CURRENT SCENARIO AND CHALLENGES IN THE ANALYSIS OF MULTITEMPORAL REMOTE SENSING IMAGES

Lorenzo Bruzzone

E-mail: lorenzo.bruzzone@ing.unitn.it
Web page: http://rslab.disi.unitn.it
Outline

1. Background and current trends in multitemporal images
2. Change detection in VHR multispectral images
3. Change detection in VHR SAR images
4. Change detection in multisensor/multisource VHR images
5. Discussion and Conclusion
1. Background and Current Trends in Multitemporal Images
In the last ten years we had a significant increase in the interest on topics related to the time series and the analysis of multitemporal data:


- Increased number of related sessions in international conferences.

- Increased number of projects related to multitemporal images and data.
The increased interest in multitemporal data analysis is due to many issues:

- **Increased number of satellites** with increased revisit time that allow the acquisition of either long time series or frequent bitemporal images.

- **New policy for data distribution of archive data** that makes it possible a retrospective analysis on large scale (e.g. the Landsat Thematic Mapper archive).

- **New policies for the distribution of new satellites data** (e.g. ESA Sentinel).
2. Change Detection in Very High Resolution Multispectral Images
Where we were 10 years ago.....

Landsat TM (burned area detection)

Before Change

After Change
CD in Multitemporal MS Images: Typical Architecture

Comparison Operators:
- Difference
- Vector difference
- Ratio
- Log-ratio

Optical Images

Synthetic Aperture Radar (SAR) Images

Analysis:
- Pixel-based thresholding
- Context-based approaches

\[
\Omega = \{ \omega_c, \omega_u \}
\]


CD in Multitemporal MS Images: Example

Landsat TM, Pre-event

Landsat TM, Post-event

Magnitude Difference Image

Pixel-Based Change Detection Map

Burned area
New Satellites with VHR MS Sensors

![Graph showing the timeline and spatial resolution of various satellites. The x-axis represents years from 1970 to 2020, while the y-axis represents spatial resolution in meters. The graph includes satellites such as Landsat 1-3, Landsat 4-5, Landsat 7, SPOT 1-4, SPOT 5, Ikonos, QuickBird, WorldView 1-2, GeoEye 1, GeoEye 2, Cartosat-2, and Pleiades-HR 1-2. Each satellite is marked with a dot along the timeline.](image-url)
CD in Multitemporal VHR MS images

July 2006
Quickbird images of the city of Trento (Italy)

October 2005
CD in Multitemporal VHR MS images

October 2005
Quickbird images of the city of Trento (Italy)

July 2006
CD in Multitemporal VHR Images: Example

Quickbird, October 2004 (true color composition)

Magnitude Difference Image

Quickbird, July 2006 true color composition

Pixel-Based Change Detection Map
Change detection in VHR Images should exploit a top-down approach to the definition of the processing architecture. This approach should:

- explicitly model the presence of different radiometric changes on the basis of the properties of the considered images;
- extract the semantic meaning of changes;
- identify changes of interest with strategies designed on the basis of the specific application;
- exploit the intrinsic multiscale properties of the objects and the high spatial correlation between pixels in a neighborhood.

CD in VHR MS Images: Architecture Design

Multitemporal data set

Identification of the tree of radiometric changes

Detection of all radiometric changes

Selection of the strategy for detecting changes of interest

Direct extraction of changes of interest

Detection of the changes of interest

Refined detection of the radiometric change of interest

Differential extraction of changes of interest by cancellation

Change detection map

Auxiliary information

Change Vector Analysis, Context-sensitive techniques, etc.
Identification of the Tree of Radiometric Changes

Radiometric Changes ($\Omega_{rad}$)

- Changes due to acquisition conditions ($\Omega_{Acq}$)
  - Differences in atmospheric conditions ($\Omega_{Atm}$)
    - Type of sensor
    - Sensor view angle
    - Sensor acquisition mode
    - Seasonal effects

- Differences in acquisition system ($\Omega_{Sys}$)

- Changes occurred on the ground ($\Omega_{Grd}$)
  - Natural disasters ($\Omega_{Dis}$)
  - Anthropic activity ($\Omega_{Ant}$)
  - Vegetation Phenology ($\Omega_{veg}$)
  - Environmental conditions ($\Omega_{Env}$)
Detection of Changes of Interest

