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Polarimetric Interferometric SAR: Literature Review and an Assessment of its utility for DND

TIF Project Memorandum

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Abstract

Polarimetric Interferometric Synthetic Aperture Radar (SAR) is a recent area of research that has had significant attention from the mid-1990s. This area of research has combined the utility of two SAR technologies: Polarimetric SAR (PolSAR) and Interferometric SAR (InSAR). Polarimetric SAR provides four channels which can be used to determine the polarimetric ellipse, and hence, structural information of the scatterer. Therefore PolSAR is suitable for target recognition and detection applications. InSAR data combines two SAR image data sets acquired from nearly the same perspective. The phase difference between these images provides information about the topography, or changes in the topography between the two image dates. InSAR methods have been used to map terrains, detect environmental changes and determine velocities of moving targets.

By combining both technologies, polarimetric InSAR (Pol InSAR) permits distinction between different distributed targets at different elevations. In particular, most current research is investigating the use of this technology for measuring the height of forest, and to help estimate its biomass. Other applications under research include terrain moisture estimation, terrain roughness estimation, and (of more interest in mapping applications) vertical obstruction detection.

Résumé

Le système radar à antenne synthétique (RAS) polarimétrique inférométrique s'inscrit dans un nouveau domaine de recherche qui fait l'objet d'une attention marquée depuis le milieu des années 90. Ce domaine combine les capacités de deux technologies RAS : le RAS polarimétrique (PolSAR) et le RAS inférométrique (InSAR). Le RAS polarimétrique (PolSAR) possède quatre canaux qui peuvent être utilisés pour déterminer l'ellipse polarimétrique et, par conséquent, pour obtenir des informations sur la structure du diffuseur. Le PolSAR convient donc aux applications de reconnaissance et de détection de cibles. Les données InSAR intègrent deux ensembles de données d'image du RAS recueillis presque du même point d'observation. La différence de phase entre ces images fournit de l'information sur la topographie ou les changements de topographie observés entre des images prises à des dates différentes. Les méthodes InSAR ont été utilisées pour reproduire des reliefs de terrain, détecter des changements environnementaux et déterminer la vitesse de cibles mobiles.

En combinant ces deux technologies, le InSAR polarimétrique (Pol InSAR) permet de distinguer entre plusieurs cibles réparties à différentes élévations. Plus précisément, les derniers travaux étudient la possibilité d'utiliser cette technologie pour mesurer la hauteur des arbres d'une forêt et pour estimer la biomasse de celle-ci. D'autres applications font également l'objet de travaux de recherché: l'estimation de l'humidité et des irrégularités du sol, et (d'un intérêt particulier pour les applications de cartographie) la détection d'obstacles verticaux.

Executive summary

Polarimetric interferometric SAR is currently attracting considerable attention of researchers worldwide. It combines the advantages of polarimetric SAR with its capability for distinguishing different types of scattering mechanisms (and hence the structural information of scatterers), with interferometric SAR and its capability to measure elevation. Hence Pol-InSAR has the potential for distinguishing, and indeed discerning the height of, various scattering mechanisms within a complex distributed target. With low frequencies radars it is being used to measure the height of some forests and to help estimate its biomass. Potential military applications include detection and recognition of military vehicles beneath a canopy, detection and recognition of complex urban structures, detection of tall obstructions that could prove hazardous to low flying air vehicles, and detection and recognition of moving targets.

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Sommaire

Actuellement, le RAS polarimétrique interférométrique attire fortement l'attention de scientifiques partout dans le monde. Il combine les capacités du RAS polarimétrique, qui peut distinguer différents types de mécanismes de diffusion et peut donc fournir des informations sur la structure du diffuseur, et celles du RAS inférométrique, qui peut mesurer les élévations. Il devient alors possible pour le Pol InSAR de détecter la hauteur de divers mécanismes de diffusion d'une même cible complexe répartie. Cette méthode est utilisée avec des radars à basse fréquence pour mesurer la hauteur de certaines forêts et estimer leur biomasse. Parmi les applications militaires possibles, on retrouve la détection et la reconnaissance de véhicules militaires sous couvert forestier, la détection et la reconnaissance de structures urbaines complexes, la détection et la reconnaissance de cibles mobiles, et la détection d'obstacles d'une hauteur élevée qui pourraient présenter un danger pour les appareils volant à basse altitude.

