Road Network Extraction for Remote Sensing Applications

Part of ISRO-RESPOND Project, Space Applications Center, Ahmedabad

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CERTIFICATE

This is to certify that the Mini Project-II Report entitled **“Road Network Extraction for Remote Sensing Applications”** submitted by **Jonti Talukdar (**Roll No. **14BEC057**as the partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electronics & Communication Engineering, Institute of Technology, Nirma University is the record of work carried out by them under my supervision and guidance. The work submitted in our opinion has reached a level required for being accepted for the examination.

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ABSTRACT

THE RECENT launch of numerous radar sensors (RISAT, RADARSAT etc.) as well as their widespread coverage increases the need for automatic or semiautomatic interpretation tools for radar images. In particular, line detection can be used for several applications, such as registration with other sensor images, cartographic applications, and geomorphologic studies. In this project, we are interested in the detection of the road network on satellite radar images, but the proposed method could be adapted to other images and purposes. Since synthetic aperture radar (SAR) images result from the backscattering of a coherent electromagnetic wave, they present a noisy appearance caused by the speckle phenomenon. This project aims at exploring PolSAR pro as well as developing a set of parameters essential for road network extraction. We are focused on using existing software resources for finding the best set of images which will ensure and give proper results for the problem of road network extraction. We resort to find the best set of parameters which yield best result for a given problem of back-scatter.

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NOMENCLATURE

Greek

Θ	Root of Underwood equation
A	Alpha
Δ	Delta
E	Energy change indicator

Subscripts

Min	Minimum
I	Any component

Abbreviations

SAR	Synthetic Aperture Radar
SLC	Single lookup component

Chapter 1
Introduction

1.1 INTRODUCTION

THE RECENT launch of numerous radar sensors (RISAT, RADARSAT etc.) as well as their widespread coverage increases the need for automatic or semiautomatic interpretation tools for radar images. In particular, line detection can be used for several applications, such as registration with other sensor images, cartographic applications, and geomorphologic studies. In this project, we are interested in the detection of the road network on satellite radar images, but the proposed method could be adapted to other images and purposes. Since synthetic aperture radar (SAR) images result from the backscattering of a coherent electromagnetic wave, they present a noisy appearance caused by the speckle phenomenon [1], [2]. Although most of the main axes in the road network may be detected by a skilled human observer looking for dark or bright linear structures, automatic detection remains a difficult task.

1.2 MOTIVATION

The increasing use of software location and geo mapping services has led to the birth of globalization. The advent of GPS has been useful for the generation of large amounts of data as well as users for the job of localization and mapping. Hence, the advent of the development of automated analysis has led to increasing need for development of automated analysis of algorithms which can facilitate the use of mapping and extracting specific features from sensor images. This will lead to a novel and hybrid approach of using existing software tools to model several algorithms for achieving the desired objective of road network extraction.

1.3 SCOPE OF PROJECT

This project aims at exploring PolSAR pro as well as developing a set of parameters essential for road network extraction. We are focused on using existing software resources for finding the best set of images which will ensure and give proper results for the problem of road network extraction. We resort to find the best set of parameters which yield best result for a given problem of back-scatter.

1.5 REPORT ORGANIZATION

The rest of the report is organized as follows: Chapter 2 talks about the application of remote sensing and the use of SAR data. Chapter 3 talks about the Data processing in SAR applications and Chapter 4 talks about the simulation results.

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Chapter 2

Remote Sensing and GIS: A SAR Perspective

2.1 Remote Sensing Process

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on-site observation. The process in remote sensing involves interaction of the incident radiation with the target on ground. The incident radiation can be in the form of energy from background space and solar radiation or from onboard sensors. The seven elements involved in Fig. 2.1 are shown below and are namely energy source for illumination (A), Radiation scattering from atmosphere (B), Interaction with target (C), Recording of received sensor data (D), Transmission reception and processing (E).

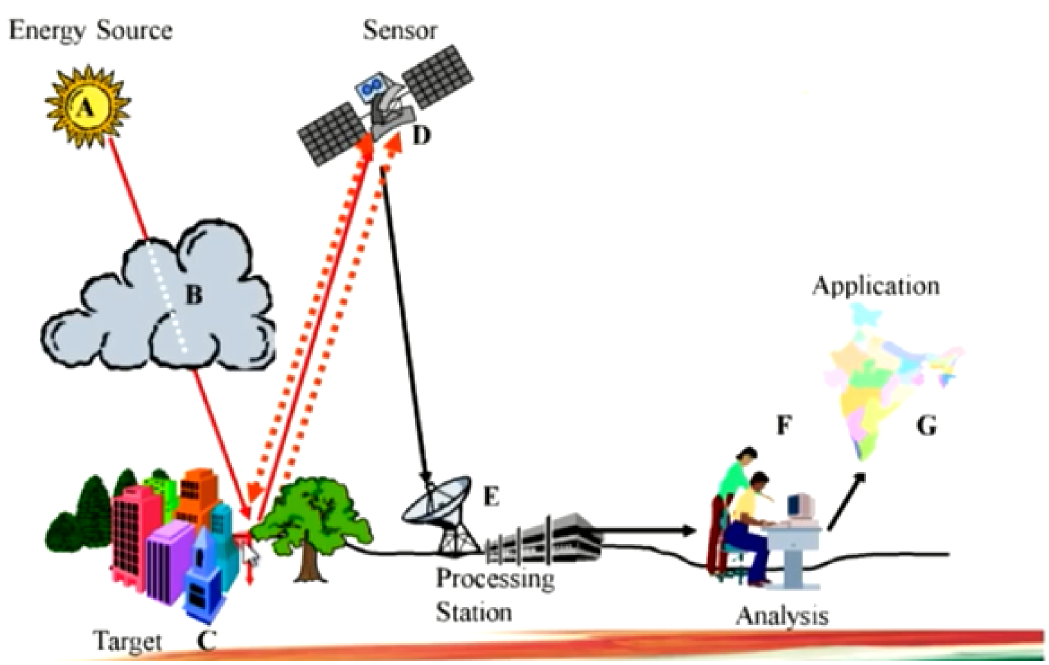

Fig 2.1 Remote Sensing Process

Remote sensing involves various navigable and space based platforms for land and ground based surveys. Hence, they form an integral part in several land and ocean based data acquisition systems which help in overall management and observation of several challenges like oil spill, deforestation, etc.

