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Combined use of spaceborne optical and SAR data Incompatible data sources or a useful procedure?

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Overview

- ***Introduction***
- ***High resolution optical satellites***
- ***Synthetic Aperture Radar (SAR)***
- ***Integrated use of optical & radar data***
- ***Conclusions***

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Introduction – Optical satellites

Use of SAR data and optical satellite images longer than 3 decades

In the first years, restricted use due to

- low resolution of images
- limited processing capabilities for implementation of rigorous models

In the recent years

- increase of optical satellites providing very high resolution data
- new rigorous models for image georeferencing

Increase of automation in processes & accuracy of products

Weaknesses: Need of GCPs

Improvement of feature extraction and change detection

Introduction – SAR systems

Spaceborne radar systems with high spatial resolution were not so rapidly developed

The situation has changed:

During last year 6 SAR systems were launched

Image resolutions of few meters or even of 1m

- New range of applications is possible
- Radargrammetry modules are integrated into DPWs
  ERDAS, ENVI, etc

Introduction – Combined use

Attempts of a combined use of optical and SAR data

In both cases the data can be images, showing the characteristics of objects differently

↓ *combined use*

More information & better results in particular applications

e.g., change detection,
features extraction,
orthoimage production,
coastal zone management, etc

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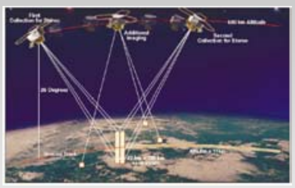
High resolution optical satellites

The latest generations of high resolution optical satellite sensors are pushbroom scanners, having the ability to acquire stereo pair imagery in along track direction, with very high stability



Optical spaceborne sensors:

- FORMOSAT, ROCSat, IRS-P5
  2-2.5m resolution in panchromatic band
- IKONOS, QuickBird II, EROS-B, CartoSat2, Kompsat-2
  0.6-1m GSD
- WorldView-1
  0.5m GSD at nadir and 59cm GSD at 25º off-nadir
- GeoEye-1
  0.41m resolution (resampled to 0.5m)

… more sensors are scheduled for the near future
(e.g. DigitalGlobe has scheduled to put in orbit three satellites in the coming months)

Mathematical models for georeferencing

- Simple sensor models (for sensors with narrow FOV)

  2D or 3D affine transformation: $x = a_o+a_1X+a_2Y+a_3Z$

  $y = b_o+b_1X+b_2Y+b_3Z$

  DLT or SDLT : $x = \frac{a_o+a_1X+a_2Y+a_3Z}{1+c_1X+c_2Y+c_3Z} + a_4xy$ $\quad y= \frac{b_o+b_1X+b_2Y+b_3Z}{1+c_1X+c_2Y+c_3Z}$

- Sensor model based on RPCs (metadata provided by the vendors)

$$x = \frac{P_1(X,Y,Z)}{P_2(X,Y,Z)} \qquad y = \frac{P_3(X,Y,Z)}{P_4(X,Y,Z)}$$

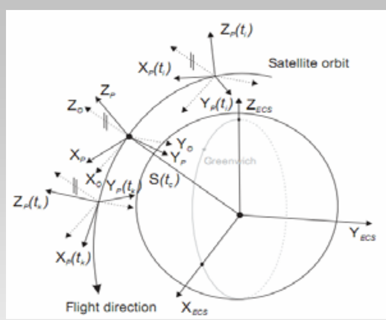
$$P(X,Y,Z) = \sum_{i=0}^{m1}\sum_{j=0}^{m2}\sum_{k=0}^{m3} a_{ijk} X^i Y^j Z^k$$

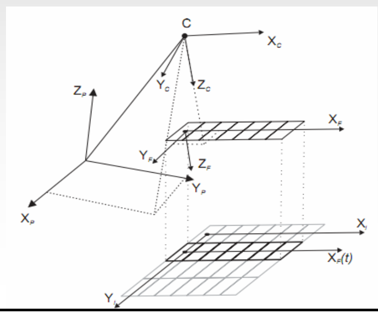
- Rigorous sensor model

  closely related to the physical reality of the imaging process

Rigorous model: Coordinate systems

- Object system (X_{ECS})
- Orbital system (X_O)
- Platform system (X_P)
- Camera system (X_C)
- Framelet system (X_F)
- Image file system (X_I)





