SAR SUPERRESOLUTION CHANGE DETECTION FOR SECURITY APPLICATIONS

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ABSTRACT

During 2006 the ESA project “Products in Support of the Common Foreign Security Policy”, included into DUE Innovator ESA Programme, has allowed Indra Espacio to demonstrate and consolidate several radar products to be used for change detection applications. These new products (derived simultaneously from ERS and Envisat imagery) have been developed using superresolution techniques and their innovation is also consequence of its application for security operations. The radar products have been validated and evaluated by the European Union Satellite Centre (EUSC) which participates in the project as a highly committed and seasoned user. The project test scenarios were selected by EUSC. The sites are typical examples of their daily operations following the mandate from the European Council and the Common Foreign Security Policy (CFSP or PESC). The selected sites present cloud cover during several months in a year, making very difficult the monitoring of those zones using optical imagery. The production methods and validation procedures will be presented as well as the validation results obtained in some of those scenarios.

1. INTRODUCTION

One of the tasks carried out by European Union Satellite Centre (EUSC) is to monitor different areas of the world using the best methodology in each case. Nowadays, that methodology is based on high resolution optical imagery. And, basically, to monitor an area lay on detecting changes between optical images acquired in different dates. But some areas of the world remain unreachable to optical satellites due to the cloud cover. Here SAR satellites can play an important role, due to its all-weather and day night capabilities [1]. But, in practise, due to the present resolution of SAR sensors (about 8-20 m) –this is to change very soon with the advent of new systems like TerraSAR-X- and the inherent speckle noise of its images, radar imagery is not used for change detection.

The aim of this project is the demonstration of several products and services from SAR data to support the routine operations of the European Union Satellite Centre (EUSC), the final user. The background interest of EUSC is the monitoring of military harbors and associated infrastructure in accordance to Non Proliferation Treaties and the production of contingency aid planning. The project, which will be running till May 2007, has been useful to develop new SAR products and to prove that they can be used to detect changes in man-made features. As well as change detection vectors, other products have been completed during the project, indeed, three products plus one additional service were defined:

- SAR Superresolution Image: SSI
- Artificial Features Map: AFM
- Change Detection Map: CDM
- Continuous Change Detection Service: CCD

The proposed products and services had to meet some user requirements. Mainly, they had to be used to monitor the selected locations in winter or cloudy season (when high resolution satellites are useless) and to detect changes in man-made features (buildings, infrastructures, etc.) during that season. Thus, SAR products and optical images will be complementary to monitor a selected area during the whole year.

In order to demonstrate the capability of those products and services, two areas were requested by EUSC. They were named Northern and Southern scenarios. Northern scenario was set by four sites, named N1, N2, N3 and N4 and Southern scenario was set by two sites, named S1 and S2. Due to confidentiality restrictions from EUSC, the actual names of the places have been withheld. Winter or cloudy season is defined as the period from October to April for Northern scenario and from April to October for Southern scenario. In the following sections product generation and validation procedures will be explained for each scenario.

2. PRODUCT GENERATION

The obtaining of the radar products is a processing chain taking as initial data SLC images, a Digital Elevation Model (DEM) and precise orbit files. First step in the chain is the obtaining of the Superresolution SAR Images (SSI’s); then, the Artificial Feature Maps (AFM’s) are obtained digitizing the artificial areas in the SSI’s and, finally, the Change Detection Maps
(CDM’s) are calculated comparing the AFM’s from different dates (supervised method).

Also, this project has been used to implement unsupervised methods to detect changes in a series of SSI’s products. An automatic tool for change detection was developed during the project [2]. Both methods to detect changes, supervised and unsupervised, have been used together to identify changes in the images during winter or cloudy season and, thus, to obtain the best CDM product.

In both scenarios the products have been obtained using ascending and descending pass images. It has been proved that same features are seen in a different way from each pass, being necessary both of them to obtain a confidence final product.

