Combined use of Spaceborne Optical and SAR Data – Incompatible Data Sources or a Useful Procedure?

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Key words: Photogrammetry, SAR, Optical satellite data, Data fusion, Orthoimage, Change detection

SUMMARY

In the recent years there is an increasing interest for high resolution satellite data to be used in a variety of applications, some of which referring to extracting geometric object information and mapping. The spatial resolution of spaceborne optical data is by now less than 1m in panchromatic image; rigorous orientation and georeferencing models have been developed, giving products (orthoimages, DTMs) of accuracies better than 1 pixel of the data. At the same time, the interest on Synthetic Aperture Radar (SAR) sensors and related processing techniques was increased, too. SAR is considered to be unique among the remote sensing systems, as it is all-weather, independent of time of day, and it is able to penetrate into the objects. New SAR sensors have unprecedented resolution, equivalent to optical data, and they introduce the concept of SAR sensors constellation. Only last year, six SAR systems were launched. SAR and optical data have differences and similarities at the same time. In the past they were considered exclusive, but today they are considered to complement rather than compete with each other. This concept is illustrated with cooperation of optical and SAR satellites, as well as with scientific studies
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In this paper, the available optical and SAR spaceborne systems are presented, focusing on their properties, the methods for processing them, the applications and the ways in which they can be combined or integrated for high quality surveying of earth's surface. Optical and SAR data can be used in sequence, in parallel and auxiliary. When processing data in sequence, the output products of the one set are used as input data for processing the other data set, e.g., for fully automated procedures without using external data etc. When processing data in parallel both data sets are independently processed and then the extracted information superimposed for presentation purposes. There are various possible uses, e.g., for coastal zone management where different kind of information are required and 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. When processing 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, e.g., improvement of DEM with optical and microwave data fusion.

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1. INTRODUCTION

The use of SAR data and optical satellite images for remote sensing applications already counts a longer than three decades' history. In the first years the low resolution of images and the limited processing capabilities combined with the need for implementation of rigorous mathematical models had restricted the use and the application range of such data. However, in the recent years the situation has changed and the interest for high resolution satellite data to be used in a variety of applications has increased significantly. Applications requiring the existence of high accuracy geometric products and mapping using photogrammetric procedures (orthoimages or restitutions) have been added to the everyday use of spaceborne data.

This has resulted to an increase of optical satellites providing a variety of choices, even for very high resolution data, with Ground Sample Distance (GSD) less than 2.5m. Simultaneously, new rigorous models were developed for image georeferencing which increased even more the automation in processes and the accuracy of the final products. However, weaknesses and needs still exist. High accuracy products are directly dependent on the use of ground control points (GCPs); improvement of feature extraction procedures and change detection results are also some of the needs.

Spaceborne radar systems which provide relatively high spatial resolution were not so rapidly developed; their highest resolution reached 15m, making the application range limited. Recently, this situation has changed; only during last year six SAR systems were launched, equipped with sensors which provide images of a resolution of a few meters or even of 1m. Consequently, a new range of applications was possible and photogrammetric techniques were introduced in the processing of such data; radargrammetry modules are integrated into Digital Photogrammetric Workstation software (e.g., ERDAS, ENVI, etc).

In this environment attempts for a combined use of optical and SAR data are of special interest. The significant differences between the characteristics of those two data sources do not encourage their combined use. However, in both cases the data can be images (either as initial data or derived after a processing), which show the characteristics of objects differently; so finally, their combined use may provide with more information and better results in particular applications. Advantages of the combined use of radar and optical satellite data have been emphasized in Bignami et al, 2004; Stramondo et al, 2006 and elsewhere, while the results of some applications for change detection (Orsomando et al, 2007), features extraction (Soergel et al, 2007; Tupin & Roux, 2003; Stilla et al, 2005), orthoimage production (Cheng, 2007), coastal zone management (Raouf & Lichtenegger, 1997), etc have been published.

In the following, a brief review of the high resolution satellite sensors is given focusing on the methods for processing their data, with an emphasis on SAR, whose capabilities and applications are less known. Integrated and combined uses of optical and SAR data are presented, together with their capabilities and future perspectives.

2. HIGH RESOLUTION OPTICAL SATELLITES

Since 1999, when IKONOS was launched, the capabilities and range of applications of optical satellite sensors data have changed. The satellite images become more and more useful for photogrammetric purposes. The latest generations of high resolution optical satellite sensors are pushbroom scanners and they have the ability to acquire stereo pair imagery along track direction. Using array detectors, which are arranged in a focal plane along a line, they can collect images with very high stability.