Rigorous sensor model

Several models, for geometric correction and georeferencing of satellite images, have been proposed:

- trying to model the platform orbits and attitudes
- using different corrections of systematic errors
- attempting to overcome the incompatibility of formats of the metadata

Collinearity equitions, including internal & external orientation modeling combined with orbit determination – propagation models :

$$\begin{bmatrix} 0 \\ -y_i + yo \\ f \end{bmatrix} = M_q \cdot M_{db}(dt) \cdot M_b(dt) \cdot \begin{bmatrix} X_{gi} - [Xo(dt) + dXo(dt)] \\ Y_{gi} - [Yo(dt) + dYo(dt)] \\ Z_{gi} - [Zo(dt) + dZo(dt)] \end{bmatrix}$$

High resolution optical satellites

- High revisit frequency
- High resolution
- Great number of satellites

Mapping and other applications:

- ✓ building modeling
- ✓ change detection
- ✓ recording and monitoring of phenomena and human activities, e.g., urban damage mapping, forest fires, damage assessment, etc

… the need for automatic procedures and reliable results is increased

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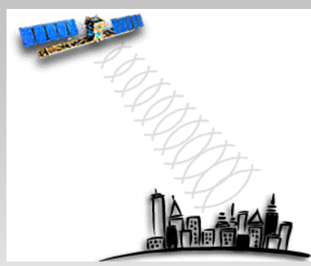
SAR: Operational Principles

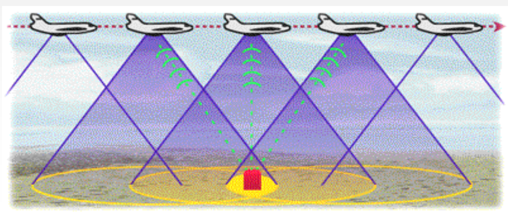
- Active microwave imaging sensor
- Own microwave illumination
- Day and night operation
- Independent of weather conditions



- SAR can not measure true optical colors
- It measures the strength & the time delay of the returning signal

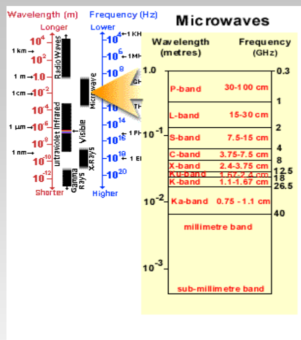
SAR sensors consist of two instruments: radar & processor

SAR's antenna
Side-looking geometry



SAR: Sensors

- Airborne
- Spaceborne (satellite or space shuttle)
- Planetary (extraterrestrial)
- Unmanned Aerial Vehicle



- L band (30 - 15cm)
- S band (15 - 7.5cm)
- C band (7.5 - 3.75cm)
- X band (3.75 - 2.40cm)

  highest resolution

Last year: TerraSAR-X, Radarsat-2, Sar-lupe II & Sar-lupe III
Cosmo-Skymed I & Cosmo-Skymed II

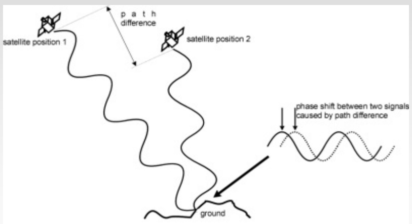
... many more are expected:
Sentinel, TerraSAR-L, Tandem-X

New sensors:
- unprecedented high resolution
- introduce the concept of SAR sensors' constellation

SAR: Methods of data processing

Interferometry (InSAR/IfSAR)

Superimpose two or more waves, in order to detect the differences
Spaceborn applications:
- Dual-pass (or Repeat-pass) interferometry
- Differential interferometry displacements with sub-cm accuracy
- Single-pass interferometry, using a platform with 2 SAR antennas
  Across-track (perpendicular to flight direction) or Along-track (parallel)



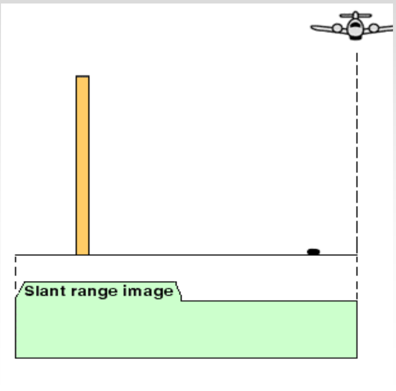
Applications: topographic mapping, DTM generation,
velocity mapping (currents mapping, detection of moving targets), change mapping (earthquake monitoring, landslides, glacier dynamics)