Direct detection

\[ X_1 \rightarrow \text{Detection of change of interest 1} \]
\[ X_2 \rightarrow \text{Detection of change of interest } K \]

\[ \text{Detection of change of interest 1} \rightarrow \text{Detection of change of interest } K \]

\[ \text{Detection of change of interest 1} \rightarrow \text{Detection of change of interest } K \]

\[ \text{Detection of change of interest 1} \rightarrow \text{Detection of change of interest } K \]

\[ \text{Detection of change of interest 1} \rightarrow \text{Detection of change of interest } K \]

Differential detection by cancellation

\[ X_1 \rightarrow \text{Detection of radiometric changes} \]
\[ X_2 \rightarrow \text{Detection of radiometric changes} \]

\[ \text{Detection of radiometric changes} \rightarrow \text{Non-relevant change 1} \]
\[ \text{Detection of radiometric changes} \rightarrow \text{Non-relevant change 2} \]
\[ \cdots \rightarrow \text{Non-relevant change } N \]

\[ \text{Detection of radiometric changes} \rightarrow \text{Refined detection of the radiometric change of interest} \]

\[ \text{Refined detection of the radiometric change of interest} \rightarrow \text{Map of changes} \]
Multilevel Approach: Semantic of Changes

Object Meta-level ($o$)

$j=1,\ldots,J_o$

Classification map, object map,…

---

Primitive Meta-level ($p$)

$j=1,\ldots,J_p$

Geometric or statistic primitives

---

Pixel Meta-level ($px$)

$j=1,\ldots,J_{px}$

Pixel radiometry

---

Study area: South part of Trento (Italy).

Multitemporal data set: portion (380×430 pixels) of two images acquired by the Quickbird satellite in October 2004 and July 2006.

Causes of Change: changes on the ground, seasonal changes, registration noise.
Example: CD Architecture Design

- Multitemporal data set
- Identification of the tree of radiometric changes
- Detection of all radiometric changes
- Selection of the strategy for detecting changes of interest
- Change detection map

- Direct extraction of changes of interest
- Detection of the changes of interest
- Refined detection of the radiometric change of interest
- Differential extraction of changes of interest by cancellation

- Change Vector Analysis, Context-sensitive techniques, etc.
- Auxiliary information
Identification of the Tree of Radiometric Changes

\[ \Omega_{Rad} \]

\[ \Omega_{Sys} \]

\[ \Omega_{Grd} \]

\[ \Omega_{Veg} \]

\[ \Omega_{Ant} \]

\[ \Omega_{Wsh} \]

Shadow changes

Registration noise

Apple trees

Grassland

New buildings

New buildings
Changes Tree and Detection Strategy

Identification of the tree of radiometric changes

\[ \Omega_{\text{Rad}} \]

\[ \Omega_{\text{Sys}} \]

\[ \Omega_{\text{Grd}} \]

\[ \omega_{\text{sh}} \]

\[ \omega_{\text{rn}} \]

Shadow changes

Registration noise

Differential detection by cancellation

\[ X_1 \]

\[ X_2 \]

Detection of \( \omega_{\text{sh}} \)

Detection of \( \omega_{\text{rn}} \)

Revised detection of \( \Omega_{\text{Grd}} \)

Map of changes
### Shadow detection

#### Multiscale analysis for \( \omega_{rm} \) detection

- **Shadow detection**
- **Comparison**
- **CVA**
- **Parcel detection**

\[ \Omega_{rad} \text{ detection} \]

\[ \Omega_{sh} \text{ detection} \]

\[ \Omega = \{ \Omega_{nc}, \Omega_{Grd} \} \]

**Example: CD Architecture**
Example: Qualitative Results

October 2005

July 2006

Reference Map

Change Detection Map
CVA Parcel Based

Change detection Map
Top-down Architecture

© Lorenzo Bruzzone
Example: Quantitative Results

<table>
<thead>
<tr>
<th>Technique</th>
<th>False Alarms</th>
<th>Missed Alarms</th>
<th>Total Errors</th>
<th>Overall accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVA pixel-based</td>
<td>5005</td>
<td>9924</td>
<td>14929</td>
<td>90.86</td>
</tr>
<tr>
<td>CVA parcel-based</td>
<td>3537</td>
<td>10261</td>
<td>13798</td>
<td>91.56</td>
</tr>
<tr>
<td>Top-down architecture</td>
<td>1470</td>
<td>8480</td>
<td>9950</td>
<td>93.91</td>
</tr>
</tbody>
</table>
3. Change Detection in Very High Resolution SAR Images
ERS SAR images of a flood in the Cat-Tien National Park, Vietnam

May 1999

September 1999

Multitemporal SAR Images: 10 years ago ….
New Satellites with VHR SAR Sensors

- JERS-1
- ERS-2
- ASAR
- PALSAR
- RADARSAT-2
- RISAT
- TerraSAR-X
- TanDEM-X
- Cosmo-SkyMed 1-4

Spatial resolution (m)

Years:
- 1990
- 1995
- 2000
- 2005
- 2010
- 2015
Multitemporal SAR Images: New challenges

Comso-Skymed SAR Images of the Earthquake of L’Aquila, Italy

In multitemporal SAR VHR images we have many sources of backscattering changes.

