MOCEM - An 'all in one' tool to simulate SAR image

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Abstract

MOCEM is a compact SAR image generator that can produce high resolution SAR images from CAD models (VRML, 3DS…) taking into account basic material descriptions. As an innovative approach, this software uses:

- an original EM formulation based on the object geometry analysis to build SAR images in a very short computation time. These formulations have been developed by skillful SAR and RCS experts;
- an original geometrical algorithm which handles the various facets visibility, including the multiple inner reflections and the interaction with the object surroundings (i.e. ground).

SAR images are typically produced in a matter of minutes, using a 2D SAR radar transfer function that takes into account the main parameters of SAR image quality (resolution, Ne$\sigma°$, tapering).

Many studies suffer from the lack of SAR images or control on SAR image content. This tool will interest scientists and labs, working on SAR image features extraction and SAR image analysis. A dedicated version called MOCEM LT has been developed for educational purposes. It offers an attractive way to explain capabilities and limits of SAR images to the scientific community which is more familiar with optical and IR images than radar.

1 MOCEM context

1.1 The new SIROS simulator

Since 1990, the CELAR, the French Electronics Defense Center of DGA (part of French MoD), is working on SAR military applications. For its studies, the CELAR has developed a simulator named SIROS[1]. This simulator, using large 3D databases, has been developed to predict the characteristics of a high-resolution military radar embedded on a future satellite[2]. In 1999, while many very high-resolution SAR images became available from RAMSES[3], the ONERA's radar operated for DGA, the SIROS architecture has been entirely revised. A New SIROS simulator, named 'SIROS 2000', has been developed to prepare expertise and users to manned or unmanned airborne vehicle for needs of Air Ground Surveillance and Time Sensitive Targeting. This new version of SIROS offers a high integration of measured SAR image and simulated contents to create large SAR images including operational scenarii (buildings, targets) for performance assessment and training.

1.2 MOCEM origins

The MIXSAR module uses existing measured images and raw data to produce new operational scenarii by 'mixing' them with simulated or measured radar signatures. MOCEM has been developed to generate these images of infrastructures and other large objects for which no ISAR measurements, or not enough SAR images, were available.

1.3 MOCEM concept

To produce a simulated SAR image of an object, we need to compute the complex reflectivity of the scene along the radar trajectory.

Unfortunately, being theoretically rigorous, this method appears unusable for large objects or scenes (computation time), complex objects (accuracy of CAD models and EM properties). Moreover, it is not adapted for natural or diffused surfaces surrounding the object. The MOCEM concept is based on standard CAD model (not specifically created for radar applications and RCS code constraints), and basic EM models description. After a geometrical analysis, it localizes EM important phenomena for SAR imaging and computes level and directivity responses. Then image is obtained by convolution with the SAR chirp response along the SAR radar path. A common hypothesis is used, considering, intrinsic object response do not change inside the bandwidth of the chirp.

2 MOCEM principles

2.1 The EM "behavior" model

It is commonly observed that large objects are usually not as 'perfect' as their CAD model. So the rigorous EM computation appears different from the observed SAR image. Also the best models are never sufficiently detailed on small parts, due to the fact that

many parts cannot be accurately modeled in CAD geometry (corrugated iron, wire mesh, gravel…). MOCEM offers an interesting new way to produce SAR images in these situations.
The process used in MOCEM is not based on usual RCS codes principles but on the estimation of EM effects that has been observed on measurements of the object. That's why we use to call this software a "EM behavior model".
The MOCEM approach is to not generate raw data of the object and then proceeds to a SAR or ISAR focusing. Here the concept is to locate effects considering coherent and non-coherent response.
This approach is dedicated to scenes including diffuse effects and to object whose geometry and materials generate numbers of bright points coming form specular and multiple bounds.

