PSInSAR validation by means of a blind experiment using dihedral reflectors

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Objectives

Assess the performance of InSAR approach using artificial reflectors with a focus on:

- **Precision** and **accuracy** of estimated motion
- **Multi-geometry** and **multi-platform** capability
- Long term **stability** of the reflectors
- Radar Cross Section required for **application in urban environment**

Framework

- Deploy of 2 couples of dihedral reflectors (for ascending and descending geometry)
- Move one couple of targets in both East-West and vertical direction between 2 acquisitions
- Estimated the horizontal and vertical displacement from the interferometric phase using Envisat and Radarsat data
Why dihedral reflector?

Dihedral reflectors have been preferred to conventional trihedral reflectors with the same RCS for their smaller dimension → greater mechanical stability.

\[ RCS = \frac{8 \cdot \pi \cdot L^4}{\lambda^2} \]

\[ RCS = \frac{4 \cdot \pi \cdot L^4}{3 \cdot \lambda^2} \]

\[
\begin{align*}
L &= 1 \text{m} \\
\lambda &= 0.0566 \text{m}
\end{align*}
\]

RCS=7845 m²

RCS=1307 m²
Constraint on Signal to Clutter Ratio

H_p: \( \sigma_Q^2 = \sigma_I^2 = \sigma^2 / 2 \)

\[
\sigma_\phi = \sqrt{\frac{\sigma_Q^2}{A^2}} = \sqrt{\frac{1}{2 \cdot \frac{A^2}{\sigma^2}}} = \sqrt{\frac{1}{2 \cdot \text{SCR}}}
\]

A SCR equal to 20dB should guarantee a \( \sigma_\phi < 0.3 \text{ mm} \)

Clutter = 60 m²
Example: Radarsat descending data

Suitable location for the dihedral reflectivity based on the SCR requirement
Two GPS antennas have been installed. A couple of dihedral reflectors has been deployed as reference point. The other reflector has been used as target to be monitored.
High sensitive to orientation

Require an accurate assessment of the direction of the satellite illuminating beam
For Radarsat (the antenna is not yaw-steered) the squint-angle has to be taken into account.
Dihedral orientation: visibility from two different geometries

1. Evaluate $\text{LOS}_1$ components
2. Evaluate $\text{LOS}_2$ components
3. Compute the perpendicular vector \( \text{PERP} = \text{LOS}_1 \times \text{LOS}_2 \)
4. Compute the bisector vector $\text{BIS}$
5. Deploy the dihedral backbone accordingly to the perpendicular vector
6. Rotate the dihedral reflector to meet the elevation requirement
Radarsat S3 ascending

BEFORE dihedrals deployment  AFTER dihedrals deployment
Radarsat S3 descending

BEFORE dihedrals deployment

AFTER dihedrals deployment
Envisat IS2 descending

BEFORE dihedrals deployment

AFTER dihedrals deployment
Envisat IS2 ascending

BEFORE dihedrals deployment

AFTER dihedrals deployment
Interferometric phase mix

Differential phase difference between two reflectors:

$$\Delta \phi = \phi - \phi_{REF} = \Delta \varphi + \frac{4\pi}{\lambda} \Delta r + K_{DEM} \Delta H + \Delta \alpha + \text{noise}$$

- **Reflectivity change**
- **LOS displacement**
- **Elevation**
- **Atmospheric delay**

**IF** $\Delta \varphi \approx 0$ (phase stability)

- $\Delta \alpha \approx 0$ (reflectors are very closed each others, about 30 m)
- $\Delta H \approx 0$ (same elevation)
- noise $\approx 0$ (high SCR)

$$\Delta \phi = \frac{4\pi}{\lambda} \Delta r$$

**LOS Displacement**
3D displacement recovery

Combining 2 different geometries:

\[
\begin{align*}
V_1 &= \cos(\theta_1) \cdot V_{rH} - \sin(\theta_1) \cdot V_{rE} \\
V_2 &= \cos(\theta_2) \cdot V^{\theta}_{rH} + \sin(\theta_2) \cdot V_{rE}
\end{align*}
\]
The processed data

Four data sets were independently analyzed. Since the beginning of the experiment (20th October 2004) the following images were collected:

- Radarsat ascending S3 (11 images)
- Radarsat descending S3 (12 images)
- Envisat ascending IS2 (3 images)
- Envisat descending IS2 (5 images)
Ground truth vs Radarsat data

E-W component
Standard deviation: 1.3 mm

Vertical component
Standard deviation: 1 mm
LOS component: Projected ground truth vs Envisat data

Envisat ascending

Envisat descending
PS on LIDAR data

Image courtesy of OGS
Elevation Differences (PS vs LIDAR)

800 PS
Mean = 0.115
Mode = -0.1
StDev = 1.98
Profiles

![Graphs showing Profiles](image-url)
Conclusions (1)

- A **multi-geometry** and **multi-platform** analysis has been performed in order to retrieve the **2D displacement** (**vertical** and **East-West** components)

- **Phase stability** of the deployed artificial reflectors has been proved to be reliable over a period of more than **10 months**

- The agreement between ground truth and InSAR displacement estimation confirm the **millimetric accuracy** achievable
  - standard deviation **1 mm** along vertical direction (Radarsat)
  - standard deviation **1.3 mm** along East-West direction (Radarsat)
Conclusions (2)

- LIDAR data (Optech 3033) allowed a first validation of precise elevation values on a sparse grid of radar targets (PS). After removal of systematic errors, the dispersion of the elevation values of satellite radar targets (PS) turned out to be < 2 m.

- A synergistic use of PSInSAR and LIDAR data could open a new scenario for remote sensing applications and terrain mapping.

- LIDAR data can speed up the PS analysis (elevation retrieval) and can allow, together with HR optical data, the physical characterization of the radar target (i.e. What are we looking at?)
Thanks for your attention.
GPS measurements: Vertical direction

- Differential GPS (distance of about 54 m)
- 3 permanent GPS stations
- Precise ephemeris data from IGS (International GNSS Service)
- Ionospheric and tropospheric correction adopted
GPS measurements: North-South and East-west components

North-South component

East-West component

GPS daily measurement
GPS compensated measurement