PolSARpro v4.0

A General Presentation
1 INTRODUCTION

The software package, called PolSARPro v4.0 Software is developed to provide by the end an Educational Software which could offer a tool for self-education in the field of Polarimetric SAR data analysis, and to be accessible to a wide range of users, from novices (in terms of training) to experts in the field of Polarimetry and Interferometric Polarimetric SAR data processing. For this, the tool is conceived as a flexible environment, proposing a friendly and intuitive graphical user interface (GUI), enabling the user to select a function, set its parameters and run the software.

PolSARPro v4.0 Software is a complementary Toolbox to existing commercial SAR image processing packages (ENVI, PCI …) and must be considered as a Polarimetric SAR data processing software which proposes well-established algorithms in the field of polarimetric and polarimetric-interferometric radar signal processing with high-level functionalities for in-depth analysis.

2 CONTEXT AND PRINCIPAL OBJECTIVE

SAR remote sensing allows all weather, global scale imaging and estimation of important bio and geophysical parameters about the Earth's surface. It is achieved by sensing scattered electromagnetic fields reflected from the Earth surface when emitted by an electromagnetic energy source situated on an aircraft, spacecraft or satellite outside of the Earth's atmosphere. The development of multi-parameter SAR techniques such as Polarimetric SAR (PolSAR) and Polarimetric Interferometric SAR (Pol-InSAR) is advancing rapidly, and these novel radar technologies are constantly extending decisively the range of applications of radar in remote sensing. Due to new polarimetric radar sensors (ENVISAT ASAR, ALOS-PALSAR, RADARSAT-2 and TerraSAR-X), it is now shown that the accelerated advancement of PolSAR techniques is of direct relevance and of priority to local-to-global environmental ground-truth measurement and validation, stress assessment, and stress-change monitoring of the terrestrial and planetary covers. PolSAR and Pol-InSAR remote sensing techniques offer efficient and reliable means of collecting information required to extract biophysical and geophysical parameters about the Earth's surface and have found successful applications in crop monitoring and damage assessment, in forestry clear cut mapping, deforestation and burn mapping, in land surface structure (geology) land cover (biomass) and land use, in hydrology (soil moisture, flood delineation), in sea ice monitoring, in oceans and coastal monitoring (oil spill detection) etc ...

Due to, both, the ESA’s desire to augment his collection of software packages, known as the Envisat Toolboxes, and the feedback from the Workshop on “Applications of SAR Polarimetry and Polarimetric Interferometry”, held at ESA-ESRIN, Frascati, Italy, on 14-16 January 2003, it was proposed to expand the existing PolSARpro software to handle data from current and future spaceborne missions (in addition to those airborne missions already supported), thus providing a comprehensive suite of functions for the scientific exploitation of fully and partially polarimetric data and the development of applications for such data.

PolSARpro v2.0 Software was developed under contract to ESA (“Development of a Polarimetric SAR Image Analysis Tool”, ESA–ESRIN Contract n° 17863/03/I–LG). Today a new version of the sofware (PolSARpro v3.0 then PolSARpro v4.0) is continued to be developed under contract to ESA (“Continued Development of PolSARpro Software”, C.C.N to ESA–ESRIN Contract n° 17863/03/I–LG) by a consortium comprising:

- I.E.T.R - University of Rennes 1 (France): Prof. Eric Pottier, Dr Laurent Ferro-Famil, Dr Sophie Allain and Dr Stéphane Méric
The development of the PolSARpro Software is conducted in association with the different international Space Agencies (ESA, NASA-JPL, CSA, JAXA) and in collaboration with:

- CNES (France): Dr Jean-Claude Souyris
- DLR (Germany): Dr Martin Hellmann
- IECAS – MOTL (China): Dr Wen Hong, Dr Cao Fang
- Niigata University (Japan): Prof. Yoshio Yamagushi
- N.R.L (USA): Dr; Jong-Sen Lee, Dr Thomas Ainsworth
- Ressources Naturelles Canada (Canada): Dr Ridha Touzi
- University of Illinois at Chicago (USA): Prof. Wolfgang M. Boerner
- U.P.C Barcelona (Spain): Dr Carlos Lopez

The objective of the current project is to provide an Educational Software that offers a tool for self-education in the field of Polarimetric SAR data analysis at University level and a comprehensive suite of functions for the scientific exploitation of fully and partially polarimetric multi-data sets and the development of applications for such data. The PolSARpro v4.0 Software will establish a foundation for the exploitation of Polarimetric techniques for scientific developments and stimulate research and applications developments using PolSAR and Pol-InSAR data.

Figure n°1 proposes the PolSARpro Main Entry Screen evolution since the beginning of its development (2003).
3 Software Portability

The PolSARPro v4.0 Software proposes a graphical user interface (GUI) written in Tcl-Tk (more than 260000 lines managing around 180 widget windows) and contains more than 600 C routines (around 280000 lines) which perform the different processing functions.

The PolSARPro v4.0 Software runs today on the following platforms: Windows 98+, Windows 2000, Windows NT 4.0, Windows XP, Linux I386 and tomorrow on Unix-Solaris and Macintosh OS.

All the development languages and compilers used in PolSARpro v4.0 Software are open source and completely free. There is no use of any 4th generation programming languages (such as IDL or MATLAB) thus avoiding any licensing problem and associated cost.

During installation, there are no system modifications, update or reconfiguration, thus preserving the total integrity of the host machine. Users are just required to install the different open source softwares like the Tcl-Tk wish interpreter and the IMG and GnuPlot packages.