Governmental agencies of more than 10 countries and private companies worldwide have placed in orbit, or are planning to do so, high resolution commercial satellites. Already in FORMOSAT, ROCSat (Taiwan), IRS-P5 (India) with 2-2.5m resolution in panchromatic band, and IKONOS, QuickBird II, EROS-B (Israel), CartoSat2 (India), Kompsat-2 (Korea) with 0.6-1m GSD, WorldView-1 (launched in September 2007 - orbit altitude 496km, period 94.6min) with 50cm GSD at nadir and 59cm GSD at 25^{o} off-nadir, suitable for precise mapping, change detection and in-depth image analysis was added. It has 17.6km width swath and expected accuracies of 4-6.5m without GCPs. (http://www.digitalglobe.com/about/ worldview1.html). Similar or even better results are expected from GeoEye-1, which has an estimated launch date early second quarter 2008; its sensor has 0.41m (resampled to 0.5m) image resolution in panchromatic and 1.65m in multispectral imagery, while the accuracies of the products will be of the size of 3m, according to the estimations given by the company which will operate it. (http://www.geoeye.com/products/imagery/geoeye1/ default.htm).

Most of these satellites provide the necessary parameters for photogrammetric processing, like the interior orientation parameters of the camera, which is carried in the satellite system, and orbital data. According to the application (accuracy specifications, existence of GCPs), the provided metadata for the particular sensor and the processing software, the appropriate mathematical model is selected:

- Simple sensor model. For satellite sensors with a narrow field of view, like IKONOS, simple sensor models can be used, such as the 2D or 3D affine transformation, DLT (Baltsavias et al, 2001; Yamakawa & Fraser, 2004). Their validity and performance is expected to deteriorate with increasing area size, rotation of the satellite during imaging, poor GCP distribution or mountainous terrain.

- Sensor model based on RPCs. A Rational Function Model (RFM) is generally the ratio of two polynomials derived from the rigorous sensor model and ground control and/or sensor orientation information. For some of the sensors, a set of rational polynomial coefficients (RPCs) are provided by the vendors (in metadata of images). These models do not describe the physical imaging process but use a general transformation to describe the relationship between image and ground coordinates. It has been shown that no loss in accuracy is to be expected when RPCs are used for georeferencing, as long as a few GCPs will be used for the elimination of systematic errors (Fraser & Hanley, 2003). Two translations are sufficient with IKONOS, while QuickBird exhibits more nonlinearities and requires a higher order transformation.

- Rigorous sensor model. Many models that are closely related to the physical reality of the imaging process (nearly parallel projection in along track and perspective projection across track) have been developed for geometric correction and georeferencing of satellite images. These models can achieve high accuracies, but their efficiency depends on sensor type and they are mathematically complicated, while some of the involved parameters (especially in the interior orientation) are highly correlated. Several models have been proposed, trying to model the platform orbits and attitudes, using different corrections of systematic errors and attempting to overcome the incompatibility of formats and definitions of the metadata provided by the different sensors (Tao et al, 2000; Fritsch & Stallmann, 2002; Dowman & Michalis, 2003; Baiocchi et al, 2004; Weser et al, 2007). In all cases the mathematical model is the collinearity equations, including internal and external orientation modeling, combined with orbit determination-propagation models. The internal orientation parameters are focal length, principal point displacements, line curvature, line rate, lens distortion etc; some or even all these parameters are not always involved in the model.

Due to the above characteristics, the optical sensors imagery is no longer used only in traditional remote sensing applications (e.g., classification) but in mapping as well, and also in more specified applications, like building modeling (Baltsavias et al, 2001), change detection, etc, with a further perspective. The high revisit frequency (of a few days for each satellite) and the great number of high resolution optical satellites which are scheduled for the near future (e.g., DigitalGlobe has scheduled to put in orbit three satellites in the coming months), will allow recording and monitoring of phenomena and human activities (e.g., constructions) which are developed rather quickly (change detection, urban damage mapping, forest fire damage assessment, etc).

Under such circumstances, the need for automatic procedures and reliable results are increased. For example, orthoimage is the most common mapping product derived from optical satellite imagery. However the need for GSPs, in order to achieve high accuracies, and the accompanying manual measurements of their image coordinates, increase the cost and restrict the automation of the whole procedure. Only the combined use of directly georeferenced data, derived from other sources, may lead to fully automated procedures, which are necessary in same mapping or monitoring applications. Also, in applications like feature extraction and change detection the characteristics of the optical data may be a burden, since their efficiency and accuracy are limited by the optical resolution, or by the capability, accuracy and reliability of image matching in automatic procedures. Their combination with data derived from other sources may increase the rates of success.