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Introduction: Polarimetric Interferometry

Polarimetric Interferometric Synthetic Aperture Radar (SAR) is a recent area of research that has had significant attention since the mid-1990s. This area of research has combined the utility of two SAR technologies: Polarimetric SAR (PolSAR) and Interferometric SAR (InSAR).

Briefly, Polarimetric SAR provides four channels which can be used to determine the polarimetric ellipse, and hence, structural information of the scatterer. The extraction of this information is suitable for target recognition and detection applications, where different approaches are required for point and distributed targets. Further discussions in the text will describe more thoroughly the polarimetric information and decomposition methods.

InSAR data combines two image data sets (some applications, such as tomography use many data sets) that are images from two similar synthetic aperture arrays which are separated spatially by a distance, referred to as the baseline distance. This distance is typically small. The phase difference between these two (or more) images provides information about the topography, or changes in the topography between the two image acquisition times. InSAR methods have been used to map terrains, detect environmental changes and determine velocities (e.g. fast vehicle motion or slow geological subsidence motion are recovered from image pairs which are separated with appropriate elapsed times) of moving targets.

Recent Polarimetric InSAR (Pol InSAR) research has been primarily orientated towards InSAR applications that distinguish, and indeed highlight, different distributed targets located at the same position but at different elevations. In particular, most current research attempts to exploit the difference in the scattering mechanism between the floor of a forest and its canopy to measure the height of the forest canopy, and help estimate its biomass. Good forest height estimates have been obtained predominantly by the same team of researchers for simple forest structures using the L-band to P-band radar frequency bands.

The challenge for the PolInSAR research at Defence Research and Development Canada (DRDC), which is funded through a Technology Investment Fund (TIF), is to: 1) research the current methods for frequency bands available to Canada (e.g. RADARSAT 2), and 2) develop methods which are more suitable for military applications. Although mapping the topography is of importance to Canada’s military, particularly for Geomatics applications, there are many other potential applications which are relevant to the military and which should be explored.

This report is organized as follows. This first section, introduces the subject area of PolSAR and InSAR in greater detail. The second section will overview the scientific literature of the PolInSAR subject area, discussing current research. The third section will be devoted to a discussion of military applications for PolInSAR and the developments required for this.

Interferometric SAR

Across-track SAR interferometry was first proposed as a means to extract topographic information in the mid 1970's [27, 21]. The technology is now commonly used for accurate Digital Elevation Model (DEM) generation. Across-track interferometry requires that two SAR images are acquired from nearly the same perspective, separated in both the across track and across range directions. The images can be acquired simultaneously using two antennas on a single platform (single-pass interferometry) or by repeated passes of a single antenna (repeat-pass interferometry). The transmit and received polarizations of the radar are usually identical, either both HH (e.g. RADARSAT) or VV (e.g. ERS-1/2). Consider a mathematical approach. Two antennas separated by a baseline vector ***B*,** image a point *P* on the ground, a distance ***r*** and ***r+Δr*** from the each antenna, respectively. The received signals, $\boldsymbol{S_1}$ and $\boldsymbol{S_2}$ after SAR processing, consist of a terrain reflectivity ***u(r)*** modulated by a phase term due to range distance to the scatterer:

$$s_1(r) = u(r)e^{i\varphi_1}, \tag{1}$$

and:

$$s_2(r+\Delta r) = u(r+\Delta r)e^{i\varphi_2}. \tag{2}$$

Multiplying the first signal with the complex conjugate of the second signal forms the interferogram:

$$s_1(r)s_2^*(r+\Delta r) = \left|s_1 s_2^*\right| e^{i(\varphi_1-\varphi_2)} = Se^{i\phi}, \tag{3}$$

where ***S*** is the amplitude of the interferogram and ϕ the phase.