2.2 Remote Sensing Platforms

Several remote sensing platforms exist in the market today. They involve land based takeoff and landing systems mounted on aerial vehicles to suborbital systems as well as low earth orbit satellites launched into space. Since the first American land observation satellite launched in 1972, all kinds of technologies applied to the RS image processing have developed rapidly, including image compression, transmission, classification, fusion and understanding. All of those high resolution RS images such as IKonos, QuickBird, WorldView and GeoEye create a quick and economical way to access the newly acquired geographic information, and lay a very important basis for the further applications of RS technology. Fig. 2.3 shows all the possible platforms.

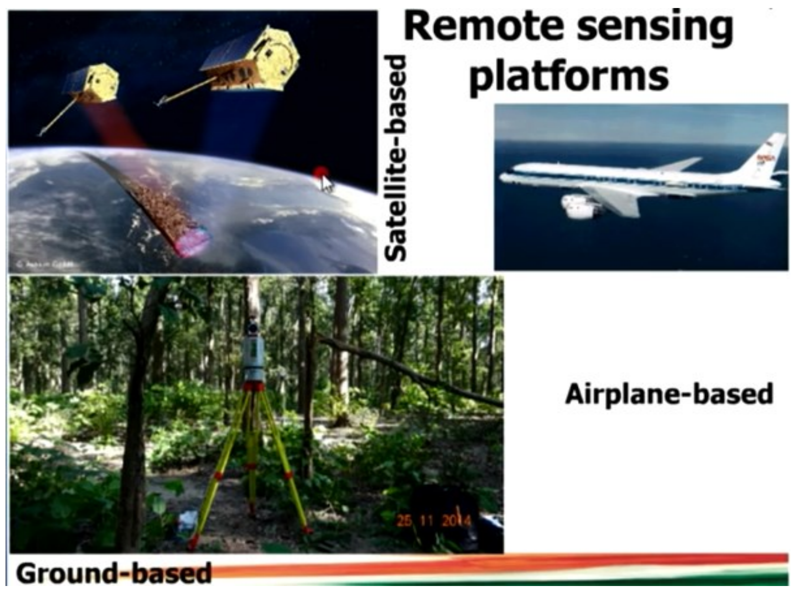

Fig 2.2 Remote Sensing Process

2.3 SAR: Synthetic Aperture Radar for Remote Sensing Images

Despite the wide variability of several remote sensing platforms, the use of SAR or Synthetic Aperture radars is widespread due to their wide variety of advantages, namely:

- Night Vision Capability due to active sensing technique based on active illumination.
- Cloud Penetration Capability and hence all weather use.
- Effective use of satellite trajectory as antenna aperture thus increasing the overall field of view and cross section per orbital period.

Fig 2.4 shows the variety of other platforms and their comparison with the SAR technology. The advantage of SAR is shown in Fig 2.3 which shows how the effective aperture of SAR is more than conventional satellites.

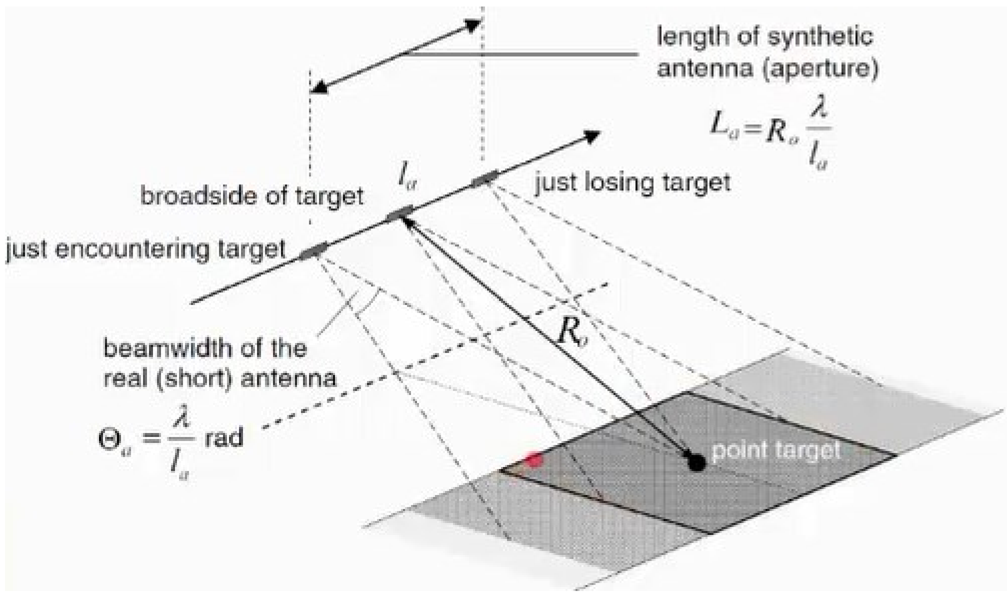

Fig 2.3 Creation of Synthetic Aperture for using in SAR Satellites

Successive pulses of radio waves are transmitted to "illuminate" a target scene, and the echo of each pulse is received and recorded. The pulses are transmitted and the echoes received using a single beam-forming antenna, with wavelengths of a meter down to several millimeters. As the SAR device on board the aircraft or spacecraft moves, the antenna location relative to the target changes with time. Signal processing of the successive recorded radar echoes allows the combining of the recordings from these multiple antenna positions – this process forms the 'synthetic antenna aperture', and allows the creation of higher resolution images than would otherwise be possible with a given physical antenna.