After all, despite the increase of satellites in number, the purchase costs of imagery, especially of the high resolution stereopairs, is still very high, e.g., compared with the cost of airborne photos; and, unfortunately this is something that is not likely to change in the near future.

3. SYNTHETIC APERTURE RADAR (SAR)

3.1 Operational principles

SAR is an active microwave imaging sensor. It captures earth's images providing its own microwave illumination and it offers the capability of day and night operation, regardless of weather conditions. SAR is not dependent on the visible, optical, part of electromagnetic spectrum. It can not measure true optical colors. Instead, it measures the strength and the time delay of the returning signal. SAR sensors consist of two instruments, the radar and the processor. The radar takes the measurements and the processor does the processing of the data collected by the radar. These two instruments are often independent to each other. The radar is mounted on a platform while the processor is somewhere on earth's surface.

The most prominent feature of SAR's radar is its oblong antenna, about 10 m in length and 2m in width for spaceborne systems. The antenna is fixed on a platform and scans a swath adjacent to platform's flight line, with side-looking geometry (Figure 3-1 left). The space-borne platform moves with about 7 Km/sec and the antenna transmits about 1,500 pulses/sec downwardly towards the area of interest (Figure 3-1 middle). The transmitted pulses reach targets and they interact with them in several ways. Part of the transmitted energy is reflected and returns to the antenna as a weaker radar echo (Figure 3-1 right). The amplitude and the phase of the backscattered signals are then recorded.

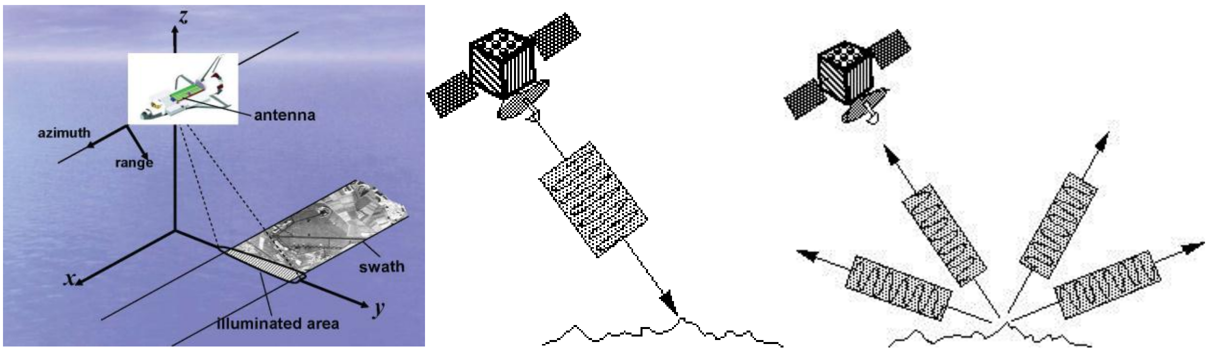

Figure 3-1: Left: Imaging geometry of a SAR system. Middle: Pulse transmission. Right: Pulse reflection (source: http://southport.jpl.nasa.gov)

As the platform moves forward, the radar transmits and receives many pulses from the same target which are combined into a stronger signal (Figure 3-2). Due to platform's movement a phase variation occurs to target's backscattered signals, as the distance between the target and the antenna varies. The differences in phases are corrected through signal processing and then the backscattered signals are added. The addition is based on coherence, a property of waves which enables them to be correlated. The added signals result in a much more focused image where more detail can be distinguished, and which, in image processing terms, is translated to higher image resolution. This has the effect of "synthesizing an antenna" which is significantly longer than the physical antenna and hence the terminology "Synthetic Aperture Radar" (SAR). In fact, the length of the synthesized antenna is different for each target and is equal with the distance between the first and the last antenna position from which the target is illuminated.

In the recent years there is an increasing interest in the development of SAR sensors and the improvement of processing techniques. The SAR systems are considered to be one of the most unique remote sensing facilities because of the all-weather capabilities, independence of time of day and the penetration ability into the objects. Only last year, six SAR systems were launched (TerraSAR-X, Radarsat-2, Sar-lupe II, Sar-lupe III, Cosmo-Skymed I, Cosmo-Skymed II) and many more are expected to be launched in 2008. The new sensors have unprecedented high resolution, and they also introduce the concept of SAR sensors' constellation.

