Defence Research and Development Canada
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Automated front wall feature extraction and material assessment using fused LIDAR and through-wall radar imagery

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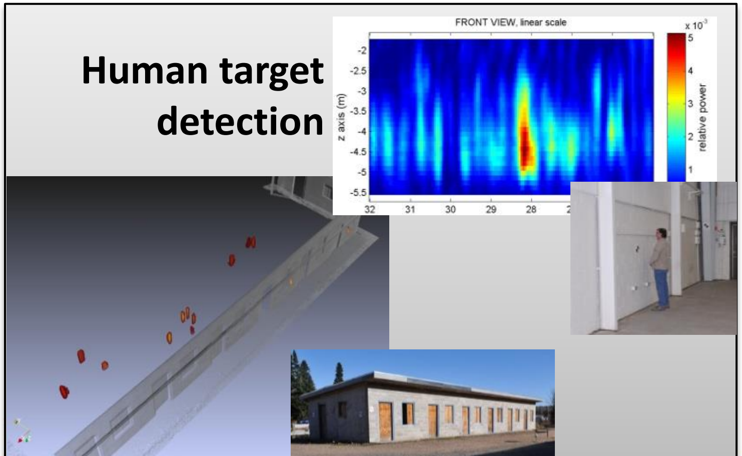
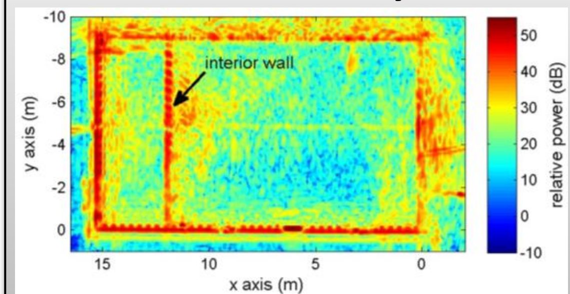
Through-wall synthetic aperture radar (TWSAR) and LIDAR

Main objectives

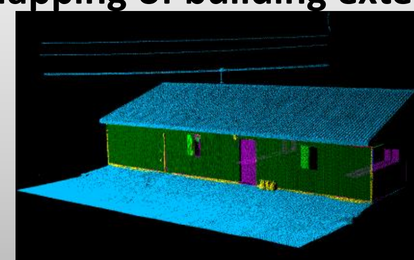
Human target detection



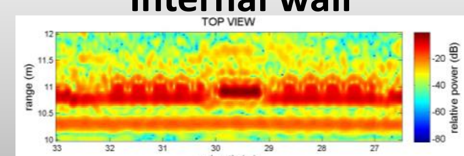
Interior room layout

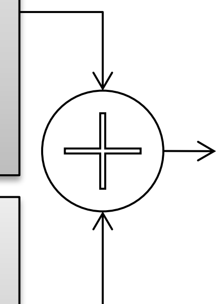


Mapping of building exterior



Internal wall

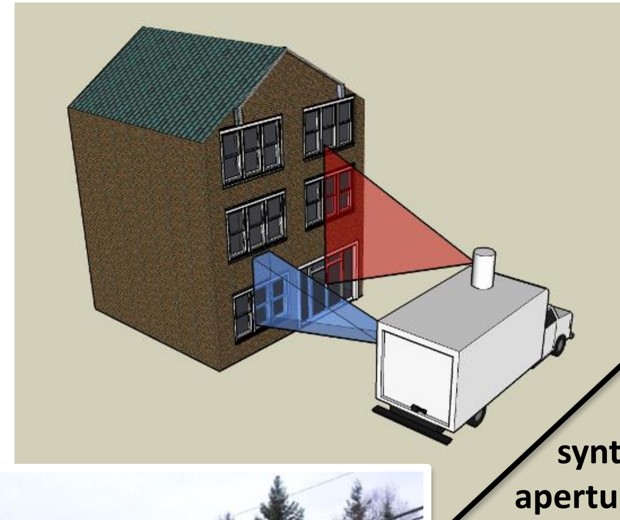




Can we provide information on wall material in an automated way?

