High location accuracy allows Reference3D supporting versatile and innovative services

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ABSTRACT

Spot Image and French National Geographic Institute (IGN) are currently populating a worldwide accurate database named Reference3D™. This database consists in three information layers : Digital Elevation Model at 1 arc-second resolution, High Resolution Orthoimage (1/6 of arc-second) and Quality Masks. Wide coverage (Dec. 05 : 11 millions km² ; annual raise of 7 M km²) and tough requirements (circular horizontal accuracy better than 16 m for 90 % of the points and vertical accuracy better than 10 m for 90% of the points) are Reference3D key advantages.

An innovative tool was designed and implemented to produce orthorectified images thanks to Reference3D data. Known as ANDORRE, the system is able to automatically register and rectify any image from SPOT satellites within horizontal accuracy compatible with GPS. The paper opens with a brief technical presentation of the automatic ortho-rectification process :

- simulation of a reference image in focal plane geometry using Reference3D™ Orthoimage ;
- modeling of the mis-registration between the reference image and the SPOT image to be processed ;
- resampling of the incoming image using Reference3D™ DEM and the improved location model.

The geometric performance assessments achieved on operational cases (different landscapes, DEM and image resolution) are also presented .
In the last part, we would elaborate around potential services (currently under decision) based upon Reference3D such as :

- a pay-per-use service allowing the full availability of a world-wide class coverage, high accuracy, database able to register any kind of satellite imagery ;
- an image download service for mobile phones, coupled with GPS / Galileo and navigation databases;
- Web-based applications ;
- …

Finally, the conclusion will try to list the technical, economic, legal, sine-qua-non conditions for the sustainability of these services.

1. OVERVIEW

Ortho-rectification of remote sensing images is an important issue for various applications. Indeed, the image ortho-rectification process combines relief effects corrections and geo-referencing with high location accuracy. Usually this process is supervised by an operator with a manual selection of ground control points (using maps or reference images) which is fastidious and may lead to variable qualities of ortho-rectification.

Reference3D™ is a three dimensional database which has been designed to take advantage of SPOT5 stereoscopic images high accuracy. This 1°x1° tiles world wide database consists in three layers : a Digital Terrain Model (1 arc.second resolution, DTED level 2 standard), an Orthoimage [1] (1/6th arc.second resolution) and Quality Masks ; with a specification of circular horizontal accuracy better than 16 m for 90 % of the points and elevation accuracy better than 10 m for 90% of the points [1].

The ANDORRE system is an operational system that leverages this database to automatically ortho-rectify SPOT images (Figure 1). The algorithmic core of ANDORRE is called TARIFA (French acronym for Automatic Image Rectification and Fusion Processing). This paper presents the concepts and the results of the operational version of TARIFA.
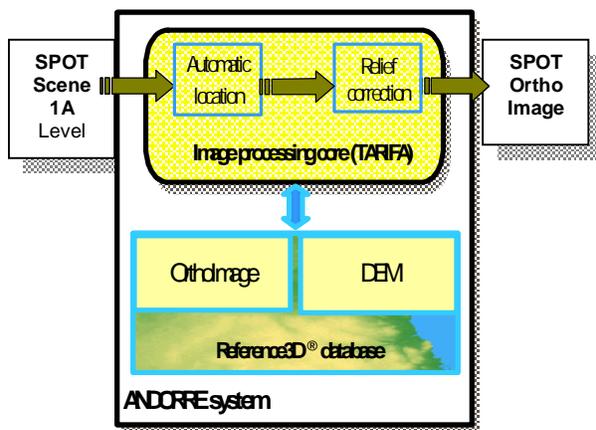

Figure 1 : Reference3D™ Database and ANDORRE

2. DESCRIPTION OF THE PROCESSING METHOD

Since the beginning of the definition of Reference3D™ database concept, the idea to take advantage of it in order to automatically rectify SPOT images has been developed.

A preliminary study was early held at French National Geographic Institute Space Department. The output of this study was a definition of an automatic orthorectification process and a prototype. This prototype had been tested against 50 different SPOT Images (from SPOT1 to SPOT4) and some simulated Reference3D™ tiles [2].

After SPOT5 launch, and first Reference3D™ tiles available, validation of the processing using SPOT5 images and real Reference3D™ data was necessary. The algorithm parameters had also to be tuned. Thus, a new version of the prototype was developed and tested by CNES.

Finally, the operational version of the algorithm was developed with CNES as prime contractor to be in integrated by Spot Image in its ground segment (ANDORRE[2]).

