Compact Active Transponders for SAR Interferometry
Experimental validation

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Outline

• Persistent Scatterer (PS) Interferometry
• Need for artificial PS
  – Compact active transponders (CATs) vs. corner reflectors (CRs)
• Validation experiment

Can a CAT replace a CR for deformation monitoring?  
In other words, is a CAT phase-stable?

• Results and conclusions
PS density can be suboptimal

- Persistent Scatterer Interferometry (PSI):
  - Measurements of ground deformation at radar scatterers (PS) that are phase coherent over a period of time

Ground deformation per year (2003-2009) due to gas extraction and salt mining at Harlingen, The Netherlands, using PSI on Envisat ASAR data.
Compact Active Transponders for SAR Interferometry

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Challenge the future

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PS density can be suboptimal

- Persistent Scatterer Interferometry (PSI):
  - Measurements of ground deformation at radar scatterers (PS) that are phase coherent over a period of time
  - **Urban areas**: spatial density of PS usually high (100-300 PS/km² with ERS/Envisat)
  - Ground deformation phenomena may occur in uninhabited or rural areas with few man-made structures

Ground deformation per year (2003-2009) due to gas extraction and salt mining at Harlingen, The Netherlands, using PSI on Envisat ASAR data.
PSI is opportunistic

• For reliable and effective monitoring in such areas, PS density may be insufficient

• PS form a **geodetic network of opportunity**, but the exact location of PS ‘benchmarks’ is not under our control
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- For reliable and effective monitoring in such areas, PS density may be insufficient.
- PS form a **geodetic network of opportunity**, but the exact location of PS ‘benchmarks’ is not under our control.

Traditional geodetic network design involved installing benchmarks at optimal spatial locations.
Artificial PS: corner reflectors (CRs)

- Conceptually simple
- Amplitude and phase stable, validated via several experiments
Artificial PS: corner reflectors (CRs)

✅ Conceptually simple
✅ Amplitude and phase stable, validated via several experiments

❌ Big and heavy
❌ Should be strongly anchored to the ground; autonomous motion
❌ Difficult to deploy and maintain, especially in remote areas
❌ Can be disturbed by weather conditions, fauna, vandalism or theft during long-term measurements
❌ Snow, rain and debris can accumulate; periodic maintenance
❌ Oriented according to the satellite pass and imaging modes; only ascending or descending passes can be utilised
Compact active transponders (CATs)

- **Passive** devices need to be **large**, to be able to return sufficient power to the satellite
- **Active** devices can be more **compact**
- CATs are designed to be used in **place of CRs**
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Compact active transponders (CATs)
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Radar signal from satellite
Compact active transponders (CATs)

Amplification, circuit delay and phase compensation
Compact active transponders (CATs)

Amplified and retransmitted radar signal
Compact active transponders (CATs)
Compact active transponders (CATs)
CATs as artificial PS
CATs as artificial PS

- Small (a few tens of cm), lightweight (less than 4 kg) and inconspicuous
- Sealed, function autonomously and over a wide temperature range with internal power for more than a year
- Not affected by strong winds, precipitation and debris accumulation
- Low maintenance: only to change/charge battery, check for clock drift, or upload new SAR acquisition schedule if needed
CATs as artificial PS

- Frequency-specific, only turned on during overpass: offers little interference to other radar or radio targets
- Can be used for both ascending and descending satellite modes in a single setup
- Wide beamwidth: can be used over a range of incidence angles
- Signal polarisation can be preprogrammed: can be used with any existing C-band satellite without highly accurate orientation and adjustment
CATs as artificial PS

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❓ Can a CAT replace a CR for deformation monitoring? In other words, is a CAT phase-stable?
The Delft field experiment
Location and setup
Location and setup
Location and setup
InSAR and levelling
InSAR and levelling

- SAR data acquired **every 3 days** (ERS-2 Ice-Phase Mission)
- **26 SAR images** after device installation (19 April to 3 July 2011)
- Levelling performed **within 24 hours** of most overpasses (19 out of 26)
- Levelling between **CAT-CR pairs**
- Redundancy introduced in levelling measurements, making **outlier detection** possible
CAT and CR phase extraction

- Single master interferograms generated
CAT and CR phase extraction

- Single master **interferograms** generated
- For each CR and CAT, the **phase of the pixel with maximum amplitude** extracted
InSAR processing