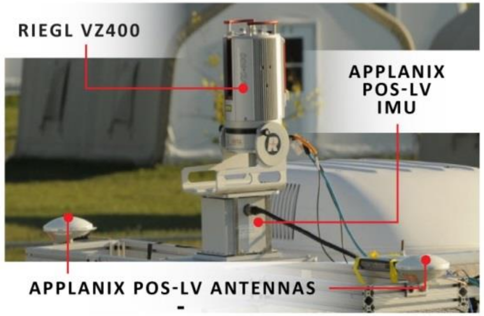
The concept of operation

- The vehicle-mounted system is driven in front of a building of interest
- Standoff distance: typically a few meters to 20 meters

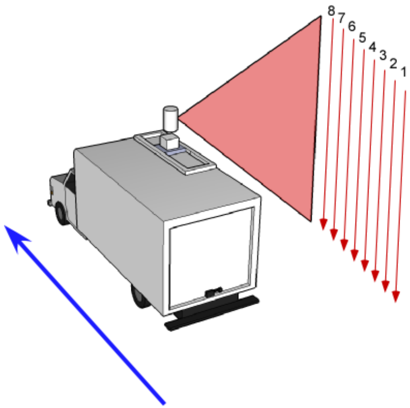


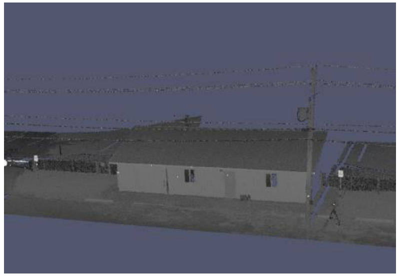
synthetic aperture radar (SAR) processing

LIDAR data processing



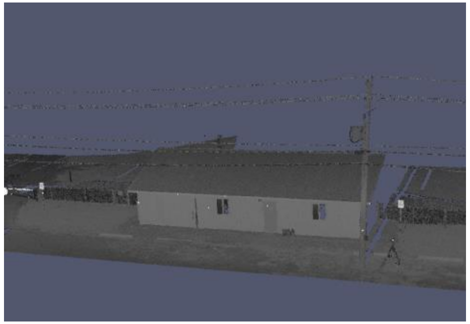
- LIDAR point cloud: Riegl VZ400 laser scanner
- Trajectory data: Applanix POS-LV geo-positioning system
- In the context of this work, the objectives of the point cloud processing are:
  - to automatically find wall planes
  - to determine the location of the solid wall, i.e. not openings or not obstructed by foreground objects

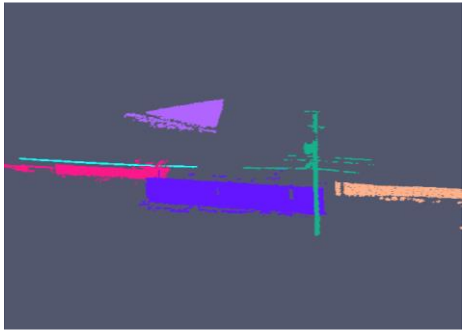




Extraction of wall planes

- Ground plane points are removed
  - Using optimized version of the random sample consensus (RANSAC) algorithm
    - A point is considered to be part of a plane if it meets two criteria:
      - its distance to the plane must be below a given threshold
      - its corresponding local normal vector must be aligned with the normal of the plane
  - Ground plane if normal has a strong vertical component
- Outliers are removed
- Remaining points are grouped into clusters
  - Euclidean Cluster Extraction algorithm
      - Minimum number of points in a cluster is set to 10
      - Maximum distance between two points that are part of the same cluster is set to 0.5 m





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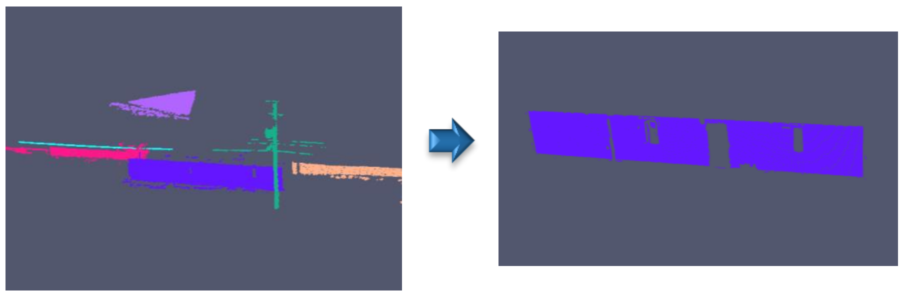
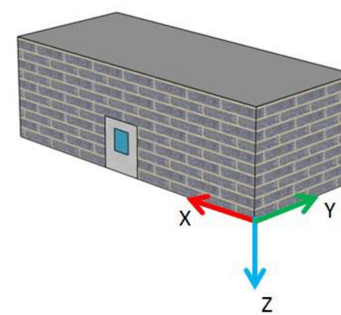
Front wall