Two phenomena are considered:
- the diffuse effect resulting from many incoherent scatterers in the image resolution cell;
- the coherent response coming from reflective surfaces, typically steel or dielectric plates (including interaction with surrounding ground)

2.2 Theoretical behavior and empirical adjustments of the EM model

Diffuse part:
MOCEM does not include a physical model to estimate the monostatic backscattering from natural surfaces or rough soils or object parts. We consider that the diffuse effect is efficiently obtained considering existing measurements and an empirical adjustment [4]. Many 'sigma0' curves are available or can be build using SAR images (if some actions have not been neglected for calibration and to collect associated ground truth). Some prediction codes [5] or dedicated facilities [6] can also be used. In MOCEM user has to introduce sigma0 curve by polarization for each material. If available, user can also introduce the correlation existing between channels using normalized statistics [7]. A similar term is also used to introduce interferometric correlation.

Coherent effect:
All surfaces, including natural surfaces, can be associated to a coherent effect. Coherent reflection is depending on dielectric properties but we can also associate a roughness that is converted into an attenuation term. By this way, we offer possibility to user to adjust behavior of building materials.
This approach can also transfers a diffuse part or an attenuation on specular reflection to consider that surfaces (including surrounding ground) are not as plane than theirs 3D-models or are missing of details smaller than radar resolution.

2.3 image building steps

CAD model
One major difficulty to conduct computations in EM domain is to have 3D-models that satisfy rigorous criteria regarding wavelength. Nearer the real model is corresponding to the 3D-model or reciprocally, less transfer to material behavior have to be done. It appears than a vehicle or buildings can be well modeled with 10000 to 20000 facets and a ship with 20000 to 50000 facets. Some facets can be added for the surrounding ground (a plate with slopes) or the sea surface (basic 2D-model)[5].

EM association
When considering SAR images, and not the RCS of a target, the spatial distribution of bright points seems more important than the very erratic level of individual points. Introducing dielectric properties and basic sigma0 curves seems enough to have first SAR image of an object. It is important to notice than the associated data that can be associated to different parts of the object by a 'group' (fig 1) offers the user the possibility to improve the model whenever he has more information on the material or gets images from SAR acquisitions.

The M3D model of radar contributors
MOCEM use a polygon intersection algorithm to get all visible parts of the scene that can be observed from the radar.
A recursive computation is done to seek illuminated facets that the radar can see after one, two or three reflections. Only 'near dihedral' or 'near trihedral' effects are considered. Double or triple reflections that are not coming form this topology are eliminated considering that there are not responding along all the SAR trajectory and may not be (well) focused.
A maximum equivalent effect is computed and will be post-processed to consider lobe effects. The maximum is equivalent of a plate seen from the radar. The RCS is $4.\pi.k.S^2/\lambda^2$ but S is limited according to resolution that define a distance cut and an azimuth cut. K is depending of dielectric properties (1 for steel). The polarimetric matrix considers the number of bounces and dielectric parameters. At this step a 3D EM model is available in memory and MOCEM can display it as a 'M3D' model. Depending of the effect the model produce facets (for specular facets), lines for dihedral and points for trihedral.

Slant image construction
Two operations are done to finalize the SAR image rendering:
- the M3D model (fig6) is projected in the azimuth-distance cell. Points are projected into a unique cell, while plates and dihedral lines are truncated with a density function considering the theoretical

SAR resolution (fig2). The lobe function depending on the contributor's (plate, dihedral …) is applied considering the SAR integration needed along the trajectory to get the required azimuth resolution.

- the diffuse effects are computed considering the surface and the aspect angle to get sigma0 for each part of visible surface in an azimuth-distance pixel cell. Full polar speckle is generated considering terms of correlation between channels. Computations are done using Σ matrix [7] to consider global polarimetric result inside the pixel containing several contributors. That is called diffuse rasterization operation in MOCEM.

At this step, a 'source image' is available with or without amplitude speckle on the HH reference channel for diffuse effects. Phase is distributed between channels according to coherence matrix. An S matrix is finally available for each pixel after a coherent sum taking into account a phase shift depending of the incidence angle and the relative position of contributors in the cell.