	Lidar	Optical Multi-Spectral	SAR
Platform	airborne	airborne/spaceborne	airborne/spaceborne
Radiation	own radiation	reflected sunlight	own radiation
Spectrum	infrared	visible/infrared	microwave
Frequency	single frequency	multi-frequency	multi-frequency
Polarimetry	N.A.	N.A.	polarimetric phase
Interferometry	N.A.	N.A.	interferometric phase
Acquisition time	day/night	day time	day/night
Weather	blocked by clouds	blocked by clouds	see through clouds

Fig 2.4 SAR vs Other Earth Observation Instruments

2.4 Our Working Dataset: Ahmedabad City

Since majority of the advantages offered by SAR prevails over other sensing paradigms, we also prefer to work on SAR data. Majority of the above mentioned sensors work basically on microwave ranges. Table I shows the correlation with the variety of space communication bands used.

TABLE I – RADAR Bands Commonly used for Sensing as well as the list of Satellites with working bandwidths.

BAND	WAVELENGTH (cm)	FREQUENCY GHz (10^9 Cycles/sec)
Ka	0.75 - 1.1	26.5 - 40
K	1.1 - 1.67	18 - 26.5
Ku	1.67 - 2.4	12.5 - 18
X	2.4 - 3.8	8 - 12.5
C	3.8 - 7.5	4 - 8
S	7.5 - 15	2 - 4
L	15 - 30	1 - 2
P	30 - 100	0.3 - 1

RISAT-1: April 2012: C-band
Radarsat 1: 1995: C-band
Radarsat 2: 2007: C-band (Quad-pol)
ERS 1: 1991-2000 :C-band
ERS 2: 1995 :C-band
JERS : 1992-98 : L-band
ENVISAT: 2002: C-band
ALOS: 2006: L-band (Quad-pol)
TerraSAR-X: 2007-20012: X-band (Quad-pol)

From Table I, it is clear that SAR works primarily with the C Band as well as some working on X band as well as L band. We will be working on satellite images of **Ahmedabad City** obtained from **RISAT I** over the period of **September and October of 2016.**

2.5 SAR Data Acquisition and C2 Matrix Generation

The SAR sensor can acquire data in the following forms:

- Single or dual channel (e.g. HH or HH/HV)
- Interferometric (single path or repeat path)
- Polarimetric (HH,HV,VV,VH)

The SAR sensor receives data in the form of a raw binary format with each line being an echo of the radar signal, that has been scattered back to the sensor by targets along the along track position. Each pixel is a complex value (that consists of a real part and an imaginary part), i.e in a+jb format.

In the raw data, the signal energy from a point target is spread in range and azimuth, and the purpose of SAR focusing is to collect this dispersed energy into a single pixel in the output image (Single Look Complex, or SLC image). Single Look Complex (SLC) is the basic single look product of the focused radar signal. Each pixel is a complex number (with a real and an imaginary part). This is followed by multi looking (MLI) which performs the basic operation of squaring the overall elongated pixel to give a good data. This process gives rise to level 1 data (SLC/MLI) from level 0 data (Raw Binary).

This can be further extended to give level 2 data which includes Georeferencing. Fig. 2.5 gives an overall transmission workflow for the conversion of the input image into a C2 martix. This is done through the software package called PolSAR Pro which is shown in next chapter.

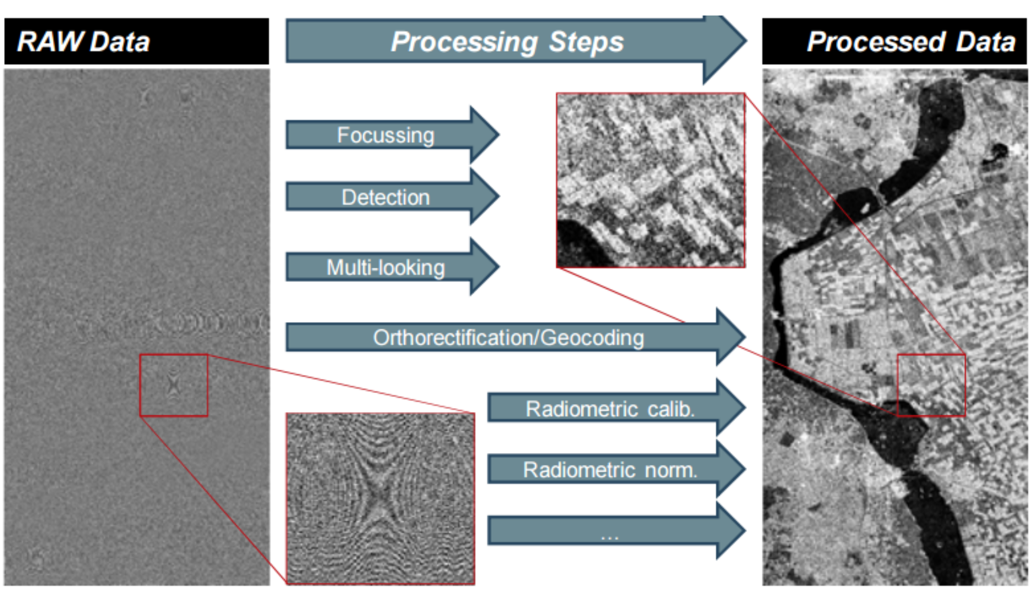

Fig 2.5 Overall process flow for conversion of level 0 data to level 1 data (C2 matrix) for further processing

After the data is obtained in the C2 matrix form, we can succeffully apply several filtering and decomposition algorithms to find the best suited one to give optimal result.

