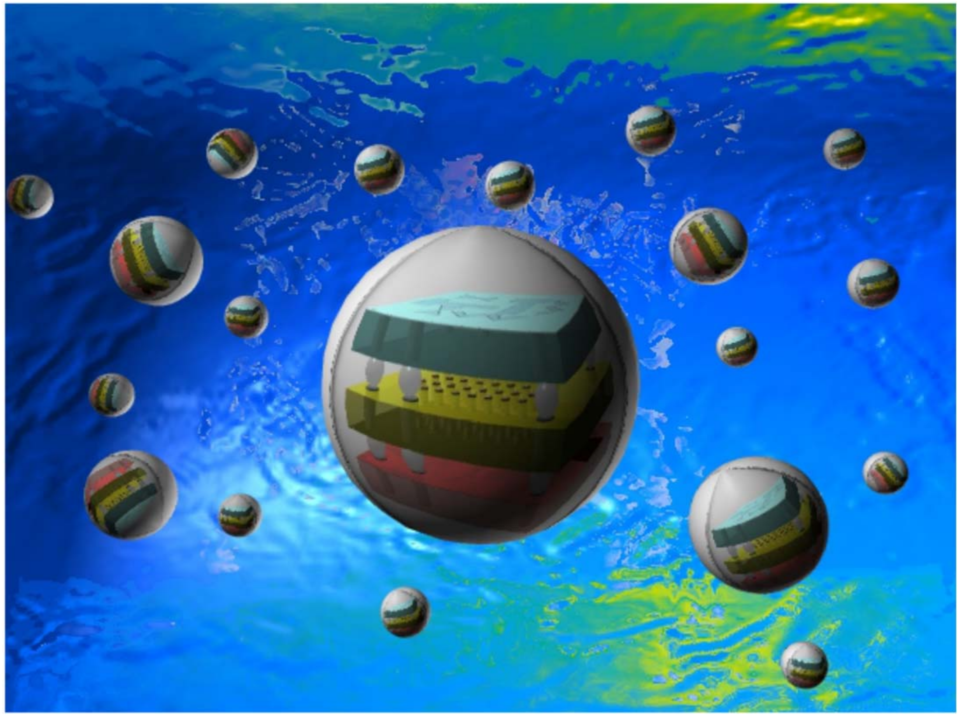


Results *Robustness precision*



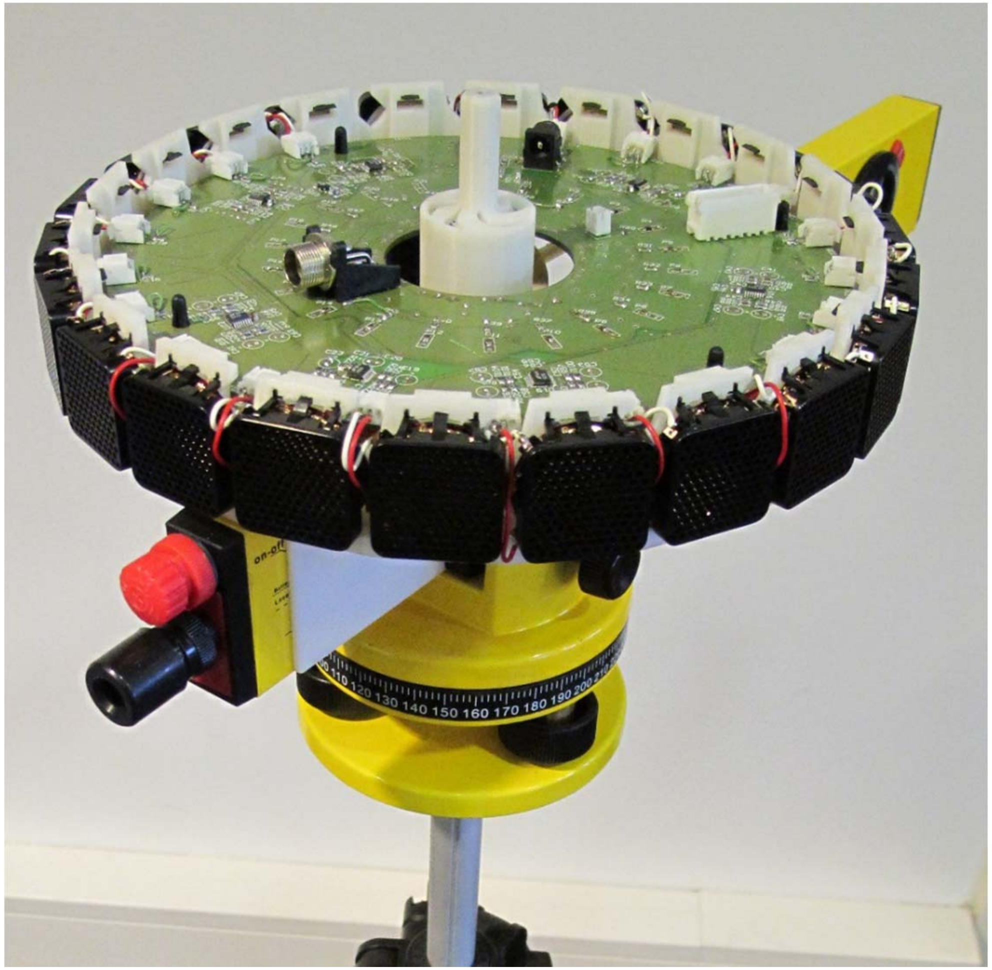
Conclusions

- **3D sensor cloud localization is feasible**
  - **without using beacons**
  - **under achievable noise characteristics**
  - **as long as sufficient inlier range measurements are available**



Future work

- **Hardware development**
- **Working with non-unique IDs**



Questions

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[1] Robust Sensor Cloud Localization from Range Measurements", IEEE/RSJ Intelligent Robots and Systems conference, Sept. 14-18, Chicago, 2014.