Image convolution for SAR rendering

Then, a basic SAR 2D-transfer function is applied to the source image. The function considers resolution, Neσ0 and tapering (to reduce side lobes), the basic SAR image quality parameters (fig3 &4). SAR raw data are not available in MOCEM but can be obtained using SIROS simulator.

Validation works

As MOCEM is basically based on Optical Geometry Method, it has same kind of limits. Considering the global RCS, results are very good in far field. For different kind of objects and targets, MOCEM images has been compared to ISAR and SAR measurements and RCS computations. It appears that MOCEM offers a good image, even if levels that widely depend on material parameters are locally a couple dB different.

2.3 MOCEM main features

MOCEM is efficient on many types of objects, including vehicles and ships. MOCEM is well suited to federate knowledge on a target in an Electromagnetic and Geometric Model, and then to generate unknown views of that object. Main features are :

- Specular effects and multiple bounces effects
- Diffuse scattering
- Dielectric and roughness properties
- Full polarimetric coherence
- Squint and several interferometry modes (V2)
- 2D radar transfer function
- 2D and 3D viewers

3 CONCLUSION

Use of MOCEM for studies

MOCEM covers many aspects of the SAR imagery (HR, squint, polarimetry, and interferometry). Considering that it is very difficult to develop SAR image analysis applications, MOCEM appears to be interesting to test algorithms and tune them, before use on actual data. As MOCEM is not a commercial software, its use is presently limited to collaborative works involving CELAR, labs and government affiliated agencies. In this context, please use form on web site at http://www.mocem.fr .

Use of MOCEM LT for didactical purposes

High Resolution SAR images appears difficult to understand. Variability of the image is also surprising to the operator. Because MOCEM is easy to use and fast for showing 3D results (fig. 5&6), it appears to be a good tool to prepare operators and students to work with SAR images or as a help in image interpretation.
A version called MOCEM LT is offered for learning or teaching purposes. Please see http://www.mocem.fr site to see how to get this dedicated software.

References

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[3] Ph Dreuillet and al. The ONERA RAMSES SAR: latest significant results and future developments, RADAR 2006 conference.

[4] F.T. Ulaby, Moore and Fung: 'Microwave remote sensing - Active and passive', Vol.2, Ed. Addison-Wesley Publishing Company, 1982

[5] C. Cochin, S. Buriau, J. Saillard, G. Delhommeau 'simulator of ocean scenes observed by polarimetric sar' - EUSAR 2000

[6] SARAPE - un outil de mesures radar du fouillis - AGARD 1996

[7] C. Cochin, J.C. Motet , E. Pottier: 'Operational polarimetric scene generator for a SAR radar simulator', Third International Workshop on Radar Polarimetry, Nantes

Illustrations

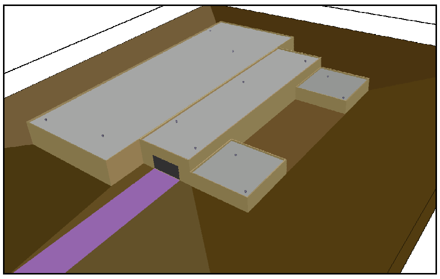
fig 1 (object view under MOCEM)

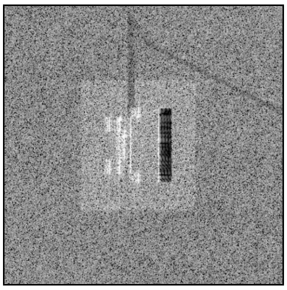
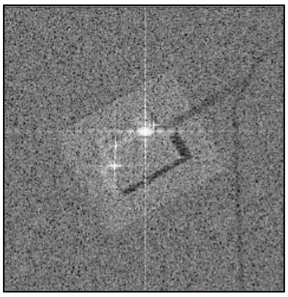
fig 3 (all effects, angle 1) fig 4 (all effects, angle 2)