Northern scenario products have been produced for two time spans: 2003-04 and 2005. Southern scenario products have been obtained for 2006.

2.1. SAR Superresolution Image (SSI)

The SAR Superresolution Image (SSI) has been defined for this project as an orthorectified temporally filtered image obtained from, nominally, 5 SLC SAR images using superresolution techniques. The SSI product can be produced simultaneously from ERS and Envisat data as far as they are obtained from the same track (and swath number 2 in the case of Envisat).

To help us in the obtaining of thematic products, three versions of SSI products have been produced:

- SSI: This is the standard SSI product and it is generated by time averaging several images from different dates (Fig. 1).

- SSI DEM compensated: This is the original SSI with the foreshortening and/or layover compensated from DEM (Fig. 2). In this way, the foreshortening and layover areas lose their brightness, helping us to detect more precisely the artificial areas.

- SSI DEM compensated + Point Target Enhancement (PTE SSI) (Fig. 3): To increase the visual dynamic range and help detect small targets, a RGB layer composition is developed by selecting different equalization values for each band instead of gray scale.

2.2. Artificial Feature Map (AFM)

The Artificial Features Map (AFM) is obtained by digitization of the artificial features present in SSI products. Photointerpretation guidelines were defined in the initial stage of the project in agreement with the user and they have been adapted to the special characteristics of each scenario. The final product is a vector layer with two classes: artificial and non-artificial fabric.

Due to the special conditions of the Southern scenario, where large urban areas are dominant, the AFM products in this scenario have been substituted for extracting different vector layers with valuable
information for EUSC staff. Thus, several features (coastline, inland water surfaces, roads, airports, harbours, bridges, non-bright areas) have been extracted from SSI’s in independent vector layers.

For all sites (in both scenarios) only one AFM has been generated in each season using both passes. In order to indicate the original pass of each polygon, a new field, “Pass”, was added to the AFM attributes table, marking A (ascending pass), D (descending pass) or B (both passes).

2.3. Change Detection Map (CDM) and Continuous Change Detection Service (CCDS)

The Change Detection Map (CDM) is defined as a vector layer where each polygon represents a change occurred between two SSI’s of different winters (yearly CDM).

In a particular case, when comparisons are made within the same winter, a new product/service is envisaged: the Continuous Change Detection Service (CCDS). This service is defined as a monthly CDM. As it was not possible to produce a vector layer every month (problems in the reception of the SAR images), the attribute table of the yearly CDM was modified in order to include two new fields: “Date”, to note the approximate date when the change occurred and “Observations”, to detail comments about the change.

For the Northern scenario, yearly CDM was produced from the traditional method (photointerpretation from images). Then, the Superresolution SAR change detector application, developed during the first stage of the project (see [2]) was used to determine the date of the change, as well as some characteristics in changes. Thus, the delivered CDM product was a combination of yearly and monthly CDM.

For the Southern scenario, changes were detected using the Superresolution SAR change detector application. Then, the changes were reproduced manually, in order to ascertain the date in which they occurred. Then a vector layer was produced with the changes and corresponding dates. Also, a field was created to incorporate the pass in which the change was detected. If new ones are found during visual inspection, they are incorporated to the vector layer.

As in the AFM case, CDM’s have been generated using both passes. Thus, for all sites (in both scenarios) only one CDM final product has been generated in each season.

3. VALIDATION PROCEDURES AND RESULTS

The validation procedures were defined in order to quantify the geometric and thematic accuracy of the products. Thus, it is guaranteed the adequacy of each delivered product to the user requirements.

There are three products to be validated: SSI, AFM and CDM (including the products obtained in CCD service) in each site. The validation of the products includes two different tests:

- Geometric validation, to ensure that the geometric quality of the product is correct, i.e., the performance of the orthorectification process. The geometric validation has been estimated over the SSI products. The other two products (AFM and CDM) were generated over the corresponding SSI’s, so they will have the same geometric accuracy.