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Chapter 3

PolSAR-Pro: SAR Data Processing

3.1 SAR Polarimetry

Radar Polarimetry is the science of acquiring, processing and analyzing the polarization state of an electromagnetic field. Radar polarimetry is concerned with the utilization of polarimetry in radar applications. Polarimetry deals with the full vector nature of polarized (vector) electromagnetic waves throughout the frequency spectrum from Ultra-Low-Frequencies (ULF) to above the Far-Ultra-Violet (FUV) [19, 20]. Whenever there are abrupt or gradual changes in the index of refraction (or permittivity, magnetic permeability, and conductivity), the polarization state of a narrow band (single-frequency) wave is transformed, and the electromagnetic "vector wave" is re-polarized.

The scattering properties of a target can be measured by a polarimetric radar, as depicted in Figure 3.1. The radar system illuminates the target with an incident wave (A), and the wave is scattered in all directions by the target (C). The radar system records the part of the scattered wave that is directed back towards the receiving antenna (B). Often the receiving antenna is in the same location as the antenna that transmitted the wave - this is called the monostatic case, and the received energy is referred to as backscatter. By controlling the polarization of the incident wave and measuring the full polarization properties of the backscattered wave, the radar system can be used to learn more about the target than by using a single polarization.

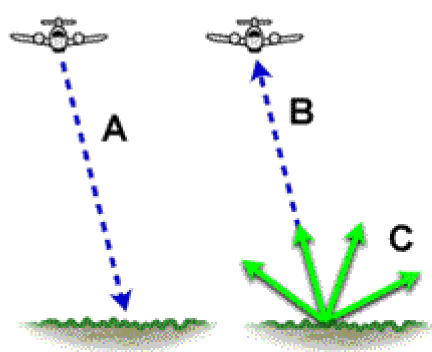

Fig 3.1 Backscatter polarimetry by SAR Radar

A polarimetric radar transmits with two orthogonal polarizations, often linear horizontal (H) and linear vertical (V), and receives the backscattered wave on the same two polarizations. This results in four received channels, i.e. HH, HV, VV and VH, where both the amplitude and relative phase are measured. The measured signals in these four channels represent all the information needed to measure the polarimetric scattering properties of the target - hence the quadrature polarization radar is also called a fully polarimetric radar. In the case of dual polarized radars, some but not the entire target scattering properties can be obtained from the two channels. **RISAT provides us with dual-pol data**.

3.2 The Scattering Matrix : C2

When a horizontally polarized wave is incident upon a target, the backscattered wave can have contributions in both horizontal and vertical polarizations. The same applies to a vertically polarized incident wave. As the horizontal and vertical components form a complete basis set to describe the electromagnetic wave, the backscattering properties of the target can be completely described by a scattering matrix, S,

$$\begin{bmatrix} E_h^{\,s} \\ E_v^{\,s} \end{bmatrix} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^{\,i} \\ E_v^{\,i} \end{bmatrix} \tag{1}$$

which describes the transformation of the Electric Field of the incident wave to the Electric Field of the scattered wave (the superscript i refers to the incident wave, and s refers to the scattered wave). Having measured this matrix, the strength and polarization of the scattered wave for an arbitrary polarization of the incident wave can be computed, as any incident wave can be expressed in the [E_h^i , E_v^i] basis set.

The four elements of the scattering matrix are complex, and can be obtained from the magnitudes and phases measured by the four channels of a polarimetric radar. Thus, the in the late forties with the introduction of dual polarized antenna technology [2, 3, 4, 5], and the subsequent formulation of *'the 2 x 2 coherent radar back-scattering matrix and the associated power density matrix'*, led to renewed interest in automating the process. If we take the complex covariance of relating to the second order statistics of partial polarimetric scattering matrix elements, we get what is known as the C2 matrix.

$$[C_2] = \begin{bmatrix} C_{11} & C_{12} \\ C_{12}^{*} & C_{22} \end{bmatrix} \tag{2}$$

The (2x2) Covariance **[C2]** matrix is constructed from a two-element unitary target vector. An outter product leads the to the definition of the corresponding (2x2) Covariance matrix **[C2]** relating to second order statistics.

$$\underline{k}_{PX} = \begin{bmatrix} S_{11} & S_{22} \end{bmatrix}$$
$$\Longrightarrow \quad [C_2] = \langle \underline{k}_{PX} \cdot \underline{k}_{PX}^{\dagger} \rangle \tag{3}$$

Where S_{11} and S_{22} correspond to the relative Sinclair elements given in Equation (1). The generation of the **[C2]** matrix is extremely important as all the processing and segmentation/clustering/feature extraction can be done only after that.

3.3 PolSAR Pro GUI and Working Environment

The Polarimetric SAR Data Processing and Educational Tool aims to facilitate the accessibility and exploitation of multi-polarised SAR datasets including those from ESA. PolSAR pro basic UI has the following key elements: Setting the environment directory, the task menu, as well as the processes menu. The overall process to set the environment and importing spaceborne sensor data is shown below.