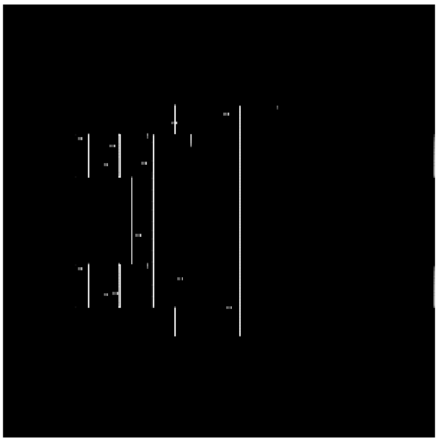
fig 2 (multiple effects occurring in source image)

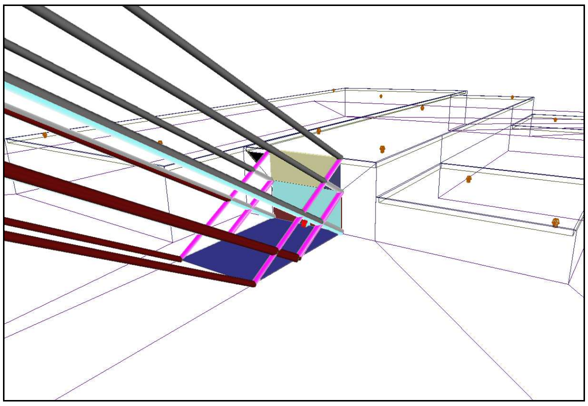
fig5 (dihedral effect associated to a selected pixel)

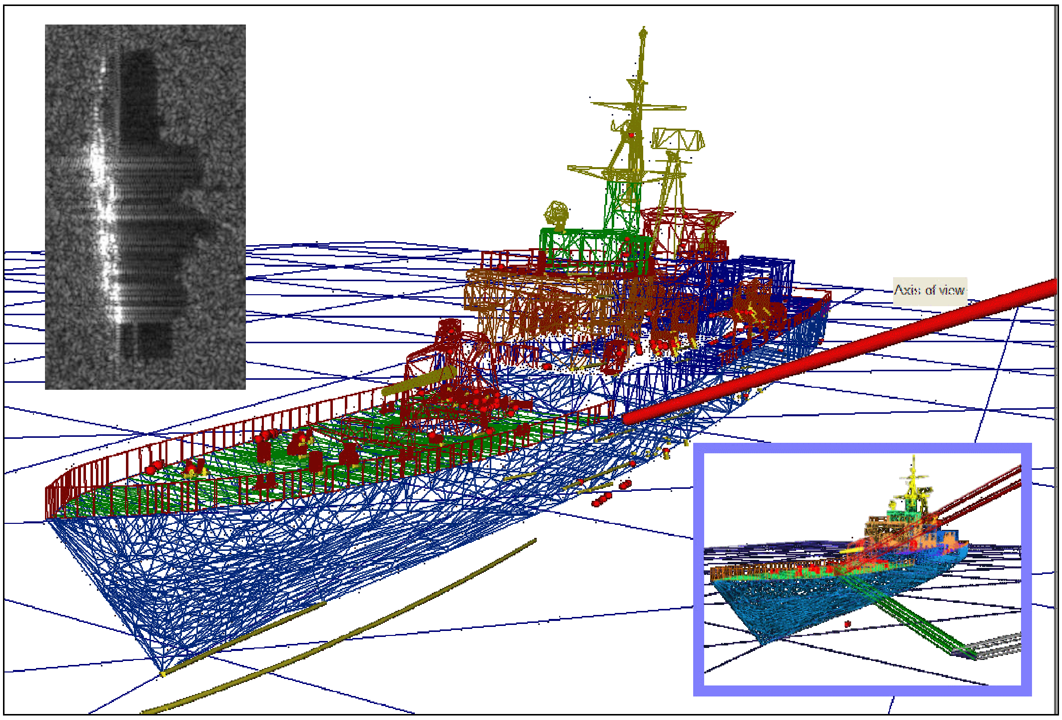

fig6 : the M3D model including dihedrons and trihedrons, represented with red spheres and orange cylinders (at their X,Y,Z azimuth-distance-interferometric radar equivalent position