The phase of the interferogram is not only proportional to terrain topography, but can also include other factors such as geometric effects, tropospheric and ionospheric effects, displacement of the target, and noise [27]. A measure of the phase noise of an interferogram is the coherence γ defined as the absolute value of the normalized cross-correlation between both signals:

$$\gamma_{\text{int}} \equiv \frac{\left|\left\langle s_1 s_2^* \right\rangle\right|}{\sqrt{\left\langle s_1 s_1^* \right\rangle \left\langle s_2 s_2^* \right\rangle}}. \tag{4}$$

The interferometric coherence varies between 0 and 1. When the two signals are completely uncorrelated, $\gamma = 0$. Then they are identical, $\gamma = 1$. Consequently the achieved accuracy of the measured interferometric phase is reduced by any loss of coherence. The total observed coherence, γ_{total}, can be given in terms of the product of some of the more significant correlation factors [16]:

$$\gamma_{int} = \gamma_{thermal} \times \gamma_{temporal} \times \gamma_{baseline} \times \gamma_{troposphere} \times \gamma_{ionosphere} \times \gamma_{coregistration} \times \gamma_{volume}. \tag{5}$$

$\gamma_{thermal}$ is the thermal correlation coefficient and is a function of the thermal noise of the two systems. In repeat-pass interferometry sub-pixel resolution changes in the backscatter, such as moving tree branches at C-band, will reduce the temporal correlation, $\gamma_{temporal}$. As the across-range and across-track distance between the antennas (called the perpendicular baseline, $B_{\perp}$) increases, the baseline correlation, $\gamma_{baseline}$ decrease [40]. Tropospheric and ionospheric effects can both impact the coherence. A badly registered image pair reduces $\gamma_{coregistration}$. Finally volume scattering within a target (such as fresh water lake ice) can reduce γ_{volume}, thereby affecting the overall observed coherence. It is important to note that γ_{volume} is also inversely proportional to the perpendicular baseline [17, 40]. As a consequence the coherence over fresh water lake ice may be high for InSAR passes with a small $B_{\perp}$ and low for pass with a large $B_{\perp}$ [16].

Polarimetric SAR

While interferometric SAR employs a single polarization, polarimetric SAR takes advantage of the full electromagnetic vector field [44]. It is capable of simultaneously imaging a target with both horizontally (H) and vertically (V) oriented electric field vectors, and to record both the like- and cross-polarized returns. This permits the synthesis of the target's polarization signature potentially providing information about the target's structures or environment that the electromagnetic waves have interacted with through reflection or refraction processes [41].

Polarimetric SAR systems typically provide four channels that are described by the scattering matrix,

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}. \tag{6}$$

Here, the channels of the scattered data, S are denoted by a subscript, AB, for the polarization of the transmitted signal, A and the received signal, B. H and V represent respectively, horizontal and vertical directions. Reciprocity of the cross-channels is normally assume,

$$S_{HV} = S_{VH} . \tag{7}$$

This reduces the scattering matrix to three channels.

The exploitation of PolSAR data received considerable attention during the 1980's. Significant developments included methods like Van Zyl's which decomposed S into three types of dominant scattering mechanisms [41]. This method was very similar to Freeman's work [32]. Both these methods were more suitable for **distributed** targets such as ocean and forested surfaces. They were used primarily for distinguishing between rough flat surfaces such as the ocean and volume scatterers such as the forest as well as dihedral corner reflections which can either be associated with man-made objects or less commonly in nature (e.g. the intersection of a tree trunk with the ground). Ulaby also conducted work on determining SAR signatures and has written extensively on the characterization and statistics for collecting signatures of these data [45]. Of note, is the variability of these signatures as a function of season, environmental conditions and events. In addition, errors associated with calibration are an important issue. Nevertheless this work is valuable in terms of establishing some reference information. During this period, considerable research was devoted to establishing that from the scattering matrix, S, any orientation or basis can be achieved. In this way, by rotating the polarimetric ellipse, an optimal orientation can be achieved that provides greater signal to noise (e.g. Swartz [42]).

At this time, there was a significant amount of attention directed towards **point target** applications also. This work was focused on military targets that cannot be described by statistical averages due to the size of these targets and the spatial variability of the scattering type from these targets. In particular, Huynen's work focussed on elemental structure signatures and the detection of these elements that are the building blocks of these targets [43]. This was an area that attracted considerable attention and debate. Many scientists rejected these techniques, because typical statistical confidence tests were not achievable without a large number of pixels associates with a large surface area for one type of structure, which is not found on many military targets. These types of arguments have delayed progress in SAR military target recognition applications. There is the dichotomy that these target sizes are too small to provide meaningful statistics. Yet, there is information which can be used, provided SNR values are high, which is typically the case for military targets in many background clutter environments. In particular, a military target's spatial variability provides effectively an increase of statistical samples when a model of the target is matched or correlated in several dimensions with the SAR data. Alternatively, another method of improving the statistical results is by using more traditional array methods, where the analysis is applied to the original signal data instead of the detected pixel. The work of Huynen and others like him represent effectively a turning point in the SAR analysis methods and SAR images.