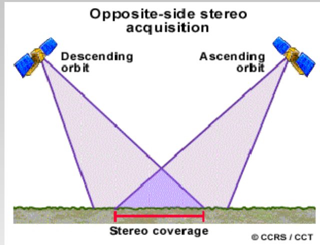
SAR: Methods of data processing

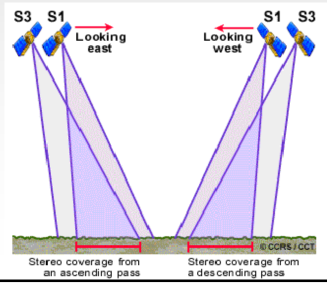
Radargrammetry: the technology of extracting object information from radar images

Products: Maps, DTMs , orthoimagery

- Same side stereo
- Opposite side stereo







SAR: Methods of data processing

Polarimetry: The radar antenna may be adjusted to transmit and receive waves of the same or different polarity (HH, VV, HV, VH)

Information about the material of the target (ice, vegetation, etc)

Applications:

- Agriculture (crop type identification, land cover mapping)
- Forestry (biomass estimation, species identification)
- Geology
- Hydrology (soil moisture, snow hydrology, flood detection)
- Ocean surveillance
- Coastal zone monitoring (shoreline extraction, oil spill detection)

SAR: Applications

Wide range of applications: reconnaissance
navigation
spatial planning
environmental monitoring
risk diagnostics
oceanography
archaeology

Mapping applications:

- Topographic mapping (features extraction, DTM generation, flood mapping, underwater bottom topography)
- Velocity mapping (glacier velocity, target's velocity, traffic monitoring)
- Change detection (ground deformation, earthquake damages, building extraction, urban structure, land cover)
- Costal zone monitoring, shoreline detection

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Integrated use of optical & radar data

Optical and SAR data present many differences and similarities

Complementary use of SAR and optical data is illustrated with:

A. Cooperation of optical and SAR satellites

- Joint CNES/ASI Orfeo international program:
  optical component of 2 satellites with sub-meter accuracy (Pleiades, developed by France)
  radar component of four SAR satellites with meter accuracy (COSMO-SkyMed, developed by Italy)
- The Brazilian SAOCOM constellation, which consists of 4 satellites is planned to be synchronized with the Cosmo-Skymed

B. Simultaneous existence of both sensors in the same satellite

e.g., ALOS satellite system

Integrated use of optical & radar data

Integrated use of optical and SAR data can be carried out:

- **In sequence**

  The **output** products of the one set are used as **input** data for the other: Information that is essential for the exploitation of the one set or demand time or pricy procedures/data, can be acquired by the other

  Application example: Generation of optical orthoimagery with DEM extracted by InSAR

- **In parallel**

  Both data sets are **independently processed** and then information that is extracted is superimposed for presentation purposes

  Application example: Coastal zone management, where a variety of different kind of information are acquired, some of them can only be extracted from optical imagery while others can only be extracted from SAR data and others from both of them

Integrated use of optical & radar data

➢ **Auxiliary**

The products of the one set are treated as **complementary** information for the products that comes out from the other set. Information that is not possible to be extracted from the one data set or it is extracted incomplete is then extracted/completed by the other set

Application examples:

- Improvement of DEM (accuracy & completeness) with optical and microwave data fusion

- Reconstruction of man made objects (buildings, bridges), optical image give information on the scene organization in order to improve 3D SAR reconstraction

… the integrated use of them is still subject of research

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Conclusions

Reasons to introduce SAR data in the fusion process with optical imagery:

- acquire data on a systematic basis, independent of weather conditions and daylight
- be sensitive to roughness and di-electric properties of the targets
- detect slow movements and changes

Expected gains:

- broaden the application range of satellite data
- increase the rates of success of some procedures
- lead to the creation of fully-automated procedures

But …

the purchasing cost of both the optical and the SAR data remains high, so their combination increases the problem

Consequently,

the extended research of the capabilities of an integrated use is of important significance