As the software is made available following the Open Source Software Development (OSSD) approach, where the source code of the C Routines is made available for free download on the Internet, it is thus possible for the users to develop additional new modules following the flexible structure of the environment. Users can easily understand how modules can be extracted from the Tool, modified and / or incorporated into their own systems.

C routines are completely independent of the system environment and can then be simply and directly compiled and linked with the provided PolSARpro v4.0 graphic and mathematic libraries. Each C routine is perfectly well documented and proposed a detailed header where users could find all the necessary information to call the function from his own system.

As an example, the header of the routine performing the H/A/Alpha Decomposition on a 3x3 Coherency Matrix (T3) is given below.

```
 PolSARpro v4.0 is free software; you can redistribute it and/or modify it under
the terms of the GNU General Public License as published by the Free Software
Foundation; either version 2 (1991) of the License, or any later version.
This program is distributed in the hope that it will be useful, but WITHOUT ANY
WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A
PARTICULAR PURPOSE.

See the GNU General Public License (Version 2, 1991) for more details.

File : h_a_alpha_decomposition_T3.c
Project : ESA_PolSAR
Authors : Eric POTTIER, Laurent FERRO-FAMIL
Version : 2.0
Creation : 08/2003
Update :

INSTITUT D'ELECTRONIQUE et de TELECOMMUNICATIONS de RENNES (I.E.T.R)
UMR CNRS 6164
Groupe SYSTEMES-PROPAGATION-RADAR
Equipe Imagerie Radar - Teledetection Polariometrie
UNIVERSITE DE RENNES I
```
Description: Cloude-Pottier eigenvector/eigenvalue based decomposition of a coherency matrix
Averaging using a sliding window

Inputs: In in_dir directory
T11.bin, T12_real.bin, T12_imag.bin, T13_real.bin,
T13_imag.bin, T22.bin, T23_real.bin, T23_imag.bin,
T33.bin

Outputs: In out_dir directory
config.txt
The following binary files (if requested)
eigenvalues: l1,l2,l3
probabilities: p1,p2,p3
alpha123: alpha1, alpha2, alpha3
beta123: beta1, beta2, beta3
delta123: delta1, delta2, delta3
gamma123: gamma1, gamma2, gamma3
alpbetdelgam: alpha, beta, delta, gamma, lambda
alpha, entropy, anisotropy, anisotropy12
asymetry, polarisation_fraction,
combinations HA, H(1-A), (1-H)A, (1-H)(1-A)

Routines:
void diagonalisation();
void edit_error(char *s1,char *s2);
void check_dir(char *dir);
float **matrix(int nrh,int nch);
void free_matrix(float **m,int nrh);
float ***matrix3d(int nz,int nrh,int nch);
void free_matrix3d(float ***m,int nz,int nrh);
void read_config(char *dir, int *Nlig, int *Ncol, char *PolarCase, char *PolarType);

The corresponding command line to run this function from any system prompt (C:\> is the following:

C:\MyDirectory> h_a_alpha_decomposition_T3 in_dir out_dir Nwin offset_lig offset_col
sub_nlig sub_ncol eigen123 proba123 alpha123 beta123 delta123 gamma123 alpbetdelgam
alpha entropy anisotropy anisotropy12 asymetry polarisation_fraction CombHA CombH1mA
Comb1mHA Comb1mH1mA

Where “in_dir, out_dir, Nwin ….. Comb1mH1mA” correspond to the different arguments and
variables to be concatenated before invoking the operating system command processor to
execute this function.

As it can be seen, the proposed open software environment approach enables the user to
select a function, set its parameters and run the routine on its own system, independently of
the PolSARPro v4.0 Software environment. This approach can also encourage users to
modify the routines to meet their individual requirements, and then to share the fruits of their
work with other users.
4 DEVELOPMENT LANGUAGES

All the languages used during the development of the PolSARPro v4.0 Software are open source and completely free.

The PolSARPro v4.0 Software is controlled through a graphical user interface (GUI) written in Tcl-Tk.

Tcl (Tool Command Language) is used by over half a million developers worldwide and has become a critical component in thousands of corporations. It has a simple and programmable syntax and can be either used as a standalone application or embedded in application programs. All of the interesting features in Tcl are represented by commands. Statements are commands, expressions are evaluated by executing commands, control structures are commands, and procedures are commands. One of Tcl's greatest advantages for building integration applications is the ease with which it can communicate with other resources. The application program generates Tcl commands (shells) and passes them to the Tcl interpreter for execution. In many cases, commands will invoke lower-level functions based on convenient C programs.

Tk is a graphical user interface toolkit that makes it possible to create powerful GUIs very quickly. Tk provides the programmer with an interface to the X11 windowing system or equivalent, and contains the well-known Jan Nijtmans' IMG package which is the Image Library that adds full support for BMP, XBM, XPM, GIF, PNG, JPEG, TIFF and postscript images.

Tcl and Tk are highly portable, running on essentially all flavours of Unix, (Linux, Solaris, IRIX, AIX, BSD) Windows, Macintosh, and more. Tcl and Tk, available for HP-UX, Linux, Solaris and Windows, are freely available for download from the ActiveTcl web portal (http://www.activestate.com/Products/Download).

The Graphic Library included in PolSARpro is the popular Gnuplot program. Gnuplot (http://www.gnuplot.info) is a free, command-driven, interactive, function and data plotting program. Gnuplot can be run under DOS, Windows, Macintosh OS, BeOS, OS2, VMW, Linux and many others. The Tcl-Tk application works by communicating with Gnuplot via a pipe and therefore it is not necessary to recompile Gnuplot or modify it in any way.