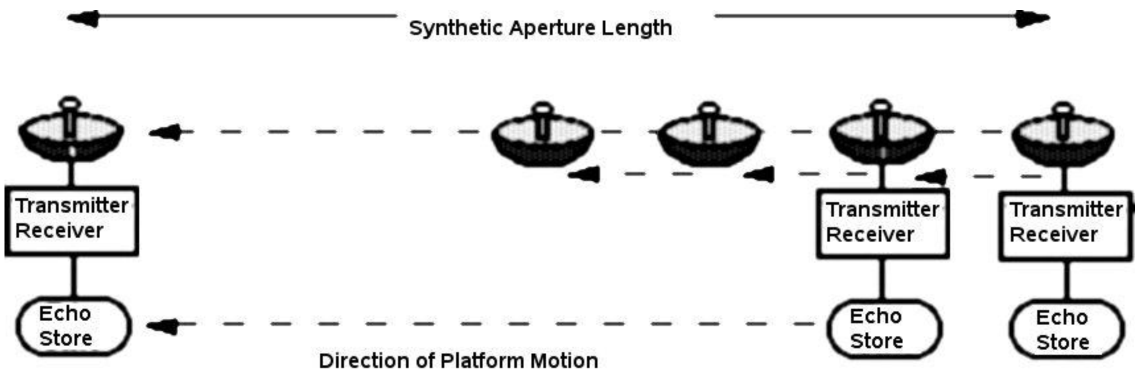

Figure 3-2: Representation of the synthetic antenna

3.2 Classification of SAR systems

The SAR sensors, according to the vehicle that carries them and to the target they survey, can be classified to:

- Airborne SAR sensors; they are mounted on aircrafts and they survey the surface of the earth. Such systems are: AirSAR (USA), C/X SAR (Canada), E-SAR (Germany), KRAS (Denmark), RAMSES-ONERA (France), EMISAR (Denmark), Pi-SAR (Japan) and STAR-3i, TopSAR, STAR-4 (Intermap).

- Spaceborne SAR sensors; they are mounted on satellites or space shuttles and they survey the surface of the earth. In Table 1 all the recent and the expected in the near future medium and high resolution spaceborne SAR systems are listed, together with their basic characteristics. The number of the satellites which launched during the last three years, and especially of those scheduled for the next period, is impressive.

- Planetary SAR sensors; they are mounted on space devices and they survey extraterrestrial planetary objects. They have proved to be very efficient for planets or satellites with opaque atmosphere, such as Venus and Titan (Figure 3-3). Such systems are: Magellan (mission to Venus, 1990, NASA), Venera 15 and Venera 16 (mission to Venus, 1983-1984, Russia), Cassini (mission to Saturn and its moons, 2004, NASA/ESA/ASI). Mars Scout Radar, which is scheduled for 2009 launch, is expected to penetrate the notorious dust storms of Mars (mission concept, NASA).

- UAV (Unmanned Aerial Vehicle) sensors; they are essentially airborne SAR systems mounted on unpiloted aircrafts. UAVs are able to fly for tens of hours without human pilot. Such systems are still experimental and include: YINSAR και microSAR (Brigham Young University) and NASA UAVSAR.

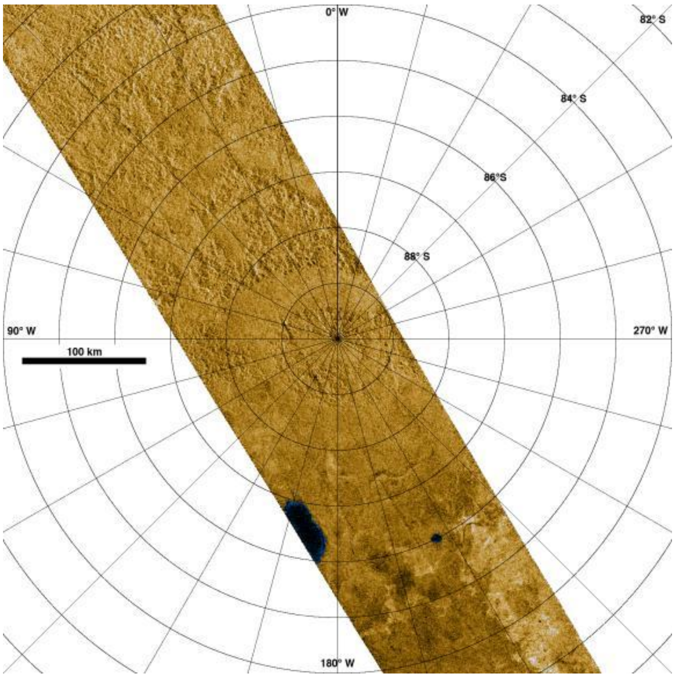

Figure 3-3: Radar images of Titan's South Pole collected by Cassini's SAR on Dec. 20 2007 (source: http://saturn.jpl.nasa.gov)

