MMW Polarimetric Data Base of Terrain Reflectivity and an Associated Image Simulator

Roger De Roo, Fawwaz T. Ulaby, Gregory Samples, Jiyoun Munn, John Costanza, Adib Nashashibi, Alaa El-Rouby and Leland Pierce
The University of Michigan
3228 EECS Bldg, 1301 Beal Ave., Ann Arbor, MI 48109-2122 USA
phone: +1-734-764-1091, FAX: +1-734-647-2106, email: deroo@umich.edu

ABSTRACT

SPRI, the Simulator of Polarimetric Radar Images, is a suite of PCI image processing programs which together can be used to simulate millimeterwave (MMW) radar images of terrain. SPRI is intended to produce images similar to existing imagery but with one or more significant changes to facilitate comparisons. These significant changes include radar frequency, angle of incidence, season of year, recent precipitation, etc.

The heart of the simulator package is a scattering matrix generator which calls upon a database of measured Mueller matrices of terrain. This generator program produces high-resolution single-look polarimetric images. Simulated images can be degraded in polarization, number of looks, resolution, etc. to match those of a particular radar sensor. Auxiliary programs have been written to help adapt existing images to the frequency and incidence angle desired. For example, a sub-suite of programs classifies shadows and manipulates them for incidence angle changes.

The simulator relies upon a database of over 2500 Mueller matrices measured at 35 and 95 GHz by instrumentation grade scatterometers. The data is organized by frequency, incidence angle, and terrain type, and is accompanied by extensive ground truth. This database is a research tool in its own right, and as such has a password-protected web interface.

1. INTRODUCTION

Radar images have proven to be invaluable tools in the remote sensing community, with regard to both civilian and military applications. With the advent of Synthetic Aperture Radar (SAR), very high resolution images can be readily generated at both centimeter and millimeter wavelengths. For many tasks, such as testing Automatic Target Recognition (ATR) algorithms, it is desirable to have a particular radar image taken with a particular sensor under particular conditions. Unfortunately, such radar images are often unavailable. This document describes the techniques for radar image simulation using SPRI, the Simulator of Polarimetric Radar Images.

The majority of any radar image consists of clutter. The clutter generation depends on two parts: a clutter database and a simulation algorithm. The simulation algorithm converts random numbers into complex scattering matrices, $S$, which are statistically appropriate for the clutter being modeled. But the conversion requires information on the covariance of the $S$ matrix elements that is unique to the particular clutter being modeled. A clutter database of measured Mueller matrices for various types of clutter under different conditions provides the information required for the simulator algorithm. Polarimetric clutter simulation is combined with existing target injection techniques to create fully polarimetric synthetic radar images.

2. THE CLUTTER DATABASE

We have collected a Clutter Database of many polarimetric measurements of the Mueller matrix of terrain at MMW frequencies and at near grazing incidence. Each of these measurements represents an average over many independent samples of homogeneous clutter under homogeneous conditions. In addition to the Mueller matrix, we have included in the Clutter Database extensive ground truth so that models for the radar backscatter may be generated from the data taking into account the underlying physical parameters which control the backscatter. These models, or the data itself, can be used to model not only homogeneous clutter under homogeneous conditions, but also under heterogeneous conditions [1].

The Clutter Database is an online repository for calibrated polarimetric backscatter measurements. As of 22 Feb 2000, the Clutter Database contains 2855 Mueller matrices measured at Ka- and W-bands. Most of this data is in an angular range near grazing, but some measurements exist at nearly all angles of incidence. All of the data is fully polarimetric, and therefore the backscattering coefficient values are available not only in the linear basis ($VV$, $HH$, and $HV$ polarizations) but also in the circular basis ($LL$, $RR$, and $LR$ polarizations).
2.1. Sources of Data

The primary purpose of the Clutter Database is to hold polarimetric MMW data collected by the University of Michigan using its ultra-fast scatterometer system [2]. An important feature of this system is the high speed with which it acquires the complete scattering matrix, thereby preserving phase coherence between polarizations. However, the University of Michigan has attempted to collect polarimetric MMW data from as many sources as possible for inclusion in the Clutter Database. The Clutter Database includes numerous measurements collected since 1991 with a network analyzer-based scatterometer system [3] designed and built by the University of Michigan. Other sources of data include clutter measured by the Army Research Laboratory with their polarimetric W-band monopulse radar [4] as part of the Smart Weapons Operability Enhancement (SWOE) program [5], and measurements of clutter by the University of Massachusetts at 35, 95 and 225 GHz [6].