- Each cluster is analyzed
  - Potential wall plane if vertical and if normal is perpendicular to the direction of travel of the vehicle.
  - Real wall if height is greater than 1.7 m (5 ft) and area is greater than $2m^2$



- Front wall is used to align the computation reference frame with a corner of the wall
  - For both LIDAR and TWSAR

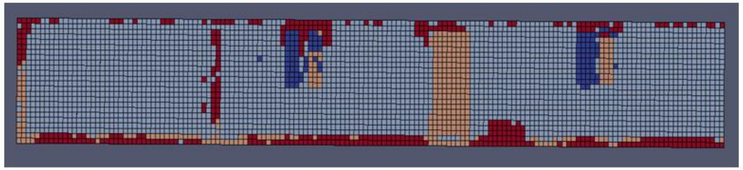


2-D occupancy grid

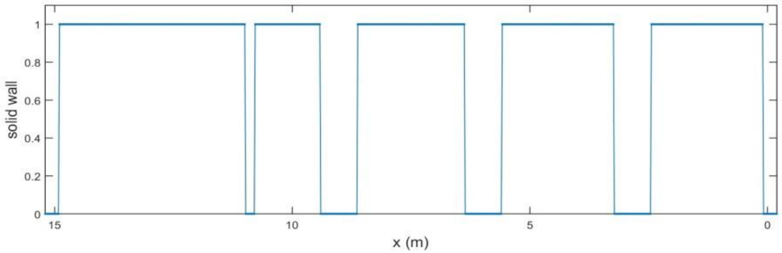
- Projection of 3-D front wall point cloud onto 2-D array of discrete cells
- Four possible states:
  - solid wall (wall material)
  - non-solid wall (objects in front of the wall e.g. electrical boxes, poles)
  - transparent (openings)
  - undefined
- TWSAR processing requires the set of x values for which the wall is primarily solid wall. We use:

$$x_i \in x_w \text{ if } 75\% \text{ of } M_w(x_i, z)|_{\text{all } z} \text{ is solid wall}$$

$$x_i \notin x_w \text{ otherwise}$$



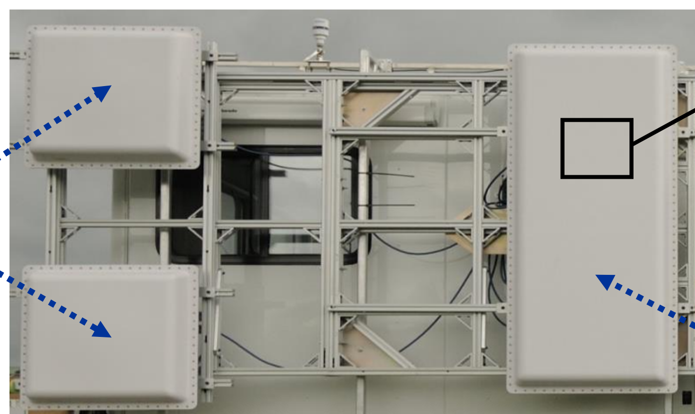
Solid wall: light blue   Transparent: dark blue
Non solid wall: red   Undefined: light orange

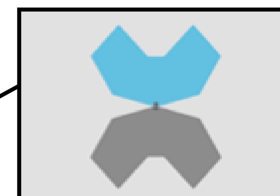


Through-Wall Synthetic Aperture Radar (TWSAR)

- The radar includes both COTS and custom components
- L-band FMCW radar (0.8 to 2.7 GHz)
- The antenna system is made of compact Y-shaped printed bowtie elements
  - very wide beamwidth
  - ideal for squinted look angles

- Range or across-track resolution
  - obtained by virtue of the large radar bandwidth
- Azimuth or along-track resolution
  - achieved through synthetic aperture radar processing with fixed synthetic aperture angle (50 degrees or 90 degrees)
- Elevation resolution (3.4°)
  - obtained with the physical vertical array