The SAR spaceborne systems use wave lengths 30-15cm, 15-7.5cm, 7.5-3.75cm and 3.75-2.40cm belonging to L, S, C and X bands respectively (Table 1). L-band SAR systems are not hindered by atmospheric effects and are capable of “seeing” through heavy rain showers. Their penetration capability with regard to vegetation canopies, glacier or sea ice, and soils is considerable. S-band SAR systems are capable of “seeing” through tropical clouds and rain showers with a minimum of attenuation. Their penetration capability with regard to vegetation canopies or soils is very moderate and is restricted to the upper layers. C-band SAR is not hindered by atmospheric effects and is capable of “seeing” through tropical clouds and rain showers. Its penetration capability with regard to vegetation canopies or soils is limited and is restricted to the top layers. Imaging radars equipped with X-band are usually not hindered by atmospheric effects and are capable of “seeing” through clouds and light rain showers. Attenuation problems can be encountered in heavy rain, particularly in tropical regions. The penetration capability with regard to vegetation canopies or soils is very limited and is generally restricted to the surface layer (Canada Centre for Remote Sensing, http://www.ccrs.nrcan.gc.ca). Sensors of this category have the highest resolution and are of great interest for applications including geometric object information.

SAR systems create anisotropic images. The Y dimension is the distance along the flight path, and the X direction is the distance of the sensor and the target and it is perpendicular to the flight path. SAR images have different resolutions in X and Y dimension named range resolution and azimuth resolution respectively. The resolution of SAR systems can be classified (Table 3-1) to Low (>15 m), Medium (2-15 m) and High (<1 m). SAR systems are able of using different acquisition modes: Stripmap, ScanSAR, Spotlight. Differenating the acquisition geometry, they can control the resolution and the swath dimensions.

3.3 Methods and tools for SAR data processing

The most well-known and applied methods for SAR data processing are: Interferometry, Radargrammetry and Polarimetry. Recently, combined use of these methods has also been proposed aiming to better exploitation of SAR data. Such combined methods are Stereo-assisted Interferometric SAR (Schubert, 2004) and Polarimetric Interferometry.

In parallel to the improvement of the mathematical models of SAR data processing, a variety of software has been developed. Some examples of those are

- commercial software tools: DIAPASON, Earthview, eCognition, ENVI, ERDAS, PCI Geomatics, GAMMA, GEOimage, InfoPACK, POLSARPRO, PulSAR, SARscape

- free software tools: BEST, DORIS, EnviView, ERS SAR Toolbox, IDIOT, OTB, RAT, UNESCO-Bilko.

3.3.1 Interferometry (InSAR / IfSAR)

SAR records the phase of the backscattered echoes as well as the amplitude. The phase is utilized during the processing of two or more sets of SAR data with the Interferometry method (Graham, 1974; Madsen & Zebker, 1998). Interferometry is a general purpose method of superimposing (interfering/adding) two or more waves, in order to detect the differences between them (Figure 3-4). Phase differences are presented in an image known as interferogram. For space-borne applications the mostly used interferometry variations are the dual-pass (or Repeat-pass) interferometry and the differential interferometry (DinSAR).

Table 3-1: Basic characteristics of spaceborne SAR sensors

SENSOR	LAUNCH	COUNTRY	BAND				RESOLUTION		
			L	S	C	X	LOW	MEDIUM	HIGH
SIR-A	1981	USA	x				40 m		
SIR-B	1984	USA	x				20 m		
LACROSSE									
LACROSSE 1	1988	USA				x			~1 m
LACROSSE 2	1991	USA				x			~1 m
LACROSSE 3	1997	USA				x			~1 m
LACROSSE 4	2000	USA				x			~1 m
LACROSSE 5	2005	USA				x			~1 m
ALMAZ-1	1991	Russia		x				15 m	
ERS-1	1991	ESA			x		26 m		
J-ERS-1	1992	Japan	x				18 m		
SIR-C/X-SAR	1994	USA Germany Italy	x		x	x		15 m	
ERS-2	1995	ESA			x		26 m		
RADARSAT-1	1995	Canada			x			10 m	
SRTM	2000	USA Germany Italy			x	x	30 m		
ENVISAT	2002	ESA			x		25 m		
ALOS	2006	Japan	x					10 m	
TERRASAR-X	2007	Germany				x			1 m
TANDEM-X	2008	Germany				x			1 m
RADARSAT-2	2007	Canada			x			3 m	
COSMO-SKYMED									
COSMO-1 & 2	2007	Italy				x			1 m
COSMO-3	2008	Italy				x			1 m
COSMO-4	to be announced	Italy				x			1 m
RISAT	2008	India			x			3 m	
TecSAR/TechSAR	2008	Israel				x			1 m
SAR-LUPE									
SAR-LUPE-1	2006	Germany				x			<1 m
SAR-LUPE-2 & 3	2007	Germany				x			<1 m
SAR-LUPE-4 & 5	2009	Germany				x			<1 m
HJ-1C (sarsat)	2008	China		x					
SAOCOM									
SAOCOM 1A & 1B	2008	Argentina	x					7 m	
SAOCOM 2A & 2B	to be announced	Argentina					to be announced		
SENTINEL-1	**2011**	ESA			x			5 m	
SSR-2 (MAPSAR)	**2011**	Brazil Germany	x					3 m	
SURVEYOR SAR									
SURVEYOR-1to 5	to be announced	China			x			10 m	
TerraSAR-L	to be announced	ESA	x					5 m	