- ERS-2 was operating in Zero-Gyro Mode since 2001; continuous **variations of Doppler centroid**, not optimal
- **Subpixel phase correction** in azimuth and range
  - to correct for **systematic phase offsets** that depend on object position within a resolution cell
  - subpixel position determined by **oversampling with a factor of 32** with respect to SLC image
- InSAR and levelling vertical height double differences calculated using the **same reference time** (13 May)
- InSAR double differences **unwrapped** to the nearest levelling double differences
Double differences: basis of comparison

InSAR:
- CAT phase difference between $t_m$ and $t_s$
- CR phase difference between $t_m$ and $t_s$

Phase to vertical height conversion

Levelling:
- Height difference between CAT and CR at $t_m$
- Height difference between CAT and CR at $t_s$

Height double difference between CAT and CR
Double differences: basis of comparison

InSAR:
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Phase to vertical height conversion

First in time and then in space

Levelling:
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- Height difference between CAT and CR at $t_s$

Height double difference between CAT and CR

First in space and then in time
Previous Delft CR experiment

- **Controlled CR experiment** in Delft
- Five CRs deployed (2003 - 2007)
- InSAR *a posteriori* precision for CR-CR double differences with ERS-2 data after subpixel correction = 2.9 mm
  (1σ standard deviation in the vertical direction)

Reference
P. Marinkovic, G. Ketelaar, F. van Leijen, and R. Hanssen.
‘InSAR quality control: Analysis of five years of corner reflector time series.’
Comparison results

- Levelling 2*sigma interval, sigma = 2 mm
- Levelling mean values
- InSAR values with 2*sigma error bars, sigma = 3 mm
- InSAR values with 2*sigma error bars (temp. corrected), sigma = 3 mm
Basis of temperature correction

Correlation = 51 %
Slope = 0.8
p = 0.02

Correlation = 46 %
Slope = 0.7
p = 0.05

Correlation = 38 %
Slope = 0.7
p = 0.11

\( p \) is the probability of getting a correlation as large as the observed value by random chance, when the true correlation is zero.

If \( p \) is small, say <0.05, then the correlation is significant.
A posteriori precision

Variance component estimation:

<table>
<thead>
<tr>
<th>Pair</th>
<th>Without temperature correction</th>
<th>With temperature correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT1 – CR3</td>
<td>3.6 mm</td>
<td>3.4 mm</td>
</tr>
<tr>
<td>CAT2 – CR1</td>
<td>5.3 mm</td>
<td>4.9 mm</td>
</tr>
<tr>
<td>I2GPS – CR1</td>
<td>5.0 mm</td>
<td>4.6 mm</td>
</tr>
</tbody>
</table>

- For InSAR CAT-CR double differences with ERS-2 data, the average a posteriori precision
  - Without temperature correction = 4.6 mm
  - With temperature correction = 4.3 mm
- Values are 1σ standard deviations in the vertical direction
Can a CAT replace a CR?

Comparison of CAT-CR and CR-CR double differences over ~450 m:

Correlation = 87 %
Summary and conclusions

• The average *a posteriori* precision of CAT-CR double differences with ERS-2 data
  - Before temperature correction = 4.6 mm
  - After temperature correction = 4.3 mm

\[\text{Without outlier removal}\]
Summary and conclusions

- The average \textit{a posteriori precision} of CAT-CR double differences with ERS-2 data
  - Before temperature correction = 4.6 mm
  - After temperature correction = 4.3 mm

- This can be compared with the CR-CR double differences from the previous CR experiment in Delft. The InSAR \textit{a posteriori precision} after subpixel correction for ERS-2 data was
  - With outlier removal = 2.9 mm
Summary and conclusions

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  - With outlier removal = 2.9 mm

- Within a 95% confidence interval, the CAT-CR measurements (2011) are as precise as the CR-CR measurements (2007)
Summary and conclusions

• The average \textit{a posteriori} precision of CAT-CR double differences with ERS-2 data
  - Before temperature correction = 4.6 mm
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\begin{align*}
\text{Without outlier removal} \\
\end{align*}

• This can be compared with the \textbf{CR-CR double differences} from the previous \textbf{CR experiment} in Delft. The \textit{InSAR a posteriori} precision after subpixel correction for ERS-2 data was
  - With outlier removal = 2.9 mm

• \textit{Within a 95\% confidence interval, the CAT-CR measurements (2011) are as precise as the CR-CR measurements (2007)}

• Further work: rigorous outlier removal, validation in a landslide-risk area in Slovenia with GPS
Thank you!