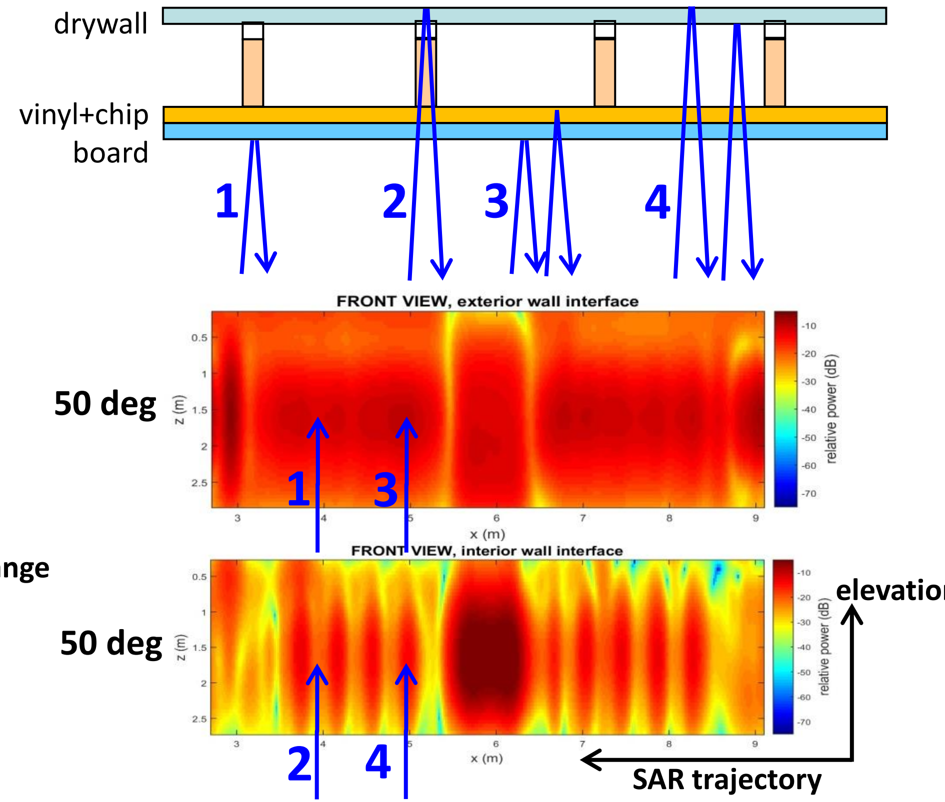


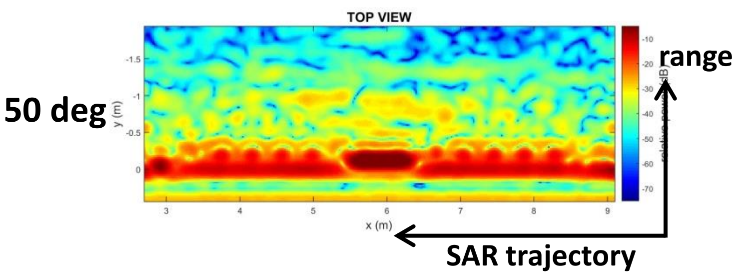


bowtie elements

3-D SAR image of wall signature

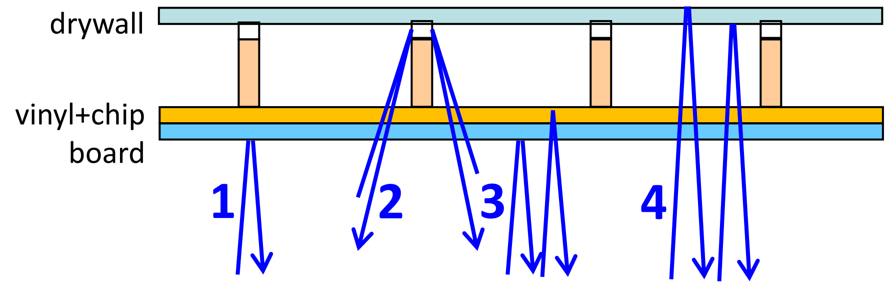
- 50 degree synthetic aperture angle:
  - specular reflection, highlights flat surfaces