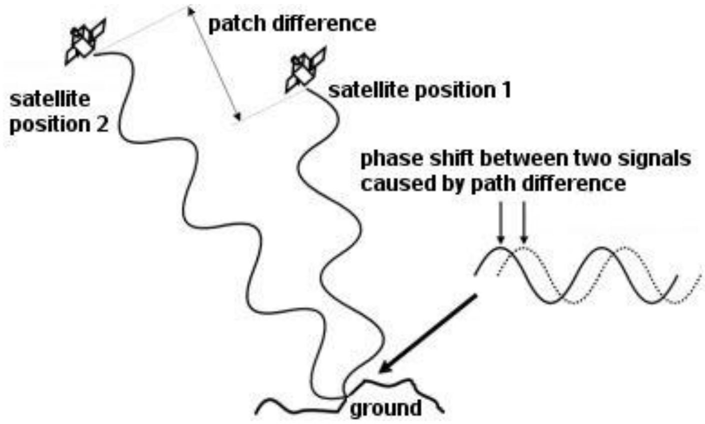

Figure 3-4: Operational principles of Interferometry (source: http://www.npagroup.com)

Dual-pass interferometry is the most popular technique for space-borne interferometric applications (Goldstein, 1998; Li & Goldstein, 1990). It is carried out with one satellite equipped with only one SAR antenna. Satellite passes twice from the same point and measures the same area with a slightly different viewing geometry. It has to be mentioned that there is also an interferometric mode known as single-pass interferometry. This technique is carried out with one moving platform equipped with two SAR antennas, either perpendicular or parallel to the direction of flight (across-track interferometry / along track interferometry). The moving platform passes only once over the area of interest. One antenna works as a transmitter and receiver (master) and the other one as a receiver only (slave). Single-pass interferometry is adapted to airborne systems**.** SRTM was the first, and the only one till today, single-pass spaceborne system. Nowadays satellite constellations is the new spaceborne SAR concept, e.g., TerraSAR & TandemX, Cosmo-Skymed.

Differential SAR Interferometry (DinSAR) is a special case of interferometry mostly used for change mapping such as earthquake monitoring, glacier velocity mapping, landslides and glacier dynamics (Gabriel, 1989). It is able of measuring displacements with high accuracy (sub-cm) using 3 data sets (3-pass or double-difference DInSAR) or 2 data sets and 1 DTM (2-pass or DEM-elimination DinSAR). Two interferograms are produced: either from combining 3 data sets or 2 data sets and 1 DTM. Those interferograms are then compared so that differences can be mapped. Permanent Scattering (PI) is a relatively new procedure based on utilization of stable natural reflectors (eg buildings) for measuring INSAR and DinSAR applications offering higher accuracy and making more stable the procedure.

Interferometry is widely applied for topographic mapping (DTM generation), velocity mapping (currents mapping, detection of moving targets) and change mapping (earthquake monitoring, glacier velocity mapping, landslides, glacier dynamics).

3.3.2 Radargrammetry

Radargrammetry was originally defined as the "science of obtaining reliable measurements by means of radar" (Levine, 1960). Later on, the definition was refined as "the technology of extracting geometric object information from radar images" (Leberl, 1990). Radargrammetry is essentially photogrammetry applied to radar images; it creates products such as maps, DTMs and orthoimagery, using well-known photogrammetric tools such as orientation, rectification, matching etc. The method is employed with single images, pairs of overlapping images, blocks of images and multi-sensor, image and non-image, data sets. Although the idea, the procedures and the resulting products lead directly to photogrammetry, radargrammetry faces some issues arising from the microwave nature of radar images and the side-looking geometry of SAR: foreshortening, layover, shadow, color. Due to these phenomena two radar images of the same area may present many differences and variability (Canada Centre for Remote Sensing). The combination of non-optical measurements and side-geometry makes the microwave image difficult to assess by the human eye although microwave imagery much resemble optical photos at first glance. Stereoscopic processing by a human interpreter is still possible. For space-borne applications mostly used radargrammetric modes are: Same side stereo and Opposite side stereo (Figure 3-5).