All the functions are written in C and compiled using GCC on Linux and Mingw32 on Windows. The Mingw32 development tools are based on the famous Gnu C compiler and use the CRTDLL.DLL runtime library which is a standard component of both Windows 95-98 and Windows NT. The compiler and the programs created with it, run on any NT or Windows 95-98 PC without the need for any additional DLL's. Mingw32 is freely available for download from the GNUWin II web portal (http://gnuwin.epfl.ch).

At last, the development tool used to develop the graphical user interface is Visual Tcl which is entirely written in Tcl/Tk and generates pure Tcl/Tk code. Visual Tcl is a freely-available, high-quality application development environment for UNIX, Windows, Macintosh and AS400 platforms. Visual Tcl (VTCL) is freely available for download from the web portal (http://sourceforge.net/projects/vtcl).
5 SOFTWARE FUNCTIONALITIES

5.1 INTRODUCTION

The PolSARPro v4.0 Software package proposes a set of implemented tools designed for the analysis of Polarimetric SAR data from airborne sensors. It provides a comprehensive suite of functions for the scientific exploitation of fully and partially polarimetric data and the development of the corresponding remote sensing applications. The different functionalities proposed by the PolSARPro v4.0 Software package are listed in the following:

5.2 POLSARPRO V4.0 SOFTWARE MAIN WINDOW

The PolSARpro v4.0 Software proposes a great collection of well-established algorithms and tools designed for the analysis of only Single and Multi Data Sets Polarimetric SAR data with specialized functionalities for in-depth analysis of fully and partially polarimetric data and the development of applications for such data. The PolSARpro v4.0 Software proposes a new interface based on a full-screen main window as shown in Figure n°2. Minimizing the PolSARpro v4.0 Software Main Window will minimize / withdraw / iconify all the opened transient windows in one single icon.

Specific interfaces dedicated to different Polarimetric Spaceborne Sensors (ALOS - PALSAR, ENVISAT-ASAR, RADARSAT2, TerraSAR-X, SIRc) or Polarimetric Airborne Sensors (AIRSAR, Convair, EMISAR, ESAR, PISAR, RAMSES) data processing can be selected from the main menu by clicking on the Sensor associated button, as shown in Figure n°3.
As shown in Figure n°4, the progress bar and the Run Trace functionalities are displayed at the bottom of the PolSARpro v4.0 Software Main Window. The progress bar widget provides progress feedback, showing to the user the status of a long-running operation. The Run Trace functionality enables a specific widget window providing operational and informative error messages. This window enables any troubleshooting by printing a backtrace with each warning or error message (equivalent to the Unix command: troff). This should help track down the cause of any error.

Specific complementary functionalities as Tutorial, Help, Tools, Create BMP and Viewer can be selected from the menu at the top-right of the PolSARpro v4.0 Software Main Window, by clicking on the corresponding button, as shown in Figure n°5.

![Figure n°5](image)

### 5.3 PolSARpro v4.0 Data Standard Format

The PolSARpro v4.0 Software can process today polarimetric or partially polarimetric data sets under many different formats. A polarimetric data set is composed of Binary files characterized by a Configuration Text File and located in a given Data Directory. The binary files have no header but must be accompanied with a configuration text file, indicating the considered data size and the polarimetric type (Full Polarimetry, Partial Polarimetry, Monostatic, Bistatic). These configuration files are automatically created by the different data processing applications proposed in PolSARpro and during any conversion procedure of sensor specific data format. In order to be correctly interpreted by PolSARpro, binary data files have to be built according to a compatible format.

- A Nrow by Ncol image is read on a row by row basis, i.e. Ncol pixels are read in a single thread and are then assigned to one of the rows of a Nrow by Ncol matrix.
- Binary data associated to real (not complex) variables are coded under the form of 4-bytes (i.e. 32 bits) float numbers.
• Binary data associated to complex variables are coded under the form of interlaced float numbers representing real and imaginary parts.

The different polarimetric data formats handled by PolSARpro v4.0 are the following:
• The (2x2) complex Sinclair $[S2]$ matrix that is the coherent polarimetric representation relating incident and scattered Jones vectors. In a general case, it is composed of four complex elements and becomes symmetric in monostatic configurations.
• The (3x3) complex Coherency $[T3]$ or Covariance $[C3]$ matrices corresponding to an incoherent polarimetric representation relating to second order statistics of the monostatic scattering matrix elements.
• The (4x4) complex Coherency $[T4]$ or Covariance $[C4]$ matrices corresponding to an incoherent polarimetric representation relating to second order statistics of the bistatic scattering matrix elements.
• A Partial Polarimetry representation consisting of two coherent polarimetric channels acquired in a reduced polarimetry configuration, and the associated (2x2) complex Covariance $[C2]$ matrices corresponding to an incoherent polarimetric representation relating to second order statistics of the two scattering matrix elements.

5.4 EARTH OBSERVER SCIENTIFIC INVESTIGATOR (EOSI) PACKAGE

The PolSARpro v4.0 Software offers the possibility to handle and convert polarimetric data from a range of well established polarimetric airborne platforms and from a range of future and planned spaceborne missions.