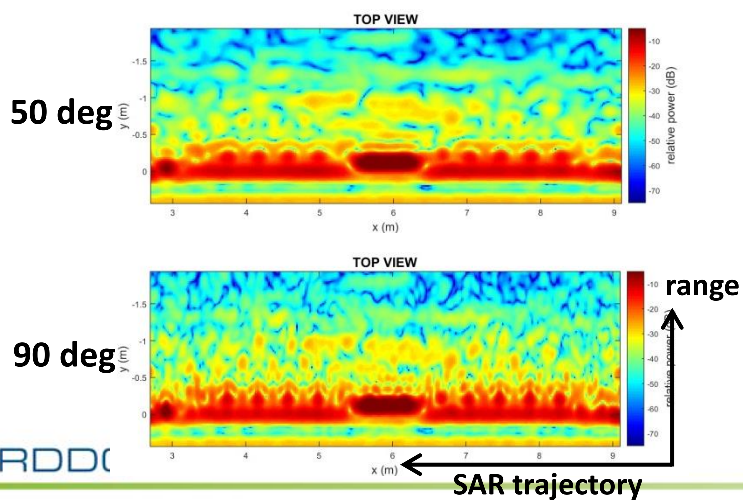


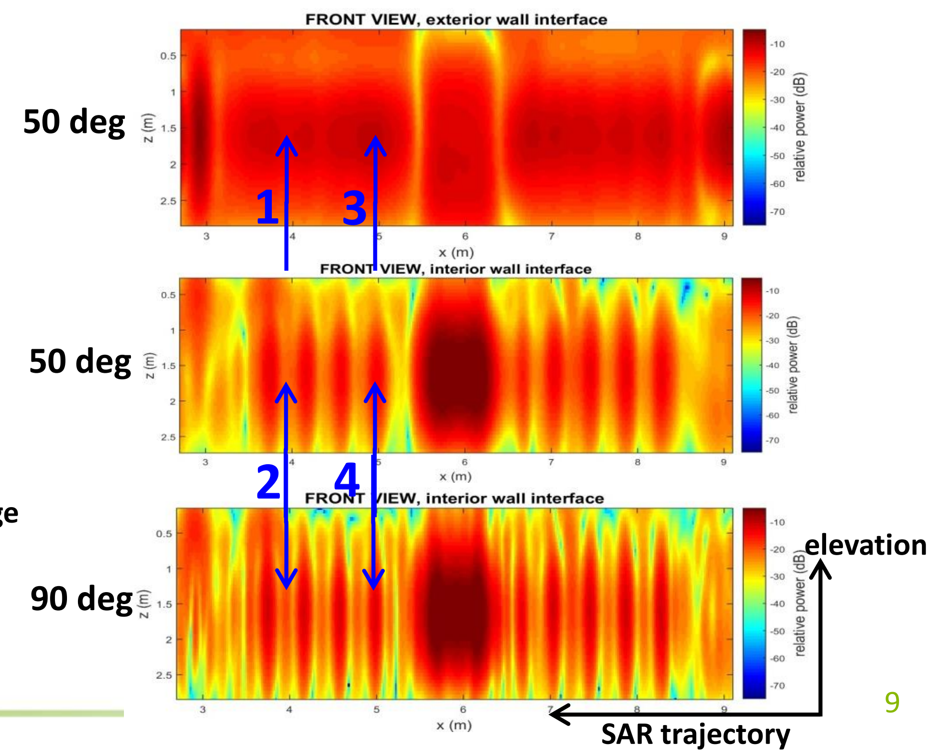


3-D SAR image of wall signature

- 50 degree synthetic aperture angle:
  - specular reflection, highlights flat surfaces
- 90 degree synthetic aperture angle
  - highlights corners