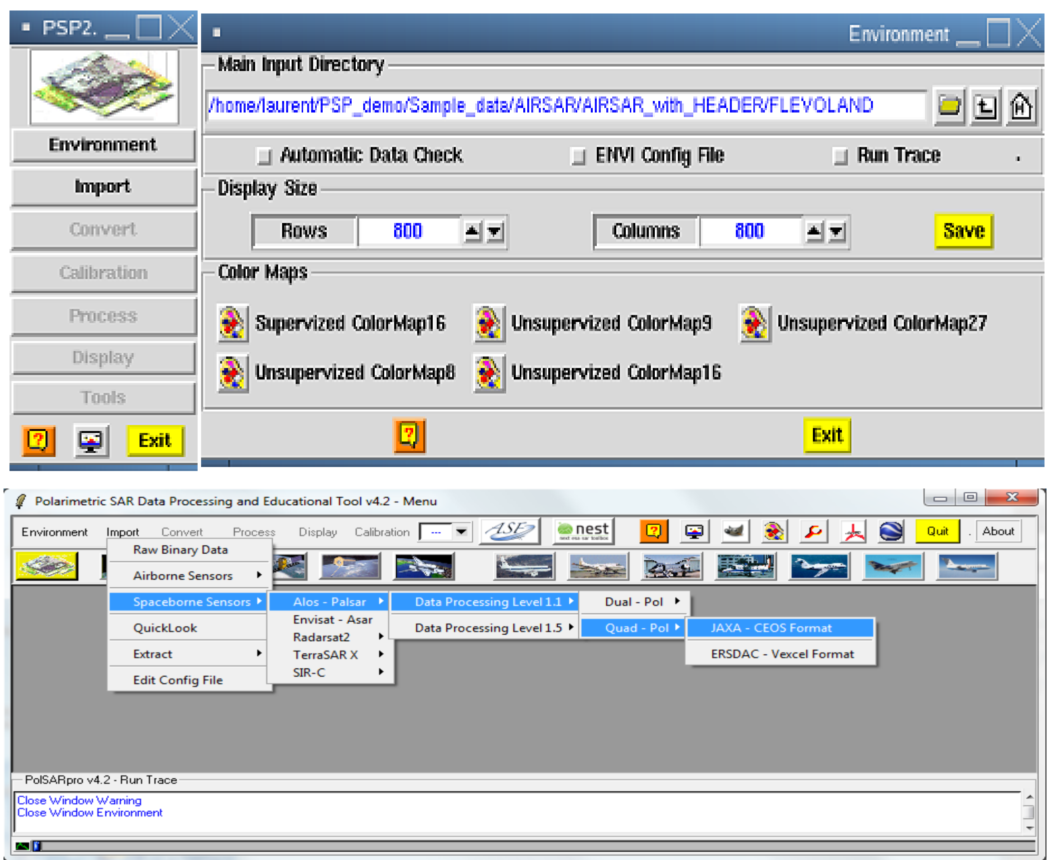

Fig. 3.2: Importing sensor data as well as setting the environment directory.

Since SAR data is in the form of LH/LV data, as well as the METADATA which contains georeferencing as well as other important information, this is useful in creating the C2 matrix for each pixel data and generating the overall final image. This is done in the current working directory itself and a completely new file is generated. A sample of that directory is shown below.

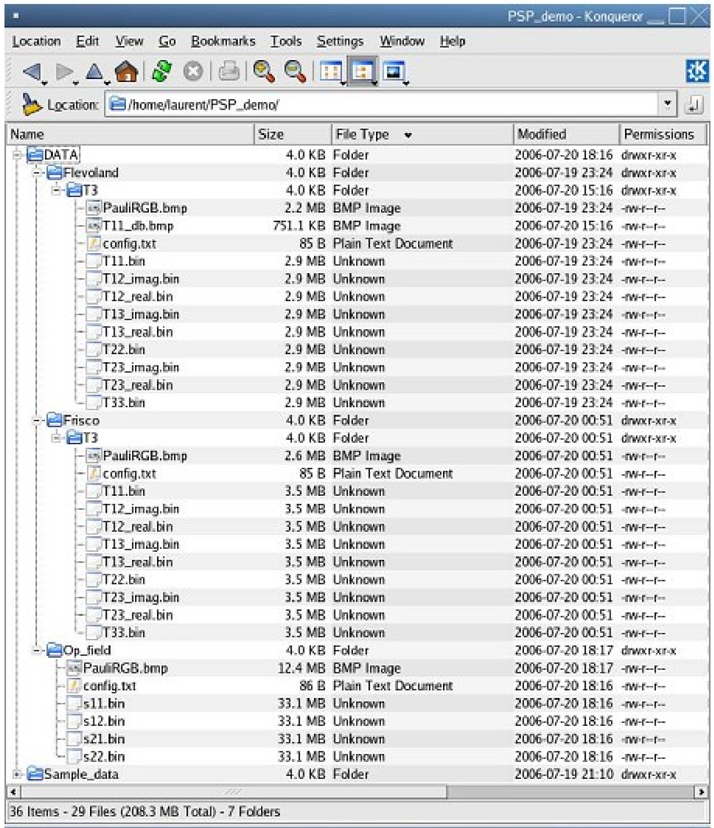

Fig. 3.3 Sample Working directory with T matrix raw binaries generated along with images in bmp format.

3.2 SAR Image Synthesis SAR Image Synthesis

The overall process of synthesizing the image from the **dual polarization data** obtained from RISAT in PolSAR Pro is done using a special set of steps as shown below:

- STEP I: The environment variable is set for the given working directory which contains the overall Dual polarized data
- STEP II: The data is imported from the RISAT option in the Spaceborne Sensors directory.
- STEP III: The C2 Matrix for the corresponding rows and columns of the raw LH/LV data is generated. The C2 matrix contains all the four elements which are necessary for the same.
- STEP IV: The RGB file is generated from the C2 Matrix.

A sample RGB image of a road network / surface image is shown created from SAR data and shown below. Further details about processing is given in the next chapter.