The PolSARpro v4.0 EO Scientific Investigator package proposes different specific interfaces, with identical functionalities, dedicated to different Spaceborne Sensors (ALOS-PALSAR, RADARSAT2, TerraSAR-X, SIRc) or Airborne Sensors (AIRSAR, Convair, EMISAR, ESAR, PISAR, RAMSES) data processing selectable from the main menu. Once selected the sensor, the corresponding button is highlighted as shown in Figure n°6.
The PolSARpro v4.0 EO Scientific Investigator package has been developed to the support of the following data sources:

<table>
<thead>
<tr>
<th>Mission</th>
<th>Sensor</th>
<th>Polarimetric Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS – PALSAR (JAXA-CEOS Format and ERSDAC-Vexcel Format)</td>
<td>PALSAR (Fine mode, Direct downlink mode)</td>
<td>Dual-Pol</td>
</tr>
<tr>
<td></td>
<td>PALSAR (Polarimetry mode, experimental)</td>
<td>Quad-Pol</td>
</tr>
<tr>
<td>ENVISAT ASAR</td>
<td>ASAR – APS Mode</td>
<td>Dual-Pol</td>
</tr>
<tr>
<td></td>
<td>ASAR – APP Mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASAR – APG Mode</td>
<td></td>
</tr>
<tr>
<td>TerraSAR - X</td>
<td>TSX-SAR</td>
<td>Dual-Pol</td>
</tr>
<tr>
<td></td>
<td>TSX-SAR (experimental)</td>
<td>Quad-Pol</td>
</tr>
<tr>
<td>RADARSAT-2</td>
<td>SAR (selective polarisation)</td>
<td>Dual-Pol</td>
</tr>
<tr>
<td></td>
<td>SAR (Standard Quad polarisation, Fine Quad polarisation)</td>
<td>Quad-Pol</td>
</tr>
</tbody>
</table>

The PolSARpro v4.0 EO Scientific Investigator specific interface is controlled through a Graphical User Interface (GUI) in order to help and guide an EO investigator to process fully polarimetric data along a ‘recommended’ processing chain summarizing essential functionalities, in order to provide a first qualitative analysis of the fully polarimetric data set processed. Theses different processing functions are proposed in the form of one batch processing, covering:

**Quad-Pol Data:**
- Import and convert the different Spaceborne Sensors or Airborne Sensors fully polarimetric data to complex 3x3 Coherency raw binary data.
- QuickLook, and Sub-Area Extraction functionalities.
- Speckle Filter (BoxCar, JS Lee refined filter, IDAN filter …)
- H / A / $\alpha$ Decomposition and analysis
- Unsupervised Wishart - H / A / $\alpha$ Classification
- Supervised Wishart and / or Gaussian Classification

**Dual-Pol Data:**
- Import and convert the different Spaceborne Sensors or Airborne Sensors dual polarimetric data to complex 2x2 Coherency raw binary data.
- QuickLook, and Sub-Area Extraction functionalities.
- Speckle Filter (BoxCar, JS Lee refined filter, IDAN filter …)
- H / A / $\alpha$ Wave Decomposition and analysis
- Supervised Wishart - H / A / $\alpha$ Classification

**Quad or Dual-Pol Co-Registered Data:**
- Import and convert co-registered data to real (intensity) raw binary data.
- QuickLook and Sub-Area Extraction functionalities.
- Creates binary files corresponding to real (Intensity) polarimetric raw binary data
- Multi Look incoherent averaging to real polarimetric intensity raw binary data.
- Speckle filtering (BoxCar, JS Lee refined filter, IDAN filter)
- Supervised polarimetric classification, based on the multivariate complex Wishart probability density function of second order matrix representations.
5.5 **PolSARpro v4.0 Single Data Set Package**

The PolSARpro v4.0 Software proposes a great collection of well-established algorithms and tools designed for the analysis of Single Data Set Polarimetric SAR data with specialized functionalities for in-depth analysis of fully and partially polarimetric data and the development of applications for such data.

The PolSARpro v4.0 specific interface performs complete end-to-end processing without the need for other software and is selectable from the main window as shown in Figure n°7.

![Figure n°7](image)

The PolSARpro v4.0 specific interface proposes the following different main functions:

- **Environnement**: This menu permits to set Main Variables and to configure the Processing Environment.
- **Import**: This menu may be used to import and convert fully polarimetric raw binary data sets from a range of established polarimetric airborne and space borne sensors to PolSARpro compatible raw binary data. It offers QuickLook and Sub-Area Extraction functionalities.
- **Convert**: This menu proposes dedicated functionalities used to convert raw binary data from a standard polarimetric format ($(S_{xx}, S_{xy})$, $(I_{xx}, I_{xy})$, $[S_2]$, $[T_3]$, $[T_4]$, $[C_2]$, $[C_3]$, $[C_4]$) to another one.
- **Calibration assessment**: This menu proposes the Calibration assessment functionality, whose functions will perform operations to correct imported data for perturbations due to the radar system prior to further processing (Cross-talk removal, Amplitude and phase imbalance, Absolute amplitude calibration (Quegan, Papathanassiou and Ainsworth procedures), SAR device impulse response analysis (3D) and characteristics metrics PSLR, ISLR, SSLR …)
Process: This menu proposes a set of implemented tools designed for the analysis of Polarimetric SAR data sets. It provides a comprehensive suite of functions for the scientific exploitation of fully and partially polarimetric data and the development of the corresponding remote sensing applications. All these processing functions are developed to be applied on the different polarimetric matrix data formats: $[S_2], [T_3], [T_4], [C_3]$ and $[C_4]$ as well as on the partial polarimetric data format: $(S_{xx}, S_{xy}), (I_{xx}, I_{xy}), [C_2]$.