For this study

- 17 different walls, 5 categories

Cinder block





Poured concrete



Vinyl+gypsum+ wood studs



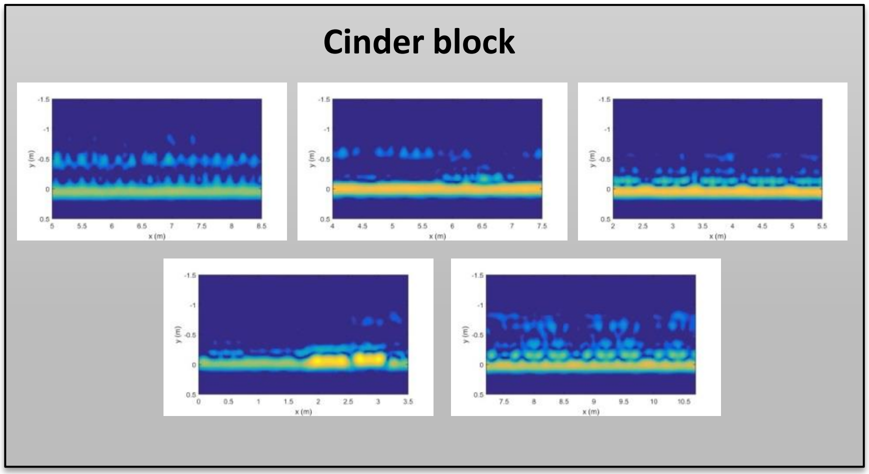
Brick + cinder block

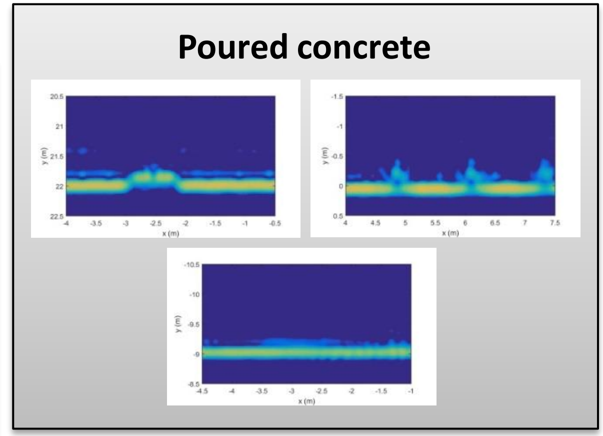

Other

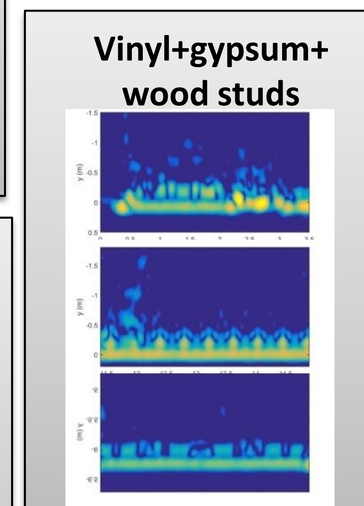


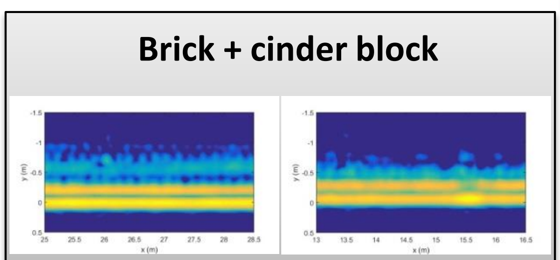

Top view 2-D SAR images of the 17 walls

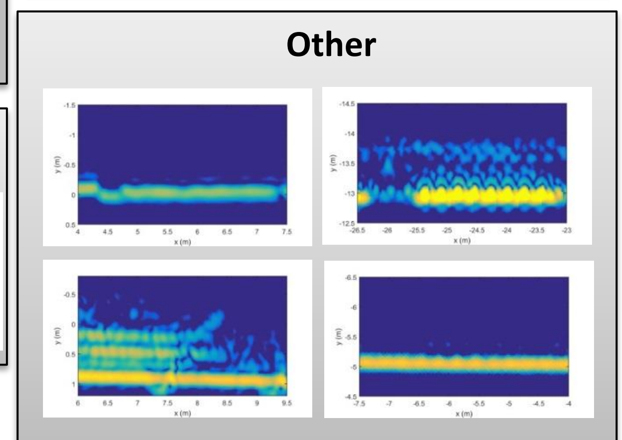
- The two strongest lines are automatically found to compute features (50 and 90 degree images)

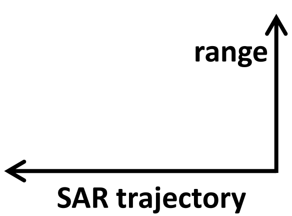








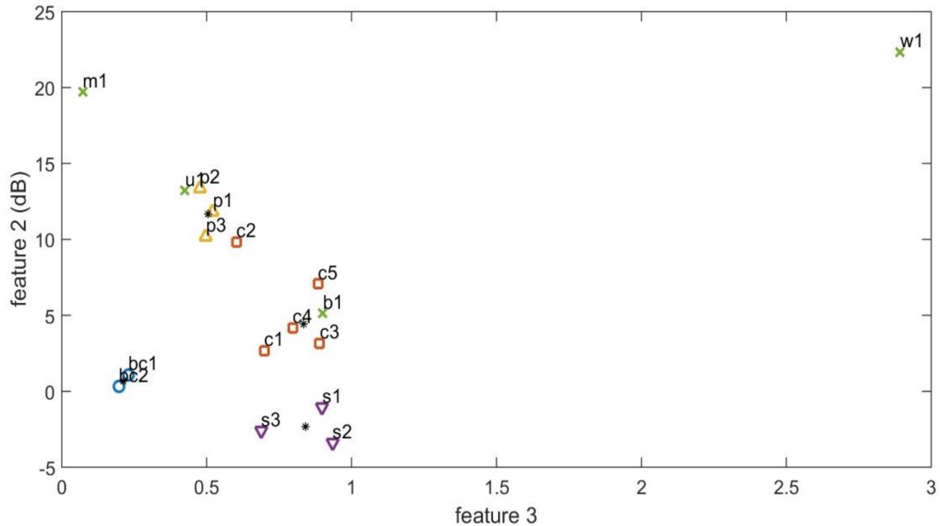




Results of clustering using two features

$$\text{Feature } 2 = s_{FL} - s_{SL}$$

Difference in standard deviations of both lines



$$\text{Feature } 3 = \frac{|(m_{FL} - s_{FL}) - (m_{SL} - s_{SL})|}{(m_{FL} - s_{FL})}$$