In the mid-1990's, an increase in PolSAR activity and developments progressed. In particular, the primary development was Cloude's coherence method that is also the foundation for later work with Pol InSAR [34, 36]. Cloude developed a coherence method based on the Pauli spin matrices. The coherency matrix T_i for the ith pixel is given by [34, 37]:

$$\vec{T}_i = \vec{k}_i \vec{k}_i^{*T} . \tag{8}$$

Where the superscript T denotes the matrix transpose, and k_i is known as the 3-D Pauli scattering vector and is given by:

$$\vec{k}_i = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix}. \tag{9}$$

For multilook data the coherency matrix becomes:

$$\langle T \rangle = \frac{1}{n} \sum_{i=1}^{n} \vec{k}_i \vec{k}_i^{*T} . \tag{10}$$

Cloude's coherence method is utilized for many applications including discriminating different distributed target types and for the Pol InSAR method. The coherency matrix is effectively a matrix decomposition method relating to underlying physical scattering mechanisms of the scatterer. It can be decomposed to determine information in two dimensions, H and α. H is a measure of the entropy or the statistical randomness of the target types. H varies from 0 (for isotropic scattering) to 1 (for totally random scattering). α is an angle between 0° and 90°, and represents the averaged scattering mechanisms. Three general different classes of scattering mechanism are identified. Small values of α are associated with isotropic surface (or Bragg) scattering, where the surface roughness is much smaller than a wavelength. Large values of α are associated with isotropic dihedral or helical scattering. Intermediary values represent anisotropic scattering characterized by a large imbalance between the *HH* and *VV*. The H and α form a plane that can be subdivided into 8 zones characterizing the various random media scattering mechanism. The H and α plane has been studied in further detail by several researchers (e.g. Pottier [33], Lee *et al* [24]) for unsupervised classification, distributed target recognition applications and the detection of man-made targets (usually found in the dihedral, low entropy region of this plane).

Polarimetric Interferometry

Pol InSAR is an area of research that currently is attracting considerable attention in the remote sensing world. It combines the technologies and advantages of both interferometry and polarimetry, permitting the separation of different types of scatterers within one resolution cell. Most of the recent research and development has been associated with Cloude's coherence methods [34, 36, 37] and the related Pol InSAR work of Cloude and Papathanassiou [15, 23, 28]. They and their collaborative research partners are devoting their efforts primarily towards applications that determine distributed target heights. In particular, for certain types of forest cover they have been successful at determining forest heights and estimating forest biomass from polarimetric interferometric pairs, using both airborne and spaceborne data. Other potential applications of this new technology under study include soil moisture estimation, surface roughness measurement, and vertical obstruction detection.

An outline of the techniques employed is introduced below, with emphasis on Cloude and Papathanassiou's methodology since their approach is the most common method studied hitherto by researchers.

Pol InSAR methods (Cloude, Papathanassiou)

The Pol InSAR methods of Cloude and Papathanassiou are an extension of Cloude's work with the coherence matrix [15, 23, 28]. A monostatic fully polarimetric interferometric system measures each scatterer in the scene from two slightly different perspectives. This results in two scattering matrices S_1 and S_2. The 3-D scattering vectors can now be written as:

$$\vec{k}_1 = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{1HH} + S_{1VV} \\ S_{1HH} - S_{1VV} \\ 2S_{1HV} \end{bmatrix}, \vec{k}_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} S_{2HH} + S_{2VV} \\ S_{2HH} - S_{2VV} \\ 2S_{2HV} \end{bmatrix} \quad (11)$$

The complex information measured by the SAR system can now be represented in form of a 6x6 matrix known as a Hermitian positive semidefinite matrix:

$$[T_6] = \begin{bmatrix} \vec{k}_1 \\ \vec{k}_2 \end{bmatrix}\begin{bmatrix} \vec{k}_1^{*T} & \vec{k}_2^{*T} \end{bmatrix} = \begin{bmatrix} [T_{11}] & [\Omega_{12}] \\ [\Omega_{12}]^{*T} & [T_{22}] \end{bmatrix}. \quad (12)$$