- Thematic validation, to ensure that the classification is correct, i.e., the features extracted correspond to their legend. Thematic validation has been carried out for the AFM and CDM products.

The validation of the products generated in the project (with 20 m and 8 m of pixel spacing) has been carried out using orthorectified high resolution optical images (with a typical pixel spacing of 1 m) and internal reports provided by EUSC. Due to security constraints, validation tests were completed in EUSC facilities. Only S1 site was validated with EUSC personnel.

3.1. Geometric validation

For each site, two SSI’s were generated in each season: one of them using ascending pass images and another using descending ones. As thematic products are generated using both passes, it was necessary to guarantee that ascending and descending SSI’s presented the same orthorectification accuracy and that their geometry was compatible. Thus, a geometric validation was carried out for each ascending and descending pair.

Furthermore, a comparison of the SSI products against orthorectified optical data was completed. The procedure to perform both geometric validation tests was to find homologue points in the images (at least 9 points) and to calculate the RMS error. The identification of the same points in both types of images could be a problem due to different characteristics of optical and radar images. But in large city areas (as the Southern scenario case) it is possible to find an acceptable number of tie points where calculate the error. In this way a quantitative validation is possible. But for the Northern scenario another validation was completed. Results obtained in each scenario are presented in the following sections.

The Northern scenario data (optical and radar) were orthorectified using a SPOT DEM with a pixel spacing of 30 m. For the Southern scenario, optical and radar data have been orthorectified using the SRTM90 DEM.

3.1.1. Northern scenario

- Ascending/descending test: the geometric validation of the ascending/descending SSI products was more exhaustive in the Northern scenario. Main reason is that the area is very irregular (a lot of lakes, hills and cliffs), so a lot of foreshortening areas appear in it.
As it was impossible to find homologue points between both passes (due to scarce urban area is present in the images), correlations between images were carried out in order to find the offsets between them. Thus an error about 24 m was found in all of sites of the Northern scenario.

- Optical imagery test: the geometric validation using optical data was only qualitative due to it was not possible to find precise homologue points between radar and optical data. The validation was carried out using the vector layers produced over the SSI products (AFM and CDM products) and the vector layers produced over orthorectified optical images (by EUSC). Both vector layers were produced in an independent way in Indra and EUSC, respectively. During thematic validation, radar and optical vector layers were overlapped to optical and radar data, respectively, and any coarse displacements were found. On the contrary, a lot of piers and pontoons digitized in AFM and CDM matched very well in optical imagery. Some examples of the qualitative geometric validation are shown in Fig. 4 and Fig. 5.

![Figure 4. In red, polygons from AFM and CDM products overlapped to orthorectified optical images. Ships have been well delimited with the polygons.](image)

In Fig. 5 a SSI product from N1 ascendant dataset is shown; a green vector layer represents the coastline and in pink, several polygons show piers in one of the ports of the image. These vector layers were digitized from orthorectified optical data by EUSC. Similar results were obtained in the other sites.

3.1.2. Southern scenario

- Ascending/descending test: A comparison of ascending and descending SSI’s was carried out in order to find homologue points where calculate the coordinate differences. A set of 10 points was identified in S1 site, obtaining a RMSE of 30.95 m. For S2 site, a set of 7 points was identified (this site presented more difficulties to find tie points due to the urban area is constituted of informal houses, mainly, and there are not large urban features as large avenues, crossroads, etc), obtaining a RMSE of 24 m.

As the production of the thematic layers has been carried out using SSI’s products from both passes and any orthorectification difference has been found during its production, the RMSE obtained is a good value. The RMSE indicates a geometric accuracy in the orthorectified products of one pixel and a half, for S1 site, and of one pixel for S2 site. We remind that a 90m spacing DEM was used to generate the SAR products.