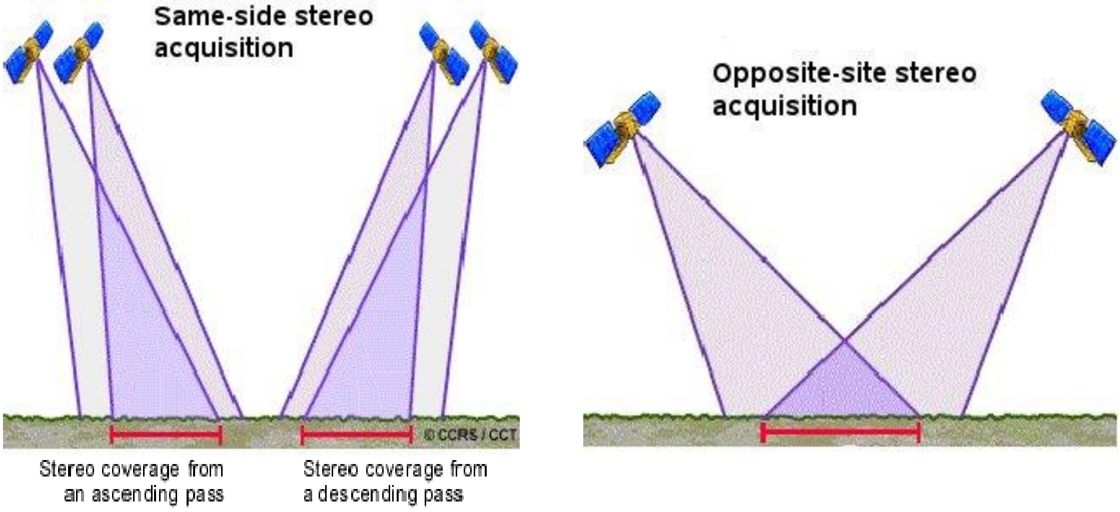

Figure 3-5: Left: Same-side stereo. Right: Opossite-side stereo
(source: http://www.ccrss.com)

3.3.3 Polarimetry

The radar antenna may be adjusted to transmit and receive waves of the same or different polarity. The possible combinations are:
- HH: transmits and receives the waves of horizontal polarity
- VV: transmits and receives the waves of vertical polarity
- HV: transmits waves of horizontal polarity and receives waves of vertical polarity
- VH: transmits waves of vertical polarity and receives waves of horizontal polarity.

The polarity is a SAR parameter which can reveal substantial information about the material of the target (ice, snow, vegetation etc.). When the transmitted wave, which has a certain polarity, is backscattered by the target, its polarity may be differentiated according to the material of the target. The evaluation of the polarity differentiation and the inferred conclusions about the material of the target is the subject of Polarimetry. So, radar polarimetry is concerned with control of the polarimetric properties of radar waves and the extraction of target properties from the behavior of reflected waves from a target (Boerner et al, 1998). Polarimetry has been used for thematic classification studies for applications such as 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).

3.4 Applications

As mentioned above, SAR offers all-weather capabilities, day-and-night land observation and penetration ability into the objects. In addition is a system able of measuring targets' topography, velocity, change and properties. As a sequence of these advantages and capabilities, SAR systems have been efficiently used for a wide range of applications such as reconnaissance, navigation, spatial planning, environmental monitoring, risk diagnostics, oceanography and archaeology; however, the potential use of SAR characteristics for mapping applications is of great interest, such as:

- topographic mapping: planimetric 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
- coastal zone monitoring: shoreline detection.

4. INTEGRATED USE OF OPTICAL AND SAR DATA

SAR and optical data present many differences and similarities, at the same time. Although in the past one stepped the other aside, nowadays the usefulness and the effectiveness of both of them is fully appreciated. Today the idea is the complementary use of SAR and optical data. This concept is illustrated with cooperation of optical and SAR satellites or with a simultaneous existence of optical and SAR sensors in the same satellite (e.g., ALOS satellite system), as well as with the compilation of scientific studies which end up in some specific applications of their combined use.