The different functionalities proposed are:

- **Change of Polarimetric Basis**: PolSARpro v4.0 offers the possibility to transform polarimetric data sets (generally acquired in the Horizontal-Vertical Basis) to any polarization basis. Changes of polarimetric basis are performed by the way of operators belonging to Special Unitary groups $SU(n)$ adapted to each polarimetric representation $[S], [T]$ or $[C]$.

- **Speckle Filtering**: PolSARpro v4.0 offers the possibility to filter incoherent polarimetric $[T_3], [C_3], [T_4], [C_4]$ raw binary data sets. Two filters are implemented:
  - The Boxcar filter performs incoherent averaging within a sliding window
  - The J.S. Lee refined filter estimates local statistics within a sliding window and filters data in an adaptive way by minimizing a least square constraint. This approach also includes the use of directional masks for the local statistics estimation.
  - The IDAN (Intensity Driven Adaptive Neighbourhood) filter (courtesy of Dr G. Vasile and Dr E. Trouve).
  - The **P.W.F** (Polarimetric Whitening Filter) filter
  - Etc…

- **Elements Processing**: Process polarimetric representation elements and create corresponding binary files, e.g. modulus, real part, intensity, phase, span ...
Create specific correlation coefficient binary files

- **Stokes Parameters and wave analysis**.

- **Polarimetric Copol and Crosspol Signatures**, and the associated graphic interface (Poincaré sphere and polarisation fork).

- The Optimal Polarimetric Contrast Enhancement (**O.P.C.E**).

- **Polarimetric Decomposition**: Apply polarimetric decompositions to coherent or incoherent polarimetric representations. The different polarimetric decomposition proposed are: Huynen, Barnes, Cloude, Holm, H/A/$\alpha$, Freeman-Durden, Krogager, Cameron, Generalized Freeman – Yamaguchi 3-components decomposition, Yamaguchi 4-components decomposition (2007), Freeman 2-components decomposition (2006).

- **Polarimetric Segmentation**: Segment and classify polarimetric data sets in an unsupervised way, using statistical techniques (Wishart distribution) or not (H/A/$\alpha$), or in a supervised way, using statistical techniques (Wishart distribution), Basic scattering mechanisms identification.

- **Rule-based hierarchical classification**.

- **Edge detectors**: Canny, Black, Marr and Rothwell edge detector procedures.

- **Data Clustering**

- **Polarimetric Entropy according Shannon theory** (courtesy of Dr J. Morio and Pr P. Refregier).

- **Coefficient of Variation, Lueneburg Anisotropy coefficient**.

- **Sub Aperture Analysis** (decomposition, applications).

- **Compact Polarimetry** (Courtesy of Dr J.C Souyris).
Surface Parameter Data Inversion using empirical and semi-empirical approaches that provide Volumetric Soil Moisture maps and Surface Roughness maps and which include the following functions:
  o Sigma-zero generation
  o Local incidence calculation from sensor geometry
  o Local incidence calculation from available DEM
  o Dubois et al. Algorithm for surface parameter estimation
  o Oh et al. Algorithm for surface parameter estimation
  o 1st Order X-Bragg Algorithm for surface parameter estimation (optional)

Data Analysis: Specific GUI based application propose to sample SAR data by defining regions of interest on which test amplitudes, amplitudes ratio, phase difference and multivariate statistics are computed. Histogram plots are displayed and users have the possibility to test the distribution against a bank of predefined functions (Gaussian, K, Gamma, Exponential …) The goodness of fit is estimated using classical testing procedures (K.S, Chi2).

Batch Procedure: PolSARpro v4.0 offers a batch functionality which permits to sequentially apply different polarimetric data processes. The different steps of this batch process are:
  o Import and convert fully polarimetric data to complex 3x3 Coherency raw binary data.
  o Speckle Filter (BoxCar, JS Lee refined filter)
  o H / A / $\alpha$ Decomposition and analysis
  o Unsupervised Wishart - H / A / $\alpha$ Classification

One or more programs may be run sequentially. Output directories are then set to the default value for each process. This functionality is proposed to guide the user along a ‘recommended’ processing chain using only essential functionality required for basic handling of polarimetric data.

Figures n°8, 9 and 10 present screenshots of different functionalities proposed in the PolSARpro v4.0 Single Data Set package.
Figure n°8 : PolSARpro v4.0 Single Data Set package Supervised Segmentation

Figure n°9 : PolSARpro v4.0 Single Data Set package
H / A/ a Decomposition
5.6 **PolSARpro v4.0 Dual Data Sets Package**

The PolSARpro v4.0 Software package proposes also a great collection of well-established algorithms and tools designed for the analysis of only Dual Polarimetric SAR data sets with specialized functionalities for in-depth analysis of fully polarimetric and interferometric data (SBPI – Pol-InSAR) and the development of applications for such data.

The PolSARpro v4.0 specific interface proposes the following different main functions:

- **Environnement**: This menu permits to set Main Variables and to configure the Processing Environment.
- **Convert**: This menu proposes dedicated functionalities used to convert raw binary data from a standard polarimetric format ([S2], [T6]) to another one.
- **Process**: This menu proposes a set of implemented tools designed for the analysis of Polarimetric Interferometric SAR data sets. All these processing functions are developed to be applied on the different polarimetric interferometric matrix data formats: [S2] and [T6].