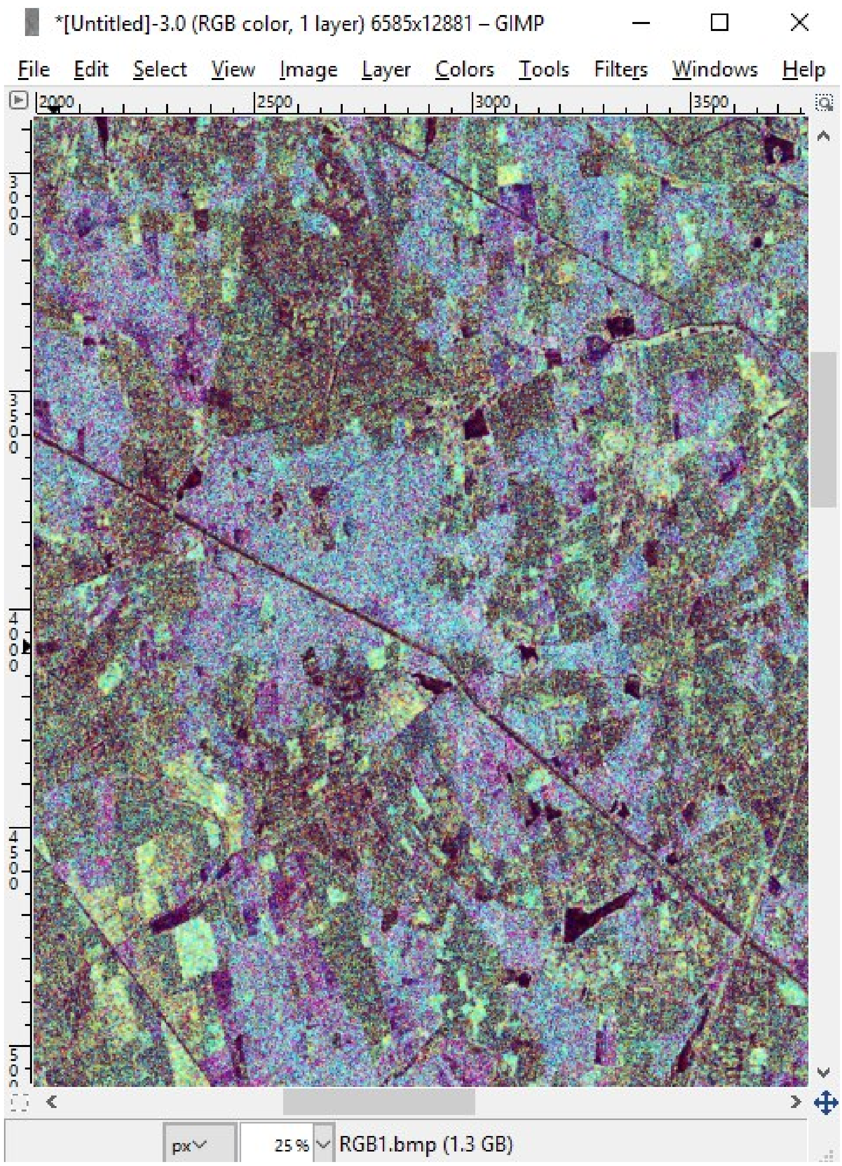

Fig 3.4 SAR image file generated from the C2 matrix

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Chapter 4

Simulation and Processing Results

4.1 SAR Processing: Speckle Filtering

Speckle noise in conventional radar results from random fluctuations in the return signal from an object that is no bigger than a single image-processing element. It increases the mean grey level of a local area. Unlike optical remote sensing images, characterized by very neat and uniform features, SAR images are affected by speckle. Speckle confers to SAR images a granular aspect with random spatial variations. Speckle noise in SAR is generally serious, causing difficulties for image interpretation. It is caused by coherent processing of backscattered signals from multiple distributed targets. Several different methods are used to eliminate speckle noise, based upon different mathematical models of the phenomenon.

A speckled intensity, Y, may be considered as a random variable whose mean value equals the unspeckled intensity, X, but affected by a large variance due to speckle. The principle of speckle filtering consists of reducing the variance of in order to improve the estimate of its mean, Eq 4.

$$\langle Y \rangle = \frac{1}{L}\sum_{i=1}^{L} Y_i \tag{4}$$

The figure below shows the values of the output images in case of both Boxcar and JS Lee filter speckle filters.