The automatic rectification process is mainly based on the improvement of the geometric model using image matching measures between Reference3D™ data and SPOT images. The algorithm is divided in four stages:

2.1 Resampling of Reference3D™ into SPOT geometry

This first stage consists in simulating an image from Reference3D™ database of the landscape seen by the satellite during the acquisition of the SPOT scene.

Thus, Reference3D™ tiles covering the SPOT scene area are first assembled in order to obtain a single orthoimage and DTM corresponding to the SPOT scene.

The rigorous sensor model of the SPOT scene is then used with Reference3D™ DTM layer to compute a resampling model from ground to raw scene geometry (using a ray tracing method which takes into account the DTM variations).

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[1] These images are orthorectified from the D.T.M. and have a high location accuracy
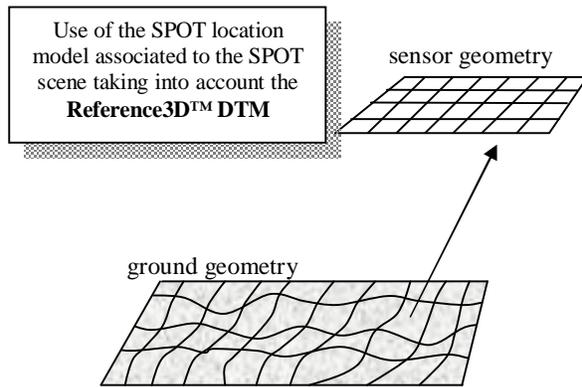
[2] http://www.spotimage.fr/andorre.html

Figure 2 : Computing simulated image resampling grid

The orthoimage layer extracted from Reference3D™ is resampled to obtain an image as seen by the satellite called the simulated image (see
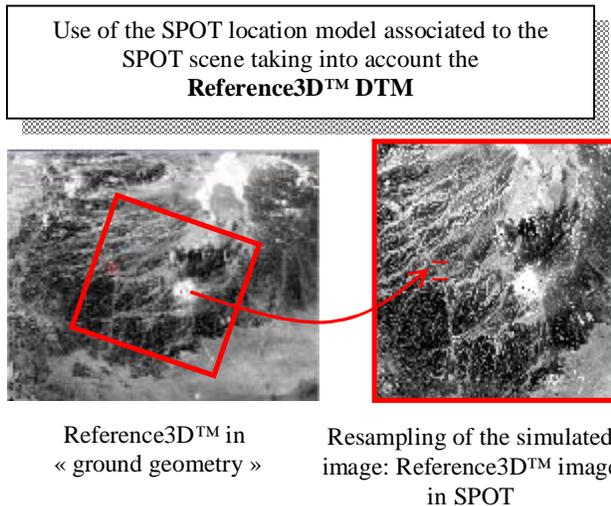
Figure 3).

Reference3D™ in « ground geometry »

Resampling of the simulated image: Reference3D™ image in SPOT

Figure 3 : Resampling of Reference3D™ tiles into "raw sensor geometry"

Thus, the remaining misregistration between simulated image and Spot scene is only due to imprecision of the SPOT location model [3].

2.2 Determination of the correction model by multi-resolution image matching

In this stage, image matching measures are computed between the SPOT scene and the simulated image in order to obtain a correction model which will allow to match the SPOT scene with the simulated image (see Figure 4).
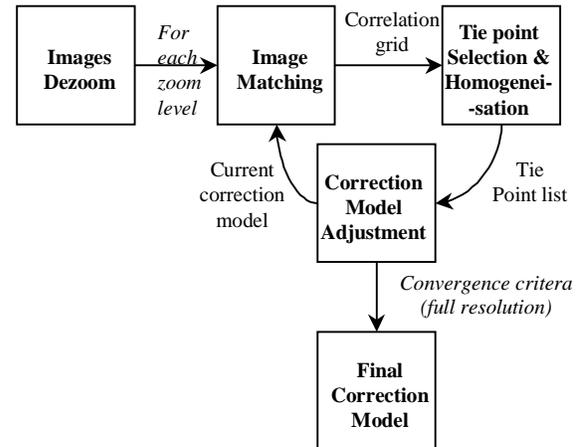

Figure 4 : Correction model estimation by multiresolution image matching

First, different zoom levels, with a ratio of 2 between different levels, are created for the two images according to the expected location accuracy. The initial zoom level is computed in accordance with (1). The goal is to keep a searching window for the image matching process of 5 pixel size.

$$MinZoomInit = \frac{LocAccuracy}{SceneResolution \times WinSearchSize} \quad (1)$$

For example, for SPOT4 10 m mode, an initial zoom level of 64 is needed.