- Optical imagery test (only for S1 site): The quantitative result was completed from a comparison of Quickbird images with ascending and descending SSI’s. 12 homologue points where found in the 3 products and the coordinate differences were calculated, obtaining a RMSE of 40.72 m for ascending product and a RMSE of 46.4 m for descending one.

After production and validation, the RMSE found is not a bad value, because it has been possible to do the validation without any modification in the orthorectification of the radar products. Thus, a difference in the radar products of 2 pixels (40 m) regarding optical images is an acceptable value of geometric accuracy.

Fig. 6 shows an example of the validation results. Vector layers obtained from radar and optical data present a displacement of about 40 m with the respective images, according to quantitative geometric validation.

3.2. Thematic validation

Thematic validation was carried out for both AFM and CDM products. They were produced from SSI products, showing the artificial features and its changes in each season. The validation of these products was made verifying if the polygons were actually artificial man-made features. The validation method was the same for AFM and CDM products: comparison with high resolution optical images.

Ideally, every AFM product had to be validated using an optical image from the following summer season when available. And every yearly CDM product had to be
checked using an optical image from previous summer and another one from next summer. As we have obtained a combined CDM product (yearly and monthly), more optical data during the winter were necessary to check the changes found from SAR data.

For the Northern scenario, optical data used during validation tasks were enough, but there are not available high resolution optical images in 2006 for the Southern scenario. Thus, only AFM products were validated using 2004 optical images. Different methodology has been applied in each scenario due to AFM production was not identical, as it was stated in section 2.2.

### 3.2.1. Northern scenario

In order to validate every thematic product, detailed templates were designed, one for each product. In the template every polygon is described by its Identification (ID), the UTM coordinates, its Area and the corresponding Pass where it was detected (A=ascending, D=descending and B=both passes). Furthermore, in CDM product template, the Date of the change and its Probability is shown too. During validation, every thematic product was overlapped to the available orthorectified optical images. An EUSC image analyst checked every polygon of the vector layer using the optical imagery and their comments were added in the corresponding field (Optical images). These comments were transformed in OK (correct) or FA (False Alarm) in the “Val” field to complete the final statistics. For CDM products, comments with the estimated date of the change were added. During validation process, a vector layer with the Not Detected (ND) artificial features was obtained from orthorectified optical imagery. The OK, FA and ND polygons are used to calculate the Probability of Detection (PD) and Probability of False Alarm (PFA) for each product. When the validation was carried out in EUSC facilities, available optical data were enough to determine the OK, FA and ND polygons in AFM products. For CDM products it was more difficult to obtain an accurate validation, because no optical data exist along the whole studied winters, which is also the main reason to develop this project.

#### 3.2.1.1. Results

Using the figures for OK, FA and ND polygons obtained after validation procedure, the validation statistics (PD and PFA) for AFM and CDM in each site of the Northern scenario were calculated. In the following section the thematic validation results obtained for N1 site are presented.

#### 3.2.1.2. N1 thematic validation results

**AFM product**

<table>
<thead>
<tr>
<th>Area&lt;0,5 ha</th>
<th>OK</th>
<th>FA</th>
<th>ND</th>
<th>TOTAL</th>
<th>PD</th>
<th>PFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area&gt;0,5 ha</td>
<td>33</td>
<td>3</td>
<td>12</td>
<td>48</td>
<td>73%</td>
<td>8%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>63</td>
<td>7</td>
<td>14</td>
<td>84</td>
<td>82%</td>
<td>10%</td>
</tr>
</tbody>
</table>

*Table 1. Validation statistics for AFM in N1*  

**CDM product**

<table>
<thead>
<tr>
<th>Area&lt;0,2 ha</th>
<th>OK</th>
<th>FA</th>
<th>ND</th>
<th>TOTAL</th>
<th>PD</th>
<th>PFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area&gt;0,2 ha</td>
<td>5</td>
<td>9</td>
<td>0</td>
<td>14</td>
<td>100%</td>
<td>64%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10</td>
<td>14</td>
<td>3</td>
<td>27</td>
<td>77%</td>
<td>58%</td>
</tr>
</tbody>
</table>