T_{11} and T_{22} are the coherency matrices given by (7) or (9) that describe the polarimetric properties for each data set separately. Ω_{12} contains polarimetric and interferometric information and is a nonhermitian complex matrix that given by:

$$\Omega_{12} = \vec{k}_1 \vec{k}_2^{*T}. \quad (13)$$

This leads directly to a generalized vector expression for the coherence given by [28]:

$$\vec{\gamma} = \frac{\left\langle \vec{w}_1^{*T} [\Omega_{12}] \vec{w}_2 \right\rangle}{\sqrt{\left\langle \vec{w}_1^{*T} [T_{11}] \vec{w}_1 \right\rangle \left\langle \vec{w}_2^{*T} [T_{22}] \vec{w}_2 \right\rangle}}. \quad (14)$$

$\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ are normalized complex vectors that describe the vectorial scattering mechanisms related to image 1 and 2 respectively. Although choice of W_1 and W_2 is arbitrary, it can be assigned in a way to optimize the coherency. This expression for coherence includes both the interferometric (γ_{int}) and polarimetric (γ_{pol}) components of the coherence:

$$\vec{\gamma} = \vec{\gamma}_{\text{int}} \vec{\gamma}_{pol}. \quad (15)$$

In the special case where $W_1 = W_2$, this leads to $\gamma_{pol = 1,}$ and $\gamma = \gamma_{\text{int}}$.

To extract physical parameters from polarimetric interferometric data, scattering models are generated that relate the desirable parameters to measurable quantities. In this case the measurable quantities is the complex polarimetric interferometric coherence. Most of the work in this area has been devoted to estimation of the forest (or crop) height and canopy density. The forest is modelled very simplistically as a vertically uniform spatial density of scatterers extending from the ground to a certain height above the ground [25, 26]. The unknowns to be determined are the forest height and the average extinction coefficient. The extinction coefficient can then be used as an input to a biomass estimation model. As long as there is a return from the volume scatterer and from the ground, and to the degree that the forest conforms to the model, this is a solvable problem. This condition precludes C-band radar for such forest applications, since radio waves at that frequency don't penetrate the canopy of most tree species. Hence for such applications, SARs with the longer wavelength of the L-, S-, or P-bands are required. If the model is complicated slightly by adding a gap between the uniform scatterer and the ground, then a dual baseline polarimetric SAR interferometry system is required to solve for all the unknowns (and a careful choice of baseline ratio is required to avoid poorly conditioned inversions) [8, 18]. As the number of baselines increase, polarimetric tomography becomes feasible as was demonstrated by Reigber & Moreira [20]. A polarimetric and interferometric micro-satellite concept has been proposed for global scale forest ecosystem monitoring [10]. A single baseline, but dual-frequency (e.g. L-band and P-band) Pol-InSAR system would also provide enough parameters to solve for the unknowns [19]. Both JPL's Airsar and DLR's E-Sar experimental airborne platforms are capable of collecting multi-frequency polarimetric data. The later is currently being upgraded to enable single-pass polarimetric interferometry data at S-band.

Other investigations into the application of polarimetric interferometry found that such a system was highly sensitive to surface moisture and roughness variations (especially in the low roughness domain) [4, 13]. They found that polarimetric interferometry coherence complemented the amplitude information to provide better estimation accuracy of surface parameters.

A number of Pol-InSAR experiments have been undertaken with the French ONERA RAMSES system [1, 3]. This aircraft has X-band and Ku-band systems that can be flown in a polarimetric-interferometry mode. Since both the X- and Ku-bands do not penetrate the forest canopy, they are not suitable for forest height or biomass estimation. Instead the envisaged applications include detection of vertical obstructions, electric lines, and other similar urban structures. Preliminary experimental results demonstrated the potential for such a system to detect vertical obstructions such a light poles of a parking lot and large electrical support structures [3]

Potential military applications and limitations

Some PolInSAR military applications which require further research include the following: 1) detection and recognition of military vehicles beneath a canopy, using methods similar to current research, 2) detection and recognition of urban structures, including structural information that provides evidence of the type of activity conducted in a building, 3) detection and recognition of tall obstructions, which are hazards to low flying air vehicles, 4) the detection and recognition of moving targets and 5) the design of a single pass PolInSAR system which incorporates features suitable for military applications. For instance, a PolInSAR system could be designed to simultaneously collect real time calibration information and velocity data in an integrated fashion. This way velocity information would help with target identification.