Difference between mean and standard deviation, for both lines

Results of clustering using two features

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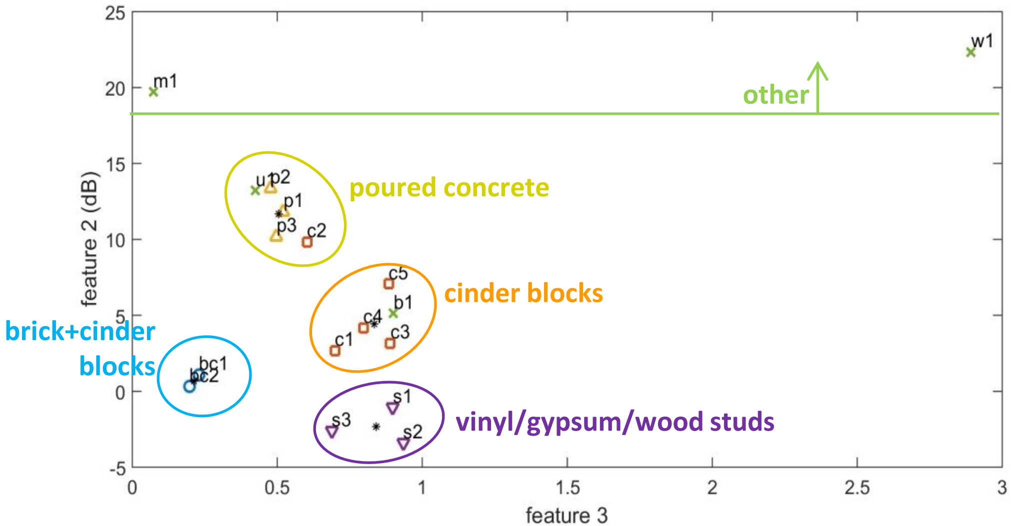
Difference in standard deviations of both lines



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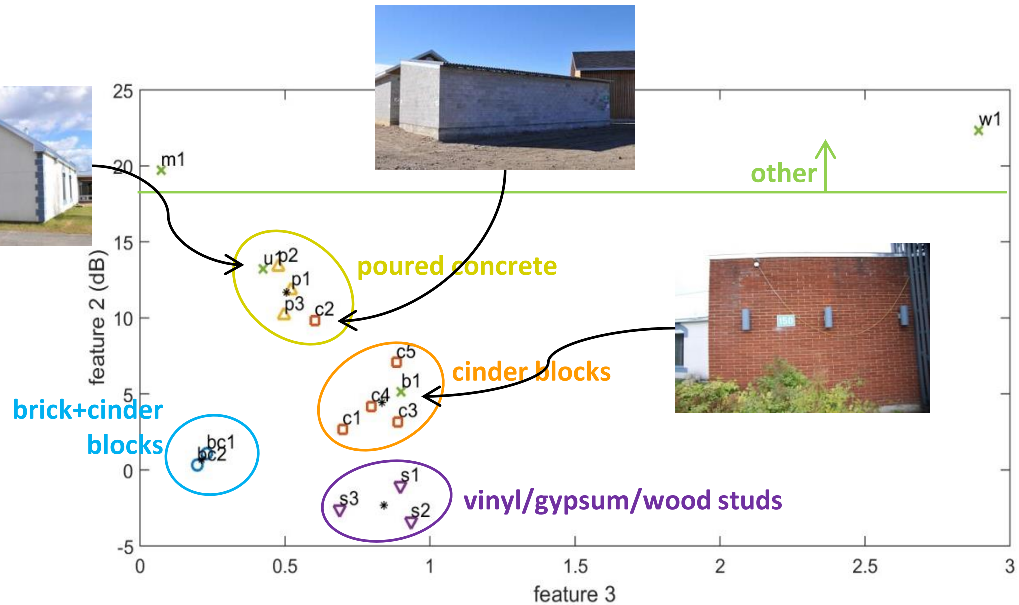

