The Parallel Implementation of the full resolution SBAS-DInSAR processing chain for surface deformation analysis in extended urban areas

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Outline

✓ Exploited algorithm

- Full Resolution Parallel Small BAseline Subset (FR P-SBAS) DInSAR algorithm

✓ Proposed approach

- Full exploitation of Big SAR Data archives
- Automatic FR P-SBAS chain for large SAR data stacks processing
- Deployment of FR P-SBAS solution on Cloud/HPC architectures

✓ Future perspective

- Mapping the ground displacements at national scale with COSMO-SkyMed
- Integration of FR P-SBAS results for large scale damage assessment analyses
The FR P-SBAS DInSAR algorithm

- An advanced Differential Interferometry Synthetic Aperture RADAR (DInSAR) algorithm to retrieve deformation time-series and velocity maps both in natural and anthropic hazard scenarios (i.e., seismic events, volcanic unrest, landslides, urban areas and single man-made structures).

- Small Baseline interferometric pairs are only considered in order to minimize the noise effects and maximize the number of detectable (coherent) measure points.

- Full Resolution Interferograms are exploited to retrieve temporal and spatial characteristics of detected displacements at full spatial resolution scale (about 3-10 m).
The Small BAseline Subset (SBAS) DInSAR approach

SAR Images → SB Interferograms → Deformation Time-series and velocity

Mean deformation velocity [cm/yr]

-0.75 ≤ v < 0.75


The Small BAseline Subset (SBAS) DInSAR approach

SAR Images → SB Interferograms → Time-series and velocity


Mean deformation velocity [cm/yr]

< -0.75

> 0.75

ERS
ENV
The Full Resolution SBAS technique: multi-scale approach

Regional scale analysis
(pixel size: ~30 m for the CSK stripmap case)

Local scale analysis
(pixel size: ~3 m for the CSK stripmap case)

The Full Resolution SBAS technique: main applications
Achieved accuracies:

- $\approx 1 - 2 \text{ mm/year}$ on the mean deformation velocity
- $\approx 5 - 10 \text{ mm}$ on the single displacement
The Full Resolution P-SBAS algorithm: block diagram

- FR-SBAS deals with low and full resolution interferograms. FR-SBAS processing starts with the retrieval of the residual interferometric phase by subtracting modulo-$2\pi$ the low resolution phase from the full resolution one.

- The residual interferometric phase is then processed to estimate the linear phase components:
  - Mean deformation velocity, $v(x, r)$
  - Residual topography, $\Delta z(x, r)$
  - Azimuthal position, $\Delta x(x, r)$
  - Thermal dilation coefficient, $K(x, r)$

- Once the linear components are filtered out from residual phase, the non-linear deformation phase $\beta(x, r)$ is finally retrieved.

- Last step carries out the combination of $v$ and $\beta$ deformation components with the corresponding low resolution ones to retrieve the full resolution signals.
The Full Resolution P-SBAS algorithm: block diagram

**Input**
- Full Resolution Interferograms
- Low Resolution Interferograms

**P-SBAS low resolution analysis**

**Full Resolution product reconstruction**

**Residual interferometric phase generation**

**Linear phase component estimation:** velocity, topography, azimuthal position and thermal dilation coefficient

\[
\begin{align*}
&\nu(x, r) \quad \Delta z(x, r) \quad \Delta x(x, r) \quad K(x, r) \\
\delta \varphi_j (x, r) \\
\langle \delta \varphi_j (x, r) - \delta \varphi_j^{\text{model}}(x, r) \rangle_{-\pi, \pi} \\
\beta(t, x, r)
\end{align*}
\]

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The Full Resolution SBAS-DInSAR analysis: a Big Data challenge

FR SBAS-DInSAR results: MILLIONS OF POINTS TO PROCESS!!!

Parallel hardware architectures based on GPU and multi-core processing
The FR SBAS technique: **sequential implementation**

<table>
<thead>
<tr>
<th>Area of Roma</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>40x40</td>
</tr>
<tr>
<td>#Images</td>
<td>129</td>
</tr>
<tr>
<td>Sensor</td>
<td>CSK</td>
</tr>
<tr>
<td>Spatial Resolution [m]</td>
<td>3x3</td>
</tr>
<tr>
<td>Time span</td>
<td>03/2011 – 03/2019</td>
</tr>
<tr>
<td>#Pixels</td>
<td>21000x15000 (&gt; 300 M)</td>
</tr>
<tr>
<td>#Interf</td>
<td>392</td>
</tr>
</tbody>
</table>
The FR SBAS technique: **sequential implementation**

~ **3000 hours (120 days)** for the sequential processing (1 single processing node) of the full frame!!!
Full exploitation of large SAR data archives