The different functionalities proposed are:

- **Speckle Filtering**: PolSARpro v4.0 offers the possibility to filter coherent [S2] and incoherent [T6] polarimetric interferometric raw binary data sets. Three filters are implemented:
  - The Boxcar filter performs incoherent averaging within a sliding window
  - The Gaussian filter performs incoherent averaging within a sliding window
  - The J.S. Lee refined filter estimates local statistics within a sliding window and filters data in an adaptive way by minimizing a least square constraint. This approach also includes the use of directional masks for the local statistics estimation.
  - The **P.W.F** (Polarimetric Whitening Filter) filter

- **Elements Processing**: Process polarimetric representation elements and create corresponding binary files, e.g. modulus, real part, intensity, phase, span ... Create specific correlation coefficient binary files

- **Interferogram and Complex Coherence generation**: Users are given the opportunity to generate complex coherences and interferograms at any possible polarization states (HHHH, HVHV, VVVV, LLLL, LRLR, RRRR etc ...), including the Lecxicographic/Pauli basis and optimal polarization states derived from Cloude and Papathanassiou coherence maximization procedure.

- **Flat earth Removal**
• **Complex Coherence analysis** using a dedicated graphic interface displaying the coherences and the coherence loci on the complex plane

• **Polarimetric Interferometric Segmentation**: Segment and classify polarimetric interferometric data sets in an unsupervised or supervised ways, using statistical techniques (Wishart distribution).

• **Forest Parameter Inversion**: This software package analyses forested terrain using single-baseline polarimetric SAR interferometry and is based on a polarimetric coherent scattering model. Forest parameters such as tree height and underlying ground topography are estimated by an inversion procedure.

• **Polarization Coherence Tomography (PCT)**: A very innovative Radar imaging technique, proposed by Prof. S.R. Cloude, which employs variation of the interferometric coherence with polarization to reconstruct a vertical profile function in penetrable volume scattering.

• **Data Analysis**: Specific GUI based application propose to sample SAR data by defining regions of interest on which test amplitudes, amplitudes ratio, phase difference and multivariate statistics are computed. Histogram plots are displayed and users have the possibility to test the distribution against a bank of predefined functions (Gaussian, K, Gamma, Exponential ...). The goodness of fit is estimated using classical testing procedures (K.S, Chi2).

The PolSARpro v4.0 software incorporates the different algorithms and softwares that have been developed in the frame of the ESA study “**Polarimetric Interferometric Mission and Applicability Study**” (ESA-ESRIN Contract n° 17893/03/I-LG), in order to propose users a processing algorithm chain required for the operational generation of a landscape classification and is composed of three main algorithms which are the following:

• **Landscape Mapping**: This application consists in delimiting the extent of forest, surface and urban areas within a SAR image. The unsupervised mapping of the different areas is based on the complementary information delivered by PolSAR and Pol-InSAR measurements over complex scenes. Indicators related to scattering randomness and stability may be derived from both PolSAR and Pol-InSAR data types and used to separate forest from other kinds of natural or artificial media. It is well known that SAR polarimetry is particularly well adapted to the analysis and description of scattering mechanisms but PolSAR parameters may saturate over media with highly random response, like dense forest observed at L band. Oppositely, interferometric SAR measurements permit to further investigate volumetric media properties but suffer from a lack of contrast over areas showing more deterministic responses like agricultural fields. The proposed landscape mapping algorithm exploits the complementarity of both data types by splitting the scene under observation into basic scattering mechanism types using PolSAR information and improving this classification from a Pol-InSAR analysis.

• **Forest Classification**: The supervised classification of forest is achieved using a classical two-stage statistical algorithm. During the learning phase, the classifier “learns” statistics of user defined classes by computing average coherency matrix estimates. Then, during the classification step, elements of the observed scene are assigned to the nearest class determined by the ML Wishart distance. Two options may be considered in order to adapt the processing to the type of media to be classified. In the case of applications requiring high resolution results, it is preferable to perform the classification algorithm on a pixel level, whereas the analysis of highly varying objects, such as forest, it might be more efficient to apply the classification over segments in order to reduce the variability of scattering behaviours. Data acquired in polarimetric and interferometric modes have complementary characteristics; their joint use provides significantly higher performance for both forest mapping and classification applications. A forest mapping approach, based on the separate use of PolSAR and Pol-InSAR information, is proposed. Each pixel of an image is identified to a basic scattering mechanism using efficient polarimetric indicators. A parameterization of an optimal interferometric coherence spectrum is used to identify volumetric targets with decorrelating properties that are associated to forest. A supervised classifier is also proposed to classify the different constituents of a forest. It is shown that the use of an unsupervised pre-segmentation is essential to reach acceptable classification rates.

• **Crop Classification**: The crop classification algorithm uses a knowledge-based approach in order to define classification rules. The crops are first classified into broad classes, i.e. bare surfaces, cereal crops, root crops, spring crops, winter crops etc using standard polarimetric
parameters such as the backscatter coefficients. Hereafter, the discrimination between the individual crop types within these broad categories is performed. The rule-based classification software package consists of two programs: the first performs the rule-based classification and the second carries out an optional K-means clustering of the rule-based classified image.

5.7 PolSARpro V4.0 Display Menu

The PolSARpro V4.0 Software offers the possibility to create and export images in an 8-bit or 24-bit dynamic range (Windows Bitmap and TIFF formats) for inclusion in reports, or import to GIS software. The different display functionalities can be applied on the following raw binary data type: \([S2], [T3], [T4], [C3], [C4]\) and \((Sxx, Sxy)\) and \((Ixx, Ixy)\) that correspond to dual polarimetric elements raw binary data.