To fully realize these applications, several issues have to be addressed. Some of these issues related to system design and its limitations. Others to the image analysis techniques emphasized in the literature to date. Almost all PolInSAR data analyzed to date are from multiple pass PolInSAR pairs. Single pass PolInSAR pairs are preferable for several reasons. They offer a constant baseline distance. They overcoming temporal decorrelation noise. In the case of spaceborne platforms they virtually eliminate atmospheric effects. There is only one SAR systems in the world that was developed specifically for this technology. That is the S-band system currently being development on DLR's E-SAR airborne platform. In addition, according to a recent article France's ONERA RAMSES X-band and Ku-band SAR systems can be flown in a "polarimetric interferometry" mode [3]. JPL has partially developed a system but has had calibration and funding difficulties. Canada has an airborne PolSAR system which could be updated to a single pass Pol InSAR system, provided modest funding was made available.

Well polarimetrically calibrated data is essential for both PolSAR and PolInSAR analysis. Yet it is surprisingly difficult to obtain well calibrated data. Historically insufficient resources have been devoted to developing more systematic calibration methods. Traditional calibration methods used are labour intensive and not well integrated into the hardware and software design. With proper system design, both automation and reliability of the PolSAR calibration could be improved.

Conventional SAR analytical methods treat targets as distributed features, which, essentially uses averaging techniques over several pixels. Traditional PolSAR and InSAR methods average over large pixel areas in order to reduce the noise error in the phase information and for image analysis. These techniques are suitable for extended feature, but not for most targets of military interest, such as military vehicles, vertical obstructions and building edges. The detail available in SAR images is not utilized when statistical methods are used on small targets such as military vehicles. Military or urban features can be viewed as a collection of point targets, which can be described by an elemental shape with a spatial position and orientation. In order to extract military information from images new analytical approaches are required, with improved reliability of target detection and recognition. It is anticipated that propagation modelling methods are one approach required as well as implementing array analytic methods used in other geophysical applications. (e.g. InSAR, PolSAR, SAR image analysis)

PolInSAR application development to date is in its infancy. So far there has only been one major development or approach for determining forest heights. This is viewed as a major potential application for PolInSAR. It is relevant for mapping the bald Earth, but more work has to be invested into other applications relevant to the military. For instance, using velocity InSAR methods, with PolSAR data could provide both better velocity and target recognition capabilities, since the scattering from a target type with a particular signature effectively provides a means to infer motion within a SAR image and discriminate the clutter from the signal. These types of problems are more difficult and are likely to require the integration of several disciplines such as Electro-Magnetic propagation modelling, statistical methods for arrays, SAR theory, polarimetric and interferometric theory.

Finally, there are inherent capabilities and limitations to SAR systems related to the physics associated with the system design specifications. These design features are optimal for some applications, but not for others. The frequency of the radar is one of the more important design features. For forest height measurement and biomass estimation for example, a C- or S-band PolInSAR system is optimal. At these frequencies the radar signal will partially be reflected by the forest canopy and partially by the ground under the canopy – a key feature for this application. At the P-band frequencies most of the radar signal is reflected by the ground beneath the canopy and little by the canopy itself. Such systems would therefore be more suitable for the detection of (e.g. manmade) structures hidden beneath the canopy and bare earth characterization. At the shorter wavelength of the C- or X-band, the radar signal is generally entirely reflected by the forest canopy's branches and leaves. These frequencies are therefore not suitable for forest height measurement. Instead radar at these frequencies may be more suitable for the detection of vertical obstruction, electrical lines, and in some other urban mapping applications.

Satellite based repeat-pass interferometry applications (such as PolInSAR) are subject to various, wavelength dependent, atmospheric effects. At longer wavelengths ionospheric effects can become severe near the Arctic or Antarctic [46]. These are not usually serious at C-bands, but can be very serious at S-, L-, and especially P-bands. The shorter wavelengths are subject to tropospheric effects. These can occur at most geographic location, even in the Arctic [47]. They can be severe at C- and X-bands, but are not thought to be serious at the longer wavelengths.