Computing Resources & Data Proximity:
Availability of distributed HPC infrastructures and data proximity

Efficient Processing Tools:
Development of parallel algorithms for HPC platforms to cut down the processing times
NFS-based distributed storage implementation designed to minimize the I/O and data transfer overhead

- All working nodes are controlled by a single Master Node
- The working nodes are connected with each other via NFS and acts as client and server at same time
- High I/O performance is obtained thanks to dedicated storage volumes shared among the nodes
- Final results are transferred to a long-term persistent storage
The Parallel Full Resolution P-SBAS algorithm: block diagram

**Input**
- Full Resolution Interferograms
- Low Resolution Interferograms
- P-SBAS low resolution analysis

**Residual interferometric phase generation**

**B**

Linear phase components estimation:
velocity, topography, azimuthal position and thermal dilation coefficient

\[ v(x, r) \quad \Delta z(x, r) \quad \Delta x(x, r) \quad K(x, r) \]

**C**

Linear phase component removal

\[ \left\langle \delta \varphi_j^{(HP)}(x, r) - \delta \varphi_j^{model}(x, r) \right\rangle_{2\pi} \]

Non-linear phase component retrieval

\[ \beta(t, x, r) \]

**GPU CUDA STEPS**

**MULTI-CORE STEPS**

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The Full Resolution P-SBAS: parallel implementation

~ 12 hours for a parallel processing solution (4 GPU and 25 CPU cores) of the full frame!!!
Sequential vs. Parallel FR SBAS processing chain: computing time for linear phase components estimation (step B)

<table>
<thead>
<tr>
<th>Environment</th>
<th>AWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>Intel Xeon E5-2686 @2.6GHz</td>
</tr>
<tr>
<td>Network</td>
<td>10GB/s</td>
</tr>
<tr>
<td>NFS storage bandwidth</td>
<td>1,5 Gbps per GPU</td>
</tr>
<tr>
<td>GPU</td>
<td>NVIDIA Tesla V100 16 GB</td>
</tr>
</tbody>
</table>

Sequential processing time: 520 hours

- 1 GPU: 8 hours
- 2 GPU: 4 hours
- 4 GPU: 2 hours
- 8 GPU: 1 hour
- 16 GPU: 0.5 hours
The FR P-SBAS results: the case study of Rome (Italy)

Ascendant orbits
Time span: 03/2011 - 03/2019
129 acquisitions

Descendant orbits
Time span: 07/2011 - 03/2019
107 acquisitions
The FR P-SBAS results: the case study of Rome (Italy)

The A90-A91 Roma-Fiumicino Highway

<-1

[cm/year]

>1
The FR P-SBAS results: the case study of Rome (Italy)

The A90-A91 Roma-Fiumicino Highway

<-1 | [cm/year] | >1

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The FR P-SBAS results: the case study of Rome (Italy)

The A90-A91 Roma-Fiumicino Highway
The FR P-SBAS results: the case study of Rome (Italy)

The Fiera di Roma area

[cm/year]

<-1 | >1

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The FR P-SBAS results: the case study of Rome (Italy)

The Fiera di Roma area
The FR P-SBAS results: the case study of Rome (Italy)

The Fiera di Roma area

![Deformation Time-Series](image)

-1 < cm/year < 1
The FR P-SBAS results: the case study of Rome (Italy)

Gasometer, Ostiense railstation and Via Giustiniano Imperatore
The FR P-SBAS results: the case study of Rome (Italy)

The Gasometer

<1 1 [cm/year]

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The FR P-SBAS results: the case study of Rome (Italy)
The FR P-SBAS results: the case study of Rome (Italy)

Ostiense railstation

< -1  [cm/year]  > 1
The FR P-SBAS results: the case study of Rome (Italy)

Ostiense railstation
The FR P-SBAS results: the case study of Rome (Italy)

Via Giustiniano Imperatore
The FR P-SBAS results: the case study of Rome (Italy)

![Map of Via Giustiniano Imperatore with displacement velocities](image)

- Displ. Velocity (cm/yr)
- Lat: 41.8553, Lon: 12.4851
- Lat: 41.8552, Lon: 12.4849

**Via Giustiniano Imperatore**
The FR P-SBAS results: the case study of Rome (Italy)

Descending orbits: Fiumicino airport
The FR P-SBAS results: the case study of Rome (Italy)

Descending orbits: Fiumicino airport
Future perspective

✓ Mapping the whole Italian territory by exploiting the full CSK data archive

✓ Integration of the FR P-SBAS measurements with structural models (FEM, semi-empirical, etc) for large scale damage assessment analyses

✓ Exploration of Big Data and AI approaches for advanced remote sensing and data interpretation methods
Thank you!