2.2. Accessing the Clutter Database

The Clutter Database is available online free of charge but it is password protected. A password can be obtained by an institution (University or corporation) when a letter of need is received at the University of Michigan from the institution’s government sponsor. Contact the authors at the email address listed for detailed information on accessing the Clutter Database.

A brief overview of the contents of the Clutter Database is available at http://larch.eecs.umich.edu/~deroo/clutterhelp

A description of QueryBuilder, the generic web interface to an SQL database, can be found at http://larch.eecs.umich.edu/cgi-bin/querystats/querystatshelp.cgi

Neither of these World Wide Web sites are password protected.

2.3. Clutter Database Structure

The Clutter Database is a MySQL-based relational database. The Structured Query Language (SQL) describes an industry standard for communicating with databases and the QueryBuilder interface simply mimics the syntax of the ‘Select’ query, the command for extracting information from an SQL-compatible database.

The Clutter Database consists of multiple tables. The main table is the ‘mueller’ table, which contains the measured Mueller matrices of clutter for many kinds of terrain under many conditions. The mueller table contains the following groups of information:

1. acquisition (date and time of the measurement, the organization which acquired the data, etc.),
2. radar parameters (center frequency, band designation, bandwidth, angle of incidence, etc.),
3. radar return (the Mueller matrix elements, \( \sigma^0 \) in linear and circular basis, phase difference statistics, etc.), and
4. clutter classification (target classes, roughness, wetness, species names, etc.).

In addition to the main table, there are the ancilliary information tables and the ground truth tables. The ancilliary information tables supplements the mueller table information on the radar systems; the ground truth tables supplements the mueller table information on the clutter classes. In both cases, the records in these tables are cross-indexed to the mueller table via the time and date of the radar measurement, as this is a unique key for the data.

3. THE IMAGE SIMULATOR

The algorithm for simulating Rayleigh clutter from a Mueller matrix is found in an appendix to an article by Lee, Grunes and Kwok [7].

First, make many individual measurements (via SAR or scatterometer) of the particular clutter type under the desired conditions. Each measured \( S \) matrix is converted to a Mueller matrix and all of these Mueller matrices are averaged together to form a single “average Mueller matrix” which represents the statistical polarimetric characteristics of that clutter. This information is stored in the Clutter Database. Fig. 1 shows this process in blue.

For simulation, we must identify a region in an image as a particular clutter type. Then, the appropriate average Mueller matrix is extracted from the Clutter Database. This Mueller matrix is converted to a covariance matrix, and this covariance matrix is decomposed into a unitary matrix of eigenvectors and a diagonal matrix of square roots of the eigenvalues. Fig. 1 shows this process in red with single headed arrows.

A random number generator is then employed to create three independent zero-mean unit-variance complex Gaussian random numbers for each pixel in the image region. These random numbers are appropriately linearly combined to create the simulated \( S \) matrix. Fig. 1 shows this process in red with double headed arrows.

For the next pixel in the image region, the algorithm repeats starting with the random number generator. Since the average Mueller matrix is the same across the region, we do not need to calculate new eigenvalues or eigenvectors. That is, subsequent pixels in a region involve only the process shown in Fig. 1 with double headed arrows.
For the next region in the image, a new average Mueller matrix appropriate for the clutter in this next region must be extracted from the Clutter Database. That is, the first pixel of each region involves the entire process shown in Fig. 1 in red.

If we subdivide the area for particular clutter type in the image to be simulated into appropriately interleaved regions, for which the conditions differ slightly, we can simulate texture and non-Rayleigh fading statistics [1]. An example of a radar image simulated with SPRI is shown in Fig. 2.

4. CONCLUSIONS

The University of Michigan has made the first component of SPRI: the Simulator of Polarimetric Radar Images. This first component of SPRI is a radar simulator which can create high-resolution polarimetric single-look clutter images. The simulator draws on a user-specified geometry and a database of Mueller matrices for the regions within that geometry to create radar clutter images. SPRI calls upon a Clutter Database of polarimetric backscatter measurements at 35 and 95 GHz.

REFERENCES


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