Often backscattering changes associated with different sources exhibit characteristics similar to each other. They can be separated only by explicitly modeling the EM behavior of complex objects.

To this end it is necessary to bridge the semantic gap between low level features and semantic information:

- Modelling the interaction between the EM waves and the imaged objects;
- Extracting the different object components with proper detectors;
- Combining object components for identifying the objects and the possible changes in their state.
Example: Building Detection in VHR SAR Images

Building EM model

VHR satellite SAR image

Primitives and Semantic: Building Detection

Despeckled image

Detected lines

Detected bright areas

Detected shadow areas

Detected building footprints
Example: Building Detection in VHR SAR Images

• Moving from object detection in single images to object change detection in multitemporal images increases the complexity of the information extraction.

• In order to define an effective general approach to change detection for VHR SAR images we have to:

  ✓ Decompose the general complex problem in simpler hierarchical problems.

  ✓ Exploit the intrinsic multiscale nature of objects present in VHR images.

  ✓ Model the specific properties of expected changes for extracting the semantic meaning of backscattering changes.

  ✓ Exploit the available prior information on the considered scenario.
Example: Building Change Detection

Objects level

Geometric primitives

Pixel Level

Building Change Detection Map

Meta-levels fusion

Problem: Error propagation

Building Change Detection Map

VHR SAR image $t_1$

VHR SAR image $t_2$

Bright Areas

Shadow Areas

Double bounce area
Architecture for Change Detection in VHR SAR


Changes in VHR SAR images implies increase or decrease of backscattering values.

Changes in buildings (i.e., new/destroyed buildings) implies simultaneous increase and decrease of backscattering.

Search for pairs of increase/decrease backscattering pattern.
Example: L’Aquila Earthquake

Multitemporal data set: section (1024×1024 pixels) of two spotlight (CSK®) images acquired before (5th April 2009) and after (12th September 2009) the earthquake of L’Aquila (Italy, 6th April 2009).

- 1m×1m resolution
- X-band
- 1-look
- Amplitude
- HH-polarization
- 57-58 degree incidence angle
- Ascending orbit
- Right look
- CSKS1
- Calibrated
- Co-registered
- Geo-referred

Optical image GeoEye, Tele Atlas 2011
Google ©

RGB multitemporal composition
(R:09/12/2009, G:04/05/2009, B:09/12/2009)

- Backscattering decrease
- Backscattering increase
- Unchanged areas

Example: L’Aquila Earthquake
Example: L’Aquila Earthquake

Pre-Crisis Reference Image

Post-Crisis Reference Image

Changed building map
- Destroyed Building
- Change (no destroyed building)
4. Change Detection in Very High Resolution Multisensor Images
Earthquake of Sichuan province, China, May, 2008
Top-Down/Bottom-Up Approaches

Classification maps, ancillary data, objects maps, cadastral map

Prediction

Simulated VHR image $t_1$

Object extraction

Classification map, object map

VHR image $t_2$

Change detection map at object level

change detection map
CD in Multisource Data: Example


Building Map at $t_1$

$t_2$ SAR incidence angle

Model of the building

Simulation of SAR Building Footprint

Simulated Building footprint at $t_1$

VHR SAR image $t_2$

Change Detection Map of Buildings

© Lorenzo Bruzzone
✓ Analysis and exploitation of time series and multitemporal images is a very important topic both from the methodological and the application perspective.

✓ Many methodological challenges are related to the properties of new satellite data that require the development of a new generation of processing techniques for the analysis of:
  • VHR multispectral and SAR images.
  • Hyperspectral images.
  • Long time series (data mining).

✓ These properties open the possibility to develop also new applications that exploit either the very high geometrical (e.g. analysis of single buildings) or spectral (e.g. detection of subtle changes) resolution and the increased revisit time (e.g. monitoring and surveillance application).