$$\text{Feature } 2 = s_{FL} - s_{SL}$$

Difference in standard deviations of both lines

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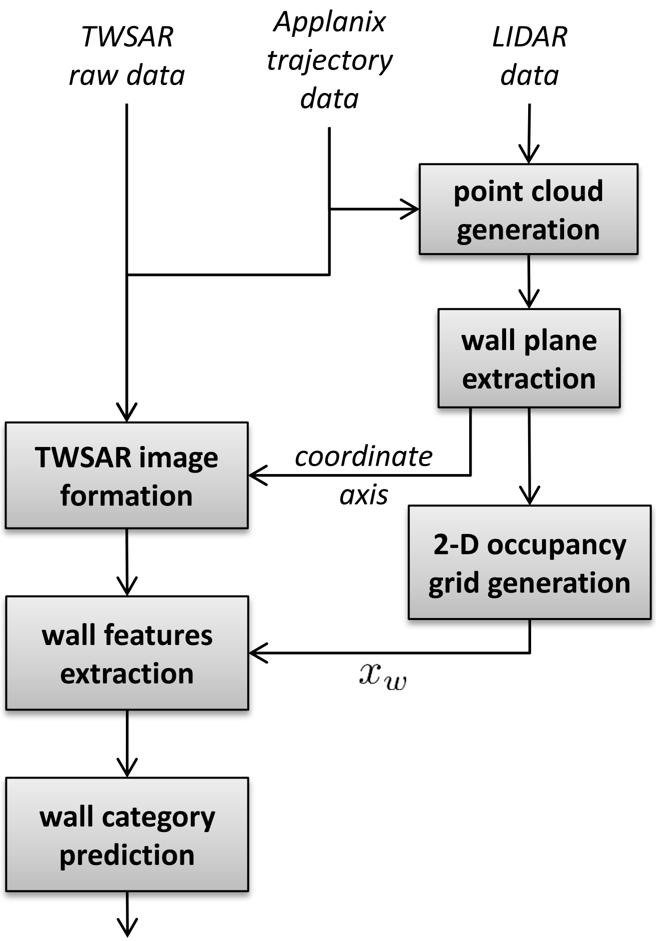
Difference between mean and standard deviation, for both lines

Summary

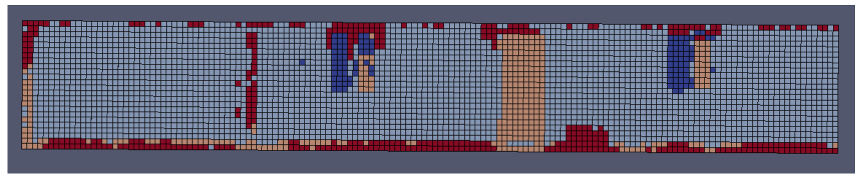
- Fused LIDAR and TWSAR information to obtain wall category
- Automated the algorithms
- Testing with larger number of samples is required
- Further post-processing is desirable to estimate wall thickness or to detect behind the wall anomalies
    - Specific to a wall category

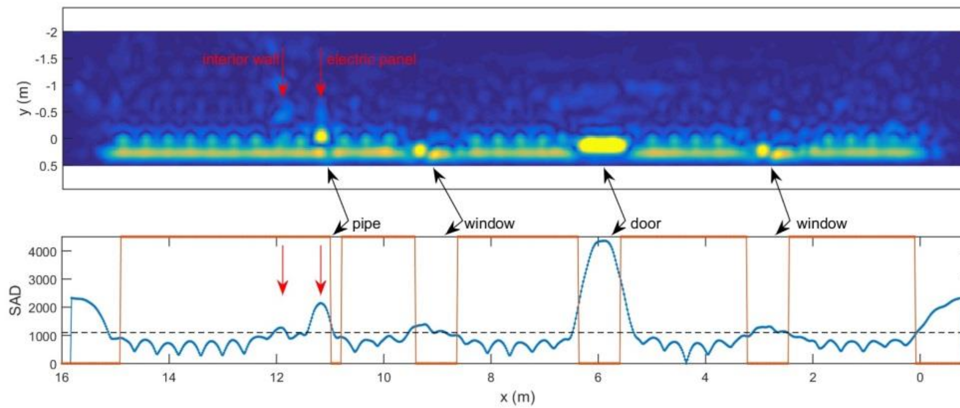


Example of anomaly detection

- Template matching using Sum of Absolute Differences (SAD)
- Vinyl/gypsum/wood studs walls

LIDAR occupancy grid





Sum of Absolute Differences (SAD) template matching