*Table 2. Validation statistics for AFM in N2*

### 3.3. Summary of thematic validation results

As a summary of the figures obtained in each site, Fig. 7 shows the PD and PFA for the thematic products obtained from N1, N2, N3 and N4. In sight of these results, in all of sites of the Northern scenario a mean Probability of Detection of 80% has been obtained. This is an excellent result taking into account the difficulties found in these scenarios: scarce urban areas and man-made features, a lot of geographical features (hills, cliffs, etc.). A high PD was...
one of the strongest requirements from the user, whereas the low PFA is not a critical issue.

<table>
<thead>
<tr>
<th></th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
<th>N4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD</td>
<td>82%</td>
<td>77%</td>
<td>62%</td>
<td>70%</td>
</tr>
<tr>
<td>PFA</td>
<td>10%</td>
<td>56%</td>
<td>17%</td>
<td>48%</td>
</tr>
</tbody>
</table>

Figure 7. Summary of the validation results.

3.3.1. Southern scenario
Every vector layer produced in each site of the Southern scenario was compared with the available optical data from EUSC and the vector layers generated from them. AFM validation has been carried out by comparison of the vector layers for each artificial feature (coastline, roads, harbour, non-bright areas, and airport) with the same vector layers obtained by EUSC staff from optical images. It was a qualitative validation and the objective was to determine if the features extracted in each vector layer corresponds with its interpretation.

It is important to keep in mind that the AFM products have been produced using images from 2006, whereas EUSC vector layers have been produced using 2004 images. Thus, differences found in both vector layers could be due to changes in the images and not to a bad interpretation of the features from radar products.

The thematic validation of the CDM product has not been carried out due to there are not available 2006 optical images. The changes detected from radar products have been overlapped to optical images in order to determine if the changes are possible or not, following EUSC staff indications.

3.3.1.1. Results in S1 site
AFM products
After comparison of vector layers with optical ones, it was shown that most of the radar vector layers identify artificial features. Some errors have been found in harbour and airport vector layer because it was not possible to extract the facilities areas (they are confused to urban area). In the case of harbour vector layer, some polygons correspond to natural features instead of artificial.

CDM product
47 changes were found and only 17 can be revised by EUSC personnel. The rest of the changes were located out of the optical imagery are. Only one of the verified changes was rejected because it was located in an area of water.

4. EVALUATION BY EUSC
EUSC is very satisfied with the results obtained in the project. They have evaluated the superresolution products with a high value, due to they provide a higher resolution than standard radar images during winter when it is not possible to get optical imagery. Nevertheless, EUSC would like to have higher spatial resolution products that could be possible to be available with new forthcoming commercial sensors. It has to be improved the delivery time of products in order to integrate these new radar products in their working practices.

5. CONCLUSIONS
In summary, this work has shown the usefulness of SAR superresolution images for change detection monitoring of artificial surfaces. Indeed, in the frame of this ESA project, SAR products generated from Envisat and ERS images have been used for security applications, according to EUSC requirements.

1-2 pixels of geometric accuracy have been obtained in both scenarios, allowing an excellent production of the thematic products without usage of ground control points.

The thematic validation in the Northern scenario was more exhaustive, since a larger number of images (radar and optical) was used. An 80% of PD and a 20% of PFA was achieved in all of sites.

The thematic validation results in the Southern scenario are only qualitative. But they have been proved (as the Northern scenario images) the excellent properties of the superresolution products to extract artificial features. The advantages of this technique and new radar products obtained with the present SAR satellites expect to be translated to the new forthcoming commercial sensors (TerraSARX, Radarsat2, Cosmo-Skymed, etc).

6. ACKNOWLEDGEMENTS
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7. REFERENCES