For each zoom level, an automatic image matching is performed. The matching is based on correlation coefficient computation and its main parameters are the correlation window size and the correlation validity threshold.

The result of the automatic matching is a grid of measured differences between the two images. This grid is filtered in order to select tie points.

Finally, the collected tie points are used to calibrate a correction model of the SPOT scene. The adjustment process includes a statistical filtering of bad points (K standard deviation filter).

The model estimation depends on the zoom level. We have defined 3 phases: a bias is estimated only for first zoom levels (phase 1), then a polynomial model (degree 1 or 2) is estimated (phase 2), and at the full resolution, some

matching iterations are made in order to refine the correction model (phase 3 or refining phase).

At each zoom level, the model previously estimated is taken into account in the matching process to predict the differences between the two images and keep a 5 pixel searching window size. In full resolution (refining phase), the convergence criteria is the difference between current and previous model and is processed for a grid of control points chosen in the image. If the difference becomes lower than a convergence threshold (usually <50cm), the model estimation is finished.

2.3 Rectification grid processing

In this stage, the rectification grid for the SPOT scene is computed by combination of the correction model previously computed, a reverse location grid in the geographic reference system WGS84 obtained by the rigorous sensor model of the SPOT image, and a conversion grid from WGS84 reference system to the cartographic system required in output.

Here, the main point is to take advantage of the full resolution of Reference3D™ DTM to produce the reverse location grid with the best accuracy possible and a minimum computing time.

Several methods have been studied to process this grid and are detailed in [5]. The principle of the choosen method is to compute the physical reverse location model on two grids of constant altitude (H1 and H2) with a large step, fill those grids by spatial interpolation and obtain the final dense grid by altitude interpolation. For a point (X, Y, H) the image location is approximated by:

- bi-linear interpolation of (X, Y, H1) in the first grid,

- bi-linear interpolation of (X, Y, H2) in the second grid,

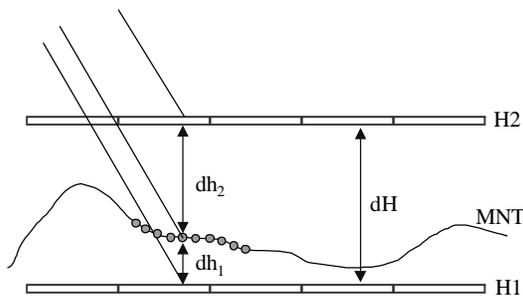- linear interpolation of (X, Y, H) between (X, Y, H1) and (X, Y, H2).

Figure 5 : Interpolated reverse model principle

This method is based on the hypothesis that the reverse location is linearly dependant on both altitude and planimetry. The determination of H1 and H2 is important to ensure this linearity. Taking the minimum and maximum altitude value on the concerned DTM is the optimal choice.

2.4 Resampling of the SPOT scene

This last stage consists in a resampling of the SPOT scene using the rectification grid processed at the previous stage.

In addition to the image rectification, all the tie points finally used to compute the correction model are converted into ground control points using Reference3D™ location. These points are kept for use in case of another processing of the same image or an image from the same datastrip.

3. OPERATIONAL VALIDATION OF THE PROCESSING

A first validation has been done step by step on the prototype version in order to tune and optimize the algorithm [5]. Then, an operational qualification of the system has been achieved on various cases. In this paragraph, we analyse some difficult cases and the robustness of the algorithm.

3.1 Tuning of the image matching algorithm and tie point filtering method

Different problems have been observed due to low resemblance between images. Figure 6 gives an example of seasonal variations over rice field landscapes in China.

In such cases, the image matching algorithm based on correlation coefficients computation doesn't find enough valid tie points between the two images. The correlation coefficients are smaller than in other cases and do not reach the validity threshold (80%).

Therefore in order to find enough tie points in all cases, a lower validity threshold must be selected (70% instead of 80% of resemblance).