Each Data Button gives access to the following display functionalities, as shown on figure n°11:

- **Create BMP file** is used to create an 8-bit or 24-bit dynamic range (Windows Bitmap and TIFF formats) bitmap image file of parameters extracted from a polarimetric raw binary data file.

- **Create RGB file** is used to create a 24-bit colour BMP image (Windows Bitmap format) containing contrasted red, green and blue channels assigned to the different polarimetric binary raw data files and combinations.

- **Create HSL file** is used to create a 24-bit colour BMP image (Windows Bitmap format) containing contrasted hue, saturation and light channels assigned to the different polarimetric binary raw data files and combinations.

![Figure n°11: PolSARpro v4.0 Display Functionalities](image)
5.8 PolSARpro v4.0 Viewer

A basic Viewer (PolSARpro Viewer PV 3.0) is offered which can be used to display and modify output results in common graphics formats as Windows Bitmap.

The Viewer PV 3.0 allows saving the Windows Bitmap output files in different graphic formats as GIF, JPG, PS and TIF. It proposes different functionalities like Image Display Size setting, In/Out Zoom function, Zoom Lens Window, Overview Window, Image Flip Up-Down / Flip Left-Right, 90° Left / Right rotation, transpose functions...

The Color Palette edition and modification functions are particularly useful for the post-processing of unsupervised classification results.

Currently, it is not planned to implement significantly more image processing functionalities. For advanced image handling, standard software, like GIMP or PaintShopPro, can be used subsequent to the data processing in PolSARpro v4.0.

Figures n°12 presents screenshots of different functionalities proposed in the PolSARpro Viewer PV 3.0.

PolSARpro Display & Viewer v3.0 EXAMPLES

Image Display size setting

ColorMap modification

Zoom Lens Window

Color Palette Edition

Overview Window

Figure n°12 : PolSARpro Viewer PV3.0 Functionalities
5.9 PolSARpro V4.0 Tools Menu

The PolSARpro V4.0 Software offers different Directory and Data File basic management functionalities and different Raw Binary File transformation tools. The different tools functionalities can be applied on the following raw binary data type: [S2], [T3], [T4], [C3], [C4] and (Sxx, Sxy) and (Ixx, Ixy) that correspond to dual polarimetric elements raw binary data.

Each Data Button gives access to the following Raw Binary Files transformation functionalities: IEEE Format Convert, Sub Data Set Extraction, Polarimetric Data 90° Right Rotation, 90° Left Rotation, 180° Rotation, Flip Up-Down, Flip Left-Right, Transposition and coherent Polarimetric Data FFT. The Data File Management gives access to the following functionalities: Copy / Delete / Rename File and Create / Copy / Delete / Rename Directory.

The PolSARpro V4.0 Software offers also the possibility to export and import Raw Binary data files to GIS softwares (ENVI, RAT).

The PolSARpro V4.0 Software is conceived as a flexible and open software environment where users can easily add new functions and components, as their need arises. The Tools Menu allows the user to automatically include, delete and run its own additional functions in the software.

6 Tutorial on Radar Polarimetry

Due to the polarimetric radar sensors ENVISAT-ASAR, ALOS-PALSAR, RADARSAT-2 and TerraSAR-X, it is now shown that the accelerated advancement of PolSAR techniques is of direct relevance and of priority to local-to-global environmental ground-truth measurement and validation, stress assessment, and stress-change monitoring of the terrestrial and planetary covers. Scientists and engineers already engaged in the fields of radar remote sensing generally gain their specialist knowledge in polarimetry by working through scientific papers and specialized literature available on the subject. The aim of this Tutorial is to provide a substantial and balanced introduction to the basic theory, scattering concepts, systems and advanced concepts and applications typical to Radar Polarimetry and Interferometry.

This Tutorial on Radar Polarimetry is completed with a review of some important aspects of radar polarimetry and interferometry to learn how to generate multiple polarization interferograms and how to use them with simple inversion models to estimate surface parameters, vegetation height and ground topography.

This tutorial can be used as a low level teaching aid for polarimetric SAR processing and is illustrated with application examples showing the full range of functions that the Tool offers (Do it yourself sections). The PolSARpro v4.0 Software is thus provided with a comprehensive in-depth documentation permitting self-education to a high level (radar experts and post graduate students). A new collection of lecture notes is also provided to illustrate the up to date concepts in polarimetry interferometry.

User have access to this wide-ranging tutorial, available in PDF format, providing a grounding in SAR Polarimetry (PolSAR) and SAR Polarimetric Interferometry (Pol-InSAR) from the main menu, as shown in Figure n°13, 14 and 15.
1. WHAT IS POLARIZATION?

1.1 Propagation of a nonuniform plane electromagnetic wave

The non-uniform behavior of electromagnetic waves is studied by the following equations, which define the propagation vector:

\[ \mathbf{E} = \mathbf{E}_0 e^{j(kz - \omega t)} \]

where \( k \) is the wave vector, \( \omega \) is the angular frequency, \( z \) is the spatial coordinate, and \( t \) is time.

The total power density, \( P = \mathbf{E} \cdot \mathbf{E}^* \), is given by:

\[ P = \frac{1}{2} |\mathbf{E}|^2 = \frac{1}{2} |\mathbf{E}_0|^2 e^{-2j(kz - \omega t)} \]

The total energy density, \( U = \mathbf{E} \cdot \mathbf{B} \), is related to the propagation constant, \( \gamma = \sqrt{\kappa^2 - \omega^2} \), where \( \kappa \) is the propagation constant and \( \omega \) is the angular frequency.