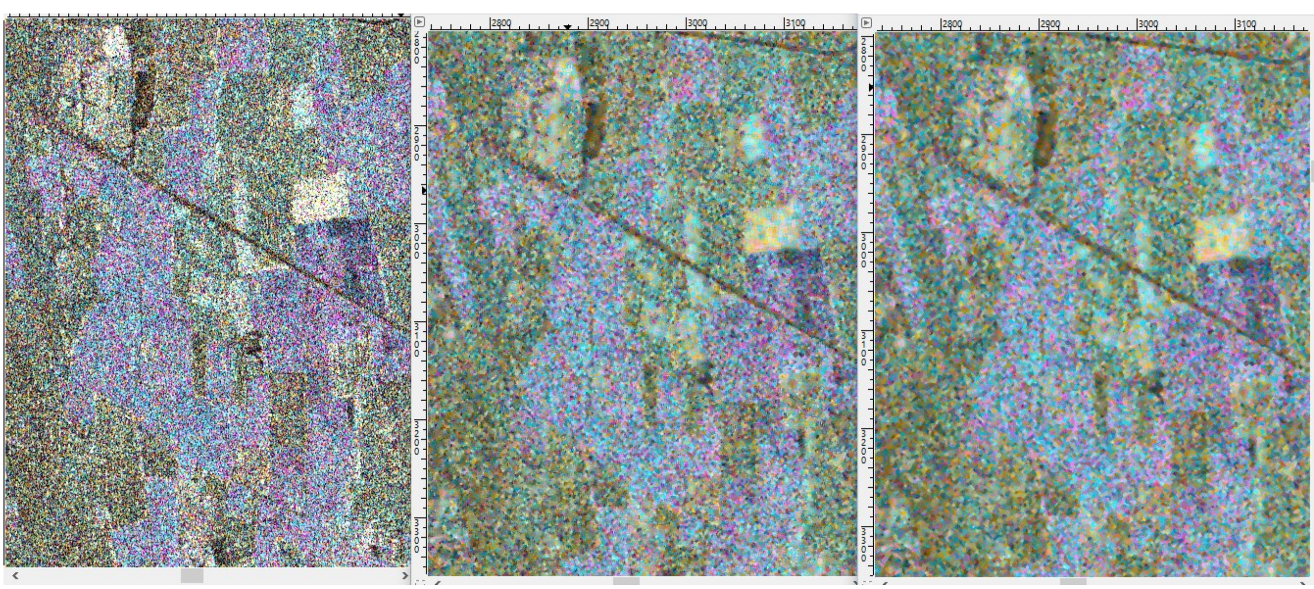

Fig. 4.1 : (a) Input Image (b) Boxcar Filter output (c) JS Lee Filter output.

4.2 The refined Lee Filter: Case Approach

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 mathematics of the same is given in [4]. The figure 4.2 shows the ouput of the speckle refined lee filter. We notice a drastic improvement in the overall output of the desired image. Making it more prefereable for extraction results.

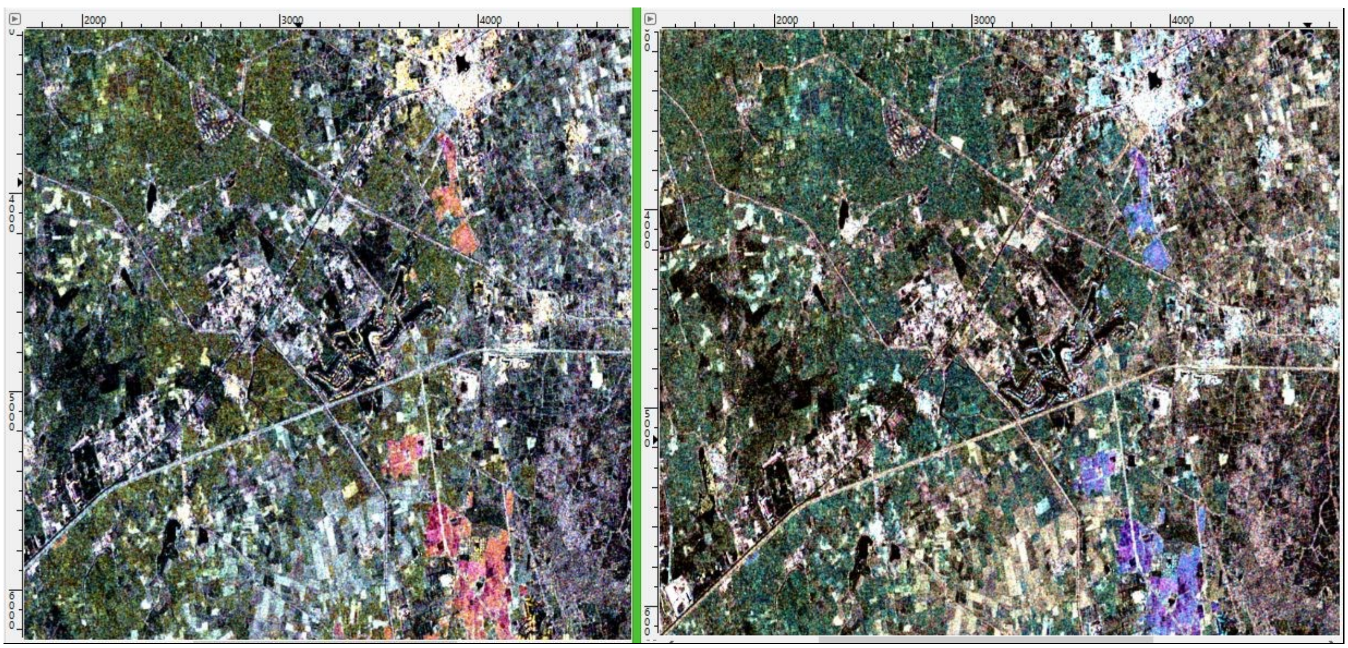

Fig 4.2 (a) The Image output post Refined Lee Filter

Fig 4.2 (b) The original image created from the [C2]

4.3 Decomposition Methods

Followed by the speckle filtering, we apply several decomposition methods to find the appropriate value of the overall parameters. Namely the following parameters are evaluated. We choose the H/Aplha Decomposition to evaluate :

- Entropy
- Anisotropy
- Lambda

The overall output for both the decomposition methods has been shown in the Fig. 4.3. It can be seen that the entropy as well as anisotropy will both be useful in case of the finding road networks but not together.