One of the more severe system limitations to date is the lack of a single platform capable of acquiring PolInSAR data. Almost all PolInSAR data to date are acquired through multiple passes of the radar platform. The time lag between acquisitions means that many targets in the scene (such as trees, vegetation, ships, vehicles) have slightly moved or changed location. This prevents such targets from being imaged with PolInSAR. A single platform capable of acquiring single-pass polarimetric interferometry data solves this problem. DLR's E-Sar experimental airborne platform is currently being upgraded to enable acquisition of single-pass polarimetric interferometry data at S-band. It is hoped that the EC CV-580 SAR will similarly be upgraded.

Summary of current investigation

This investigation will rely for acquisition of polarimetric interferometric data on Environment Canada's (EC) CV-580. This is a C-band Synthetic Aperture Radar (SAR) with a single polarimetric antenna at the base of the aircraft. Polarimetric interferometric data can therefore only be acquired in repeat-pass mode and only with a pair of passes that are close enough (i.e. a few tens of meters) to permit interferometry.

Acquiring and processing polarimetric interferometric data by multiple passes of an airborne system is fairly a complicated task. The platform stability and motion compensation requirements on the system are quite stringent. However when RADARSAT-2 (C-band) and PALSAR (L-band) are launched, acquiring such data will be much easier. Both of these satellites will be fully polarimetric capable, and capable of acquiring repeat-pass polarimetric interferometric data. It is hoped that these experiments with the EC CV-580 will provide evidence of the Pol-InSAR capabilities at frequencies similar to the RADARSAT-2 system. Furthermore, if important application of this technology is found and funding available, Environment Canada's CV-580 could be upgraded to enable **single-pass** polarimetric interferometric data acquisition.

During the summer and fall of 2002 several polarimetric interferometric missions were carried out with the EC CV-580. These experiments are detailed in another report [48]. Repeat-pass polarimetric data was acquired over Petawawa during the CAMEVAL (CAMouflage EVALuation) trials in June, nine passes were acquired over Valcartier in the first half of September, and another eight passes were acquired over Ottawa and the DRDC Ottawa campus in the later half of September. Processing of the data is still underway. Preliminary results show that several of the passes were acquired close enough in space to permit interferometry, and hence Pol-InSAR.

The CAMEVAL trial included several types of military vehicles either with no cover or under various combinations of cover (forest canopy and/or a camouflage net). One of the principal objectives of this trial is to determine, and provide evidence of, the efficacy of Pol-InSAR in discriminating military targets under a variety of cover. A secondary purpose is to evaluate its ability to extract vehicle motion from PolSAR, and in turn to determine if this additional data could help with target identification and tracking. Out of all the polarimetric passes collected during the experiment, two to five combination of passes appear to have been collected close enough in space and therefore permitting interferometric processing.

The main objectives of the Valcartier trial are to determine if forest height can be extracted using such a C-band system for moderately dense boreal forests, and to determine if military targets beneath moderately dense canopies can be detected. Out of the nine passes of data collected, a couple appear to be suitable for interferometric processing.

The Ottawa trial had several objectives. The more important of these included the study and exploitation of Pol-InSAR methods for target/feature detection (such as automated vertical obstruction detection) in the urban environment using C-band. In addition several moving targets were setup during the experiment to help determining if velocity information can be extracted from PolSAR data.

The data collected in 2002 is currently being processed and analyzed. The data has already been polarimetrically calibrated. Most of the tools for the interferometric processing of the data have been developed. These will be detailed in another report. The variety of sites used in the data collection will permit evaluation of existing and new Pol-InSAR tools for detection and recognition of targets/features of interest.

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Polarimetric Interferometric Synthetic Aperture Radar (SAR) is a recent area of research that has had significant attention from the mid-1990s. This area of research has combined the utility of two SAR technologies: Polarimetric SAR (PolSAR) and Interferometric SAR (InSAR). Polarimetric SAR provides four channels which can be used to determine the polarimetric ellipse, and hence, structural information of the scatterer. Therefore PolSAR is suitable for target recognition and detection applications. InSAR data combines two SAR image data sets acquired from nearly the same perspective. The phase difference between these images provides information about the topography, or changes in the topography between the two image dates. InSAR methods have been used to map terrains, detect environmental changes and determine velocities of moving targets.

By combining both technologies, polarimetric InSAR (Pol InSAR) permits distinction between different distributed targets at different elevations. In particular, most current research is investigating use of this technology for measuring the height of forest, and to help estimate its biomass. Other applications under research include terrain moisture estimation, terrain roughness estimation, and (of more interest in mapping applications) vertical obstruction detection.

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