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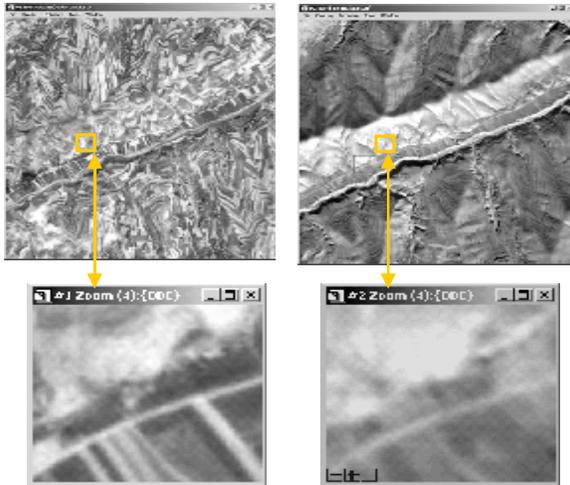
Figure 6: Image to process (summer) and Reference image (winter) and zooms on same areas

However, in some cases, this lower validity threshold may lead to 'false correlations' and bad tie points generation. We mainly observed this problem on images with low radiometric range. To avoid the risk that these bad tie points might decrease the accuracy of the correction model, they are filtered during the refining phase.

Indeed, during the refining phase, the searching window size of the image matching algorithm is reduced (from 5 to 3 pixels) taking into account the prediction model obtained in precedent phase. This eliminates aberrant points.

3.2 Modeling and Tie point selection strategy

In order to ensure a good quality model over the entire image a specific tie point selection strategy has been developed. The idea is to obtain an homogeneous distribution of tie points in the entire image. Therefore, the image is divided into several areas (usually 9) called subscenes. A given number of points is required for each subscene. If, after image matching and filtering, the resulting number of tie points is not sufficient, the image matching is performed on a higher density of points. This process is called "densification". If more valid tie points than required are found, a random selection is performed. The densification is an iterative operation which can be done several times on several subscenes.

Figure 7 represents the 9 subscenes on a SPOT5 image and the resulting tie point distribution.
The subscenes with low texture have been densified (especially subscene 3, 8 and 9).
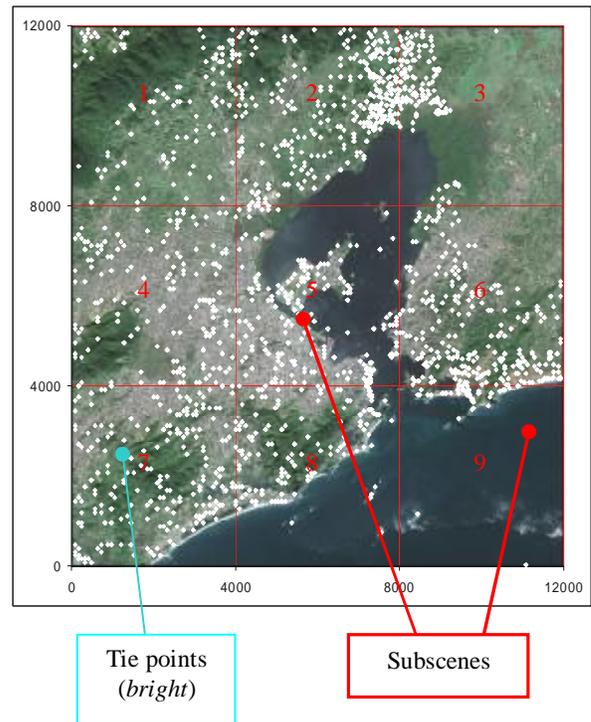The densification process has found between 150 and 250 tie points by subscenes.

Figure 7 : Homogeneous tie point distribution by subscenes SPOT5 2.5m image pseudo natural colors

However the densification of a subscene can fail if the number of tie points remains insufficient after some iterations (usually 10). The subscene is then eliminated from the tie point selection algorithm. If too many subscenes are eliminated, the overall process fails.

Moreover, the Reference3D™ database contains water and coast-line mask information that are used to guide the densification process. Thus, this strategy coupled with Reference3D™ masks allows to process images with island and sea landscapes. The subscenes totally located in water area are directly eliminated by the first tie point selection step (in
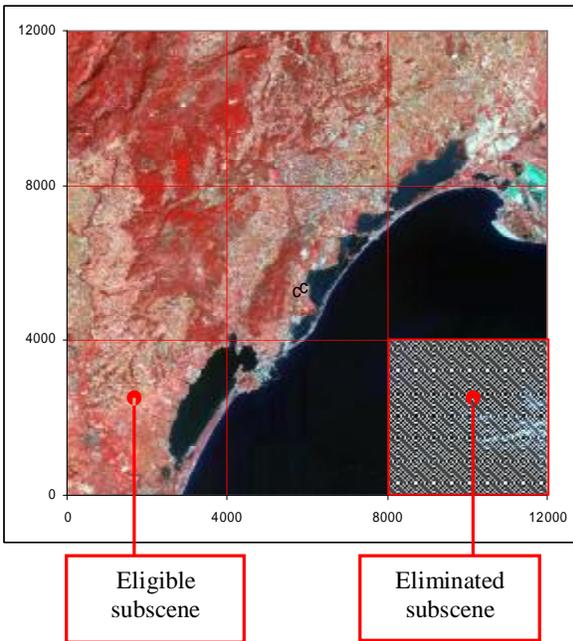Figure 8, subscene 9 is eliminated).