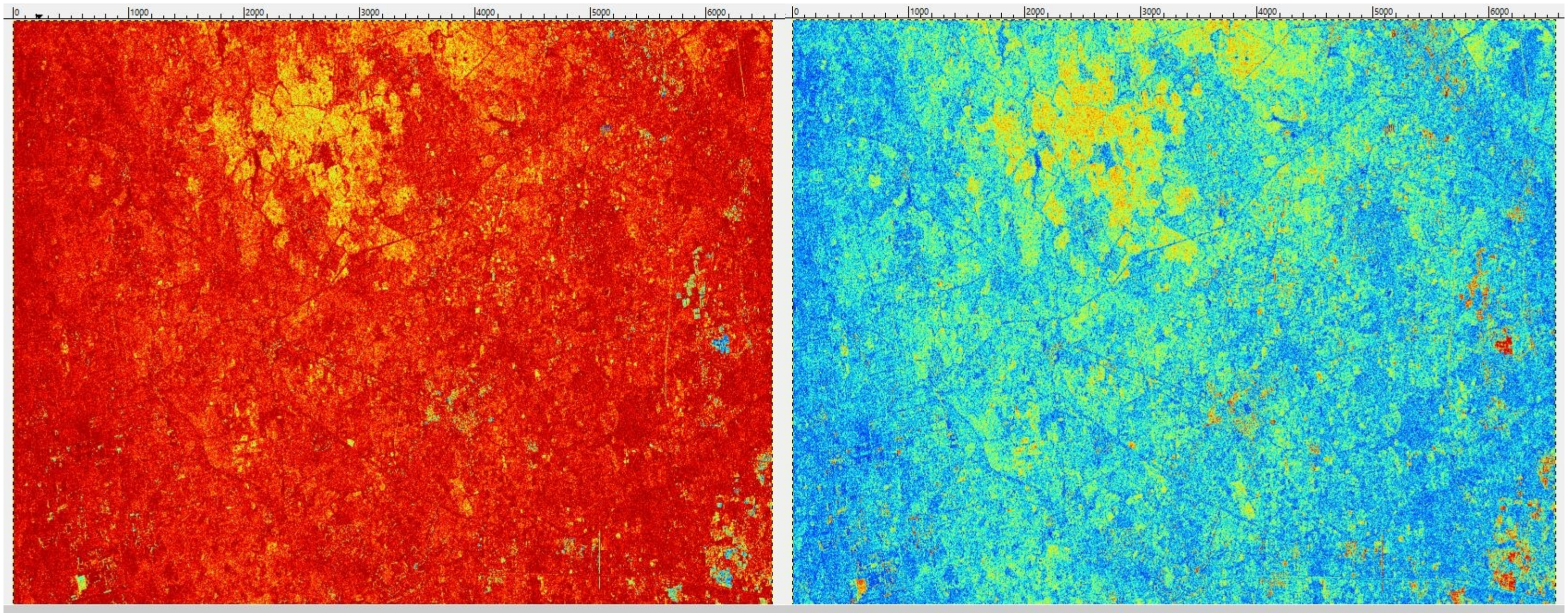

Fig 4.3 The Entropy Image as well as anisotropy results

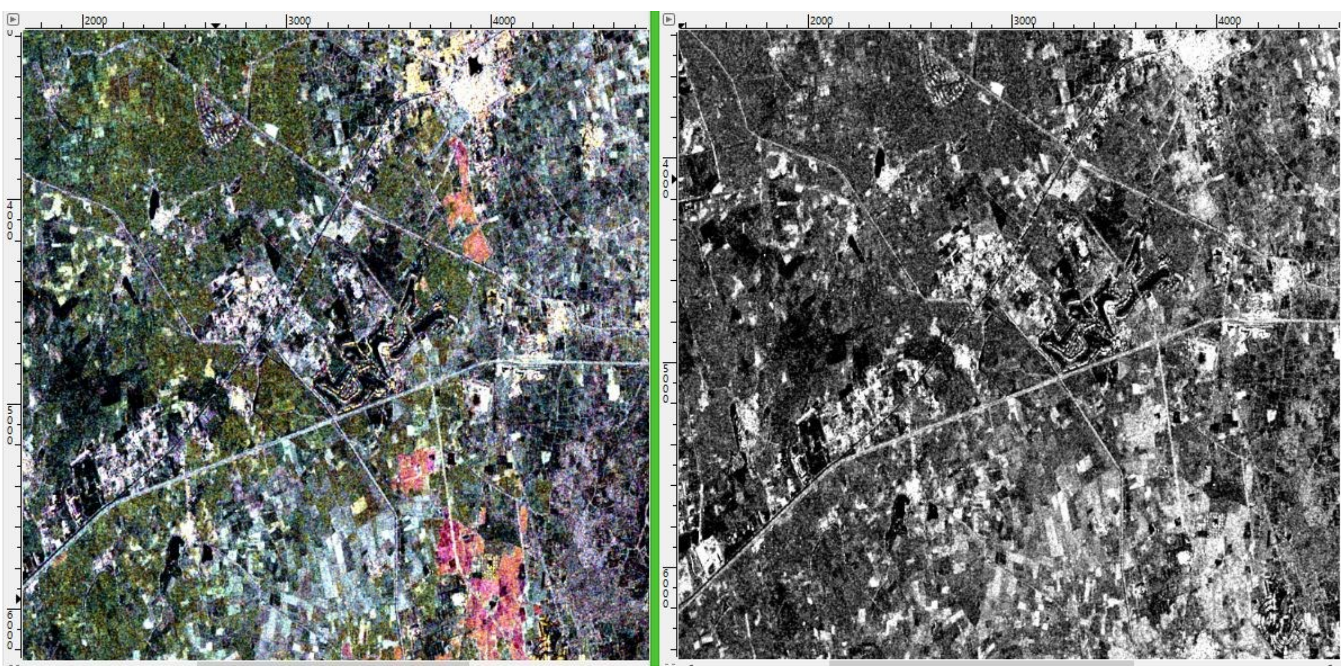

Fig 4.4 The Image output of the lambda parameter for the refined Lee filter.

Fig. 4.4 shows the final output of the lambda parameter for the refined lee filter. This is important because it shows the proper output of for the road network extraction and might be useful for further classification.

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Conclusions:

We have seen that in case of PolSAR pro and working with dual Pol data, the best option is to utilize the lambda parameter because it helps in accurate identification of proper road networks. Followed by the speckle filtering, we apply several decomposition methods to find the appropriate value of the overall parameters. Speckle noise in conventional radar results from random fluctuations in the return signal from an object that is no bigger than a single image-processing element. In such cases, the refined Lee approach works best for our case.

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