The most famous example of cooperation of satellites is, probably, the joint CNES/ASI Orfeo program:

- the optical component, Pleiades, is developed by France and consists of two optical satellites with sub-meter accuracy
- the radar component is developed by Italy and consists of four SAR satellites with meter accuracy.

The Brazilian SAOCOM constellation, which consists of four satellites, is also planned to be synchronized with the Cosmo-Skymed constellation.

The road for these recently announced cooperation at level of sensors, has been opened with scientific studies about the integrated use of optical and SAR data. It has been shown that not only is possible to combine optical and radar products but is also efficient. Nowadays it is examined what specific needs can be covered with a combined use of SAR and optical data. The EuroSDR in conjunction with the IEEE GRSS data fusion technical committee (DFC) and the ISPRS working group III/6 "Multi-Source Vision" organised a contest for airborne SAR and optical data. One of the goals was to answer the question whether it would be possible to obtain the same accuracy and quality when interpreting SAR instead of optical image data. In general it was observed that large linear (roads, highways etc) and areal features (buildings, forest areas etc) can be interpreted quite well in SAR images, while small objects of the size of a few pixels can not interpreted satisfactorily by untrained interpreters. The second phase of the contest is expected to give answers to the question of what can be gained when SAR and optical images are used in conjunction (Bellman & Hellwich, 2006).

Integrated use of optical and SAR data can be carried out in sequence, in parallel and auxiliary. When processing data in sequence, the output products of the one set are used as in-put data for processing the other set of data, aiming to ameliorate the conditions of its processing. In this case, information that is essential for the exploitation of the one set can be acquired by the other. Information that may demand time-consuming or pricy procedures/data or even information that is not possible to be acquired by optical data when processing them, can be acquired by SAR data and conversely. A representative sample of processing optical and microwave data in sequence, is the generation of optical orthoimagery with DEM extracted by InSAR. DEM extraction from optical data pre-assumes the existence of stereopairs, whose purchase is costly, while the production of high accuracy radar orthoimages is restricted due to the need for identification of GCPs on the SAR image, which, unlike optical images, it can be very difficult, particularly in mountainous areas due to foreshortening and layover effects. Another case is the DinSAR (two-pass or DEM-elimination DinSAR) with DEM generated from optical imagery.

When processing data in parallel, both data sets are independently processed and then information that is extracted is superimposed for presentation purposes. In this case it is predetermined what kind of information will be acquired by each set depending on the specific needs of the study and the capabilities of each sensor. A characteristic example is the coastal zone management (e.g., Raouf & Lichtenegger, 1997), where a variety of different kind of information are required, that is, topographic and bathymetric maps, location and monitoring of shoreline, oil slick detection, windfield measurements etc; 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.

When processing 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. Studies that have been done for the improvement of DEM with optical and microwave data fusion have shown that fused DEMs shows remarkable improvement in the accuracy measures and promising results in the enhancement of completeness (Crosetto, 1998; Honikel 1998; Karkee, 2006). Fusion techniques over SAR and optical data have also been applied for the reconstruction of man made objects (optical image give information on the scene organization in order to improve 3D SAR reconstruction), such as buildings (Tupin, 2006) and bridges (Soergel, 2006), with promising results.

Achieved results have shown that optical and SAR data can supplement each other in creating high-quality mapping products. The integrated use of them is still under examination, but it is nearly sure that we are about to see more combined techniques and applications in the near future.

5. CONCLUSIONS

Both the exclusive use of spaceborne SAR data and their combined use with optical sensors imagery, gain increasing interest for mapping and monitoring applications. The main reasons to introduce SAR data in the fusion process with optical imagery are the ability of SAR data to:

- 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.

These characteristics can broaden the application range of satellite data or increase the rates of success of some procedures (e.g., change detection, reconstruction of man-made objects) or lead to the creation of fully-automated procedures. For example, it is possible to generate high accuracy (within one pixel resolution of the data) orthoimages of SAR and optical data without GCPs, where very significant cost and time savings can be achieved, but also fully-automated batch processing for generating a large quantity of orthoimages and mosaics, especially useful for applications that require rapid results, such as disaster monitoring.

The purchasing cost of both the optical and the SAR data remains high, especially when these data are derived from high resolution sensors, so their combination increases the problem. However, for applications in large areas this may be balanced, since cost for topographic mapping or orthoimage production can be reduced significantly using satellite data. Also, there are some applications where those data's fusion constitutes the best or even the only technical solution.

Consequently, the extended research of the capabilities of an integrated use of spaceborne optical and SAR data is of important significance for a large range of applications; especially when the use of many new high resolution satellites equipped with optical, SAR or both of these types of sensors, is planned for the near future.

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BIOGRAPHICAL NOTES

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