The absorption term, \( -j\kappa \), and the refraction term, \( j\gamma \), are significant in the following scenarios:

1. The propagation of a nonuniform plane electromagnetic wave as a function of position and time.
2. The analysis of propagation effects in various media, such as atmospheric and oceanic environments.

The equation for propagation is given by:

\[ \frac{d^2}{dz^2} + \gamma^2 = 0 \]

The solutions to this equation are sinusoidal and exponential functions, which describe the propagation behavior.

Do It Yourself 7
POLInSAR Training Course

1. Objectives
To provide a self-paced introduction to POLInSAR, SAR interferometry, and techniques to extract more information from SAR data.

2. Outline
- Introduction to POLInSAR
- SAR interferometry techniques
- POLInSAR data processing
- POLInSAR applications
- POLInSAR training course

Do it Yourself
User have also access to different series of Tutorial Slide Shows, that are made available to support taught courses of for use as part of a self teaching programme, as shown in Figure n°16.

6.1 POL-INSAR LECTURE COURSE

The objective is to provide a self taught introduction to Pol-InSAR coherence processing techniques to enable users to learn the basic principles of this topic and to enable them to use more confidently and knowledgeably airborne and spaceborne Pol-InSAR processing tools developed under the PolSARpro software. To achieve this, a simulated test Pol-InSAR data set with ‘perfect’ ground truth is used to illustrate the lecture course. This test set is a simulation output from the Pol-InSAR simulator. The test data set is designed to mimic the same performance of airborne / spaceborne systems, except there are no residual motion, baseline or co-registration errors and no problems associated with temporal and SNR decorrelation sources. In this way the users can get used to Pol-InSAR principles in a controlled environment before applying the techniques to real world data sets. As a secondary objective, the modules generated can also be used for dual polarised Pol-InSAR inversion studies on arbitrary data sets to complement the more robust but complicated multipolarisation algorithm existing in the literature.

The course begins with a review of the basis theory and notation before running through a 12 step practical training course covering most of the major steps involved in processing and analysis of Pol-InSAR data.

6.2 SAR COHERENT SCATTERING AND IMAGING CODE (POL-INSAR SIMULATOR)

The Pol-InSAR lecture course is illustrated using a simulated L-Band SAR image of a woody hedge above rough ground. The data was produced using a high-fidelity; SAR coherent scattering and imaging code developed by Dr Mark L. Williams. This code has been used extensively with detailed forest models to demonstrate the feasibility of many of the techniques that PolSARpro v4.0 software seeks to illustrate and teach.

The data represents a single scene, at a single frequency, at a single imaging geometry, with a fixed resolution, and a fixed interferometric baseline. The scene is also less than realistic since it is of a homogeneous layer of randomly placed woody branches, corresponding closely to the theoretical case used to derive the volume coherence model. Whilst the data is of limited extent, it is nonetheless extremely useful for tutorial purposes as it represents a simplified system that is readily understood, and has well defined properties that make the Pol-InSAR inversion reasonably straightforward. However, it would be much more satisfactory if other scenes were available at different imaging geometries and frequencies. For example it might be useful, in addition, to have simulated data for a hedge that is twice as tall, to demonstrate that a greater interferometric baseline is required for a greater canopy height. Another example would be, perhaps, data at P-band rather than L-Band, again with a different baseline, to indicate the effects of changing frequency.

The user is provided a dedicated interface that permits the ready description of a realistic forest model and a flexible description of SAR imaging parameters. Having designed the forest and set the imaging scenario the simulation is called from within PolSARpro v4.0 software, and in a reasonable space of time, the user has available simulated polarimetric, interferometric SAR data for the scene of their choice. The PolSARpro v4.0 software user could then proceed to follow the Pol-InSAR tutorial with the data appropriate to the scenario of particular interest to them, and be able to determine that the techniques work well in a realistic situation for the sensor of their choice.

The graphical user interface (GUI) used to assign parameter values is implemented within PolSARpro v4.0 software and is shown in Figures n°17 and 18.
The PolSARpro v4.0 Software is accompanied by a detailed set of around 300 Help Files, made available in PDF format, for each individual function. The User Manual provides comprehensive documentation of the PolSARpro v4.0 Software. As each new version of the PolSARpro v4.0 Software becomes available, extra content will be added. Individual Help Files are accessible from within the software by clicking on the help icon present in the relevant dialogue box, as shown on figure n°19.
Figure n°19 : PolSARpro v4.0 Help Files

Figure n°20 : PolSARpro v4.0 Technical Documentation
The PolSARpro V4.0 Software is also accompanied by a detailed set of around 600 Technical Documentation Files, made available in PDF format, for each individual C Routine in order to provide to users information about how modules can be extracted from the Tool, modified and / or incorporated into their own systems, as shown in Figure n°20.

8 Outlook

Currently in its development stage, PolSARpro v4.0 Software (source code and elements software packages) is added gradually since 2003 and made publicly available for free download on the Internet from the ESA Web Portal (Earthnet) at: http://earth.esa.int/polsarpro as shown in Figure n°21. This web site provides:

- Details of the project
- Access to the tutorial and software
- Information about status of the development
- Demonstration Sample Datasets
- Recently obtained results

A collection of PolSAR datasets is provided for demonstration purposes only, intended to enable users to practice using PolSARpro Software and develop a better understanding of PolSAR and Pol-InSAR techniques.

![Figure n°21: PolSARpro v4.0 – ESA web site](image)