CNES R&D
and available software
for Space Images based
risk and disaster management

Geo-Information for disaster management
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Use of satellite imagery for disaster management
- Some examples
- Images co-registration
  - Similar images
  - Multi_sensor images
- Geo-referencing process description and accuracy
  - Optical images
  - Radar images
- Change detection and Information extraction
- CNES software for risk management
- CNES research programme related to risk
Advantages:

- **Spatial coverage**: (10-20 km)$^2$ for very high resolution satellites, (60-100km)$^2$ for high resolution ones – Spot5, Envisat - (500-1000km)$^2$ for global coverage ones -Vegetation-
- Many operational satellite systems, at different resolution hence adapted to different kind of disasters
- Acquisition possible independently from local facilities (telecommunications, operators), processing possible in remote sites
- Archive images growing
- Optical and / or Radar images possible: complementarity

**BUT**
Use of satellite images for disaster management (2/2)

- Operational timing constraint: no real time acquisition yet
- Images are not directly interpretable => much work required from raw data to usable information
  - Images co-registration / geo-referencing
  - Change detection
  - Damage assessment
  - Product generation (adding map info, etc…)
  - Transfer to the local authorities (fax, email, ftp…)

**Almost real-time acquisition and operational systems dedicated to risk** are a pre-requisite to provide really usable spatial products (on time, with the useful information).
Case 1: Flood in China

- Extension has been assessed at a very large scale
- 1km resolution optical images used (Vegetation on Spot4)
- No damage assessment
Case 2: Tsunami

Many images should be used because of the spatial extend
Locally, 2.5 resolution optical images used (Spot5)

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Case 3: Nyiragongo (Congo): Smaller extend. Clouds => Radar images used

An optical image from the archived is used for land cover estimation.
A before/after radar images pair (all weather) allows for damage assessment.
Their joint use allows to recognize the type of damage.

Spot P+XS image (before)

Radar images based change detection
Before / After (automatic)

Damages assessment
Discussion

- Every case is different (in terms of disaster)
- One uses the first available image after the disaster, and has to build the more adequate processing sequence, depending on
  - Available archive images (instrument, spectral bands…)
  - Knowledge / availability of local DEMs
  - Availability of local maps
- To be reactive, one should tend to automated processing

BUT what is common to all cases is

- The need for image co-registration (=> superimposable image)
- The need for geo-referencing (if data used is not already geo-referenced)
Images co-registration (1/4)

- Superimposability must be accurate (typically better than ~0.5 pixels)
- Pre-requisite for change detection algorithms
- Ideally, should be achieved (but not easy)
  - Without any knowledge about local DEM
  - Without any knowledge about acquisition geometry
  - Even after disaster, when landscape has changed locally
- In practice, when images are geo-referenced independently, they do not have, on the whole image, such a co-registration accuracy => even in this case, need for fine co-registration before change detection.
SIMILAR IMAGES

- Optical to Optical images
  - General principle: shifts computation based on maximisation of local correlation, then one image is re-sampled to the geometry of the other
    - 0.02 accuracy achievable (case of similar images, good quality interpolation filters, well sampled images), but poor accuracy may be experienced in particular with non similar images
    - In case of disaster, images locally non similar, because
      - elapsed time between acquisitions
      - surface changes due to damage
    - Damage assessment itself based on radiometry changes !!
  - Hence co-registration must be performed using homologous points on non-damaged areas, and interpolating / extrapolating on damaged areas
SIMILAR IMAGES

- Radar to Radar images
  - On same incidence images
    - Good results using SLC because same speckle (interferometric conditions)
    - But no real add-on value for co-registration. Better use multi-look images correlation
  - On images with different incidences
    - When acquisition angles become slightly different, speckle noise changes => accuracy decreases.
    - When acquisition angles are very different, ML images become very different =>
      - Refinement of NR and acquisition start time of both images by image simulation (using DEM)
      - Projection of both images on the terrain
      - Local co-registration like for optical images.
MULTI-SENSOR IMAGES

- Correlation technique no more applicable
- Recent R & D work performed in the field of space images, based on algorithms already used in the medical imaging community
  - Locally, radiometry is considered as a random variable (area must be large enough, larger than for correlation)
  - Measurement of the statistical dependence between the two distributions
  - Search for the position of the maximum similarity value => homologous points
- Applicable to Radar / Optic but also Optic / Optic pairs, in different spectral bands
Geo-referencing is THE condition for being able to use map information.

Satellite position and attitude errors impact the geo-referencing, both globally and locally.

Raw image (acquisition geometry)

Geo-referenced image geometry: superimposable to a map

\[
\begin{align*}
  x &= x_0 + r \times b \\
  y &= y_0 - r \times a
\end{align*}
\]
Images geo-referencing (2/4)

Impact of satellite position restitution errors
- Along-track
- Across-track
- Altitude

Impact of satellite attitude restitution errors
- Biases
- Variations in time

- Pitch
- Roll
- Yaw

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Satellite position / attitude restitution errors
=> errors on local elevation estimate

Example
1m resolution image
10° incidence
=> 1 pixel shift for every 5.7 m elevation error (0.5 pixels shift easy to reach with a typical 10m localization accuracy)

Example
1m resolution image
45° incidence
=> 1 pixel shift for every 1m elevation error
Conclusion on geo-referencing:

⇒ Even with already geo-referenced images, superposition is likely to be not precise enough for accurate change detection. (experience with optical images times series, and optical to radar superposition)

⇒ There is always a need for automatic co-registration

⇒ The impact of non accurate geo-referencing is more sensitive with high resolution, proportionally to the resolution

⇒ With high resolution images, we are close (or already beyond) the accuracy of the map themselves (when available)… Therefore, for a fully automatic process, one should think about automatic map to image co-registration.
Change detection and information extraction (1/2)

- Geometrical changes (e.g. Surface movement measurement)
  - Shifts measured by optical correlation or radar interferometry

- Radiometrical changes: CNES has implemented the following algorithms
  - Intensity ratio, at pixel level
  - Mutual information, on a local area
  - Local morphological gradient average direction
  - Comparison of probability density distance (before / after disaster): has proven to be well suited for radar images acquired at different incidences
  - Loss of coherence (radar/radar but also optic/optic)

  **But a promising direction is the comparison of image objects**
Objects extraction

- CNES has been working on automated man-made object recognition (road, roundabouts, suburbs, bridges, isolated buildings…)
- Supervised learning approach based on Support Vector Machines
- Evaluation with the confusion matrix (good detection, non detection, false alarm)
- Results: with 10 object classes, 150 learning examples / class
  => 80% of good detection achieved
- Drawback: slow process => extensive tests difficult, in particular on large images like Spot5 ones (24000*24000 pixels)
  => Need for pre-selection using a different technique (pre-conscious user models used)
Aim: Automatic production of damage maps
- Superpose images acquired at different dates, from any satellite instrument, radar or optical
- Detect changes
- Produce damage maps

Development environment: Python (portable, automatic MMI building)
- Not fully available yet, but expected soon. Underlying software used:
  - Geometrical modelling
  - Re-sampling
  - DEM generation (when not already available)
  - Object recognition
  - Change detection
CNES research program related to risks

R&D on-going work

- Continuation on object extraction (improvement of computer time by a two-pass method)
- Implementation of optical to radar image geometrical models
- Continuation of work on radar stable detectors
- Development of algorithms for optic / radar change detection