Figure 8 : Eligible and eliminated subscenes on a coast landscape SPOT5 HX image

3.3 Measuring rectification accuracy

A final estimation of the ortho-rectified product accuracy is done by measuring the misregistration beetwen the SPOT rectified image and Reference3D™ ortho-image on a random set of 1000control points (that have not been used in the computation of the model). The process has been tested over various landscape types (desert, forest, sea coasts, urban areas, etc …), various DTM types and various SPOT images (from SPOT2 20m to SPOT5 2.5m resolution). For each processed images (about 100 different images), the residual circular error measured in meters for 80% of the control points is lower than 2 meters.
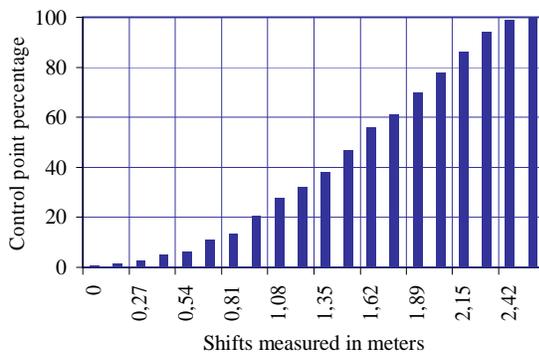

Figure 9 : Rectification accuracy

Moreover, the computing time performances meet the requirements to ensure an intensive use.

4. POTENTIAL SERVICES BASED ON REFERENCE3D

Since the launch of SPOT 5, more than 108 Millions km² of HRS stereo-pairs have been qualified to fit with Reference3D specifications.

The high location accuracy of this worldwide database allows supporting versatile and innovative services. After the success story of the ANDORRE system, Spot Image is willing to make this database available to a large range of customers wherever they live. They could be offered to fully access the Reference3D database through the 3D On-Site / On-Line services.

Depending on his needs, the user could choose either to host the database within his premises or to an on-line access to the database (located within Spot Image premises). The On-Site service will guarantee full confidentiality to the users regarding the area. Thanks to this Internet-based service, customer would be also more aware about product availability.
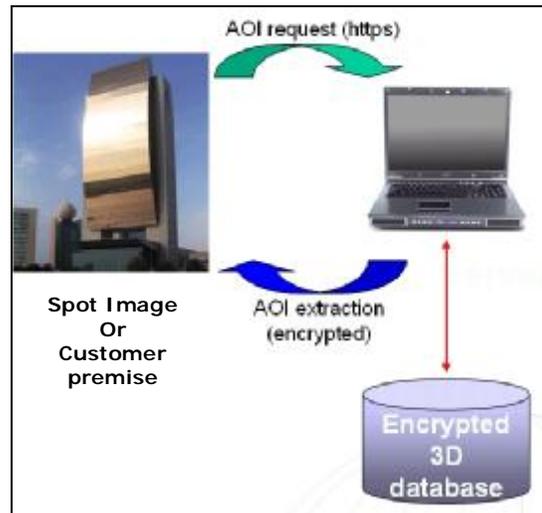

Figure 9: Principle of 3D on-Site / On-Line services

Furthermore, this 3D On-Line pay-per-use innovative service would allow any value-added company to set-up cost-effective satellite based services such as high accurate image ortho-rectification whatever the area requested by their customers.

Jointly with the forthcoming GPS/Galileo navigation system, 3D On-Line would be of great interest for mobile phone users' community.

Finally, thanks to its OGC standard conformity, 3D On-site/On-Line services will ease and contribute towards the emergence of new web-based applications of Earth Observation data.

5. CONCLUSION

The 3D On-site/On-Line services should ensure a wide use of Reference3D high quality geo-data that proved very useful for orthorectification of various. Some key conditions should however be met to allow their sustainable development :

Technical conditions are common place (wide band Internet at both ends, robust encryption …), as well as legal ones (licensing, dissemination only through allowed channels,…).

These services should necessarily rely upon a user - provider partnership agreement, both to warranty to the user that any of his AOI will be covered within a reasonable delay, and to sustain the long-haul production effort of a near-world-wide database. This is done through a yearly or multi-year purchase commitment from the user, thus making the economical model sustainable.

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