ADVANCED REMOTE SENSING TECHNIQUES FOR FORESTRY APPLICATIONS:
A CASE STUDY IN SARAWAK (MALAYSIA)

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3 SPOT IMAGE

ABSTRACT
This paper reports the operational implementation of new techniques for the exploitation of remote sensing data (SAR and optical) in the framework of forestry applications.
In particular, we present a new technique for standing timber volume estimation. This technique is based on remote sensing knowledge (SAR and optical synergy) and forestry knowledge (forest structure models), proved fairly accurate.
To illustrate the application of these techniques, an operational commercial case study regarding forest concessions in Sarawak is presented. Validation of this technique by comparison of the remote sensing results and the database of the customer has shown that this technique is fairly accurate.

I. INTRODUCTION
An important issue in today's operational remote sensing is to assess the potentialities of the joint use of multi-sensor satellite imagery to improve the discrimination between forest and non-forest, between forest types, between crops and clearcuts, and between crop types.
In addition, several complementary issues, relative to terrain topography or to the detection and monitoring of man-made infrastructures and natural structures must also be addressed.
For a complete and comprehensive exploitation of multi-sensor synergy and complementarity, new
III. PRE-PROCESSING OF THE REMOTE SENSING DATA

Pre-processing of the remote sensing images has been particularly stressed. Indeed, the quality of this pre-processing contributes substantially to the accuracy of the final thematic products.

a) Optical (SPOT-XS) images:

Atmospheric corrections are carried out using a statistic-empirical method based on both the results of a Tasseled Cap analysis, and an atmospheric model. The Tasseled Cap transformation belongs to the family of Principal Component Analysis (PCA) transformations. The difference to the usual PCA is that the principal axes are not obligatorily perpendicular.

In the course of this atmospheric correction procedure, haze detection is performed, and a haze image is produced in order to estimate the optical depth of atmospheric aerosols. This haze image, where atmospheric effects are enhanced could also be used for other applications.

b) SAR images (RADARSAT and ERS):

Complete radiometric calibration of the SAR images is carried out, according to the specifications of the various data providers.

Then speckle noise filtering is performed. To this end, Bayesian Maximum A Posteriori (MAP) single-channel and vector statistically adaptive speckle filters recently developed by PRIVATEERS N.V. are used.

Detectors based on the local spatial autocorrelation functions of both the speckle and the scene in SAR images are incorporated to these filters, to refine the evaluation of the non-stationary first order local statistics. This improves both restoration of the scene textural properties and the preservation of scene structural elements, to produce speckle filtered images without loss in spatial resolution [1]. Two filters have been developed, for single SAR images, or for multi-channel SAR images. It can be demonstrated that these new Bayesian speckle filters present the structure of control systems [2].

Thus, their application is regarded as the first processing step of application-oriented control systems designed to exploit the synergy of different SAR sensors, or of SAR and Optical sensors.

IV. TOPOGRAPHY

a) Generation of Digital Elevation Model:

First of all, a SAR stereogram is produced, using the two RADARSAT multi-incidence SAR images. From this stereogram, a Digital Elevation Model (DEM) is produced by radargrammetry.

In the study shown, the horizontal DEM accuracy is better than 15 meters; the vertical DEM accuracy is better than 20 meters.

b) Ortho-rectification:

In remote sensing images acquired by side-looking sensors, relief is systematically displaced with regard to its true geographical location, due to the viewing geometry. This effect is particularly important in SAR images. It also affects Optical images acquired in off-nadir looking direction.

For both the optical and the SAR images, the corresponding local geometrical corrections...
(geocoding, or in other words ortho-rectification) are performed, using the DEM.

c) Correction of terrain induced effects:

For both the optical and the SAR images, the radiometric corrections for slope angle and aspect angle effects are carried out, using the DEM. These corrections account for the variation of effective scattering area with local slope and orientation, as well as for the variations in illumination conditions. Effects of the variations in illumination conditions on the image radiometry are evaluated using a physical backscattering model (SAR images), or a semi-empirical radiance model (Optical images).

![Figure 2: Terrain corrected (geocoded), and geo-referenced SAR images. Radarsat-S7 in red, Radarsat-S2 in green, ERS in blue.](image)

**V. DETECTION ISSUES**

Forest managers and timber industry often need accurate knowledge of the hydrological network (rivers and water bodies) and of the forest communication network (roads, and forest and/or logging tracks). Often, the hydrological network is considered as part of the communication network.

Automatic extraction of the hydrological and communication network is performed in the remote sensing images by pattern recognition techniques based on the analysis of local first order [3], and/or second order local image statistics [2].

Since, due to the geometrical viewing conditions, complete detection by using either Optical or SAR data alone is often impossible, detection is performed simultaneously in at least two remote sensing images.

Within cloud free areas of the SPOT image, detection is carried out using the SPOT and a RADARSAT image. This way, complementarity between Optical and SAR information enables to detect reciprocally missing features and to achieve complete detection.

Within the cloud-covered areas of the SPOT image, the linear network is extracted using the two RADARSAT images acquired at different incidence angles to detect reciprocally missing features and to achieve complete detection.

In a further step, the extracted network is automatically vectorized within the GIS. This vector layer can then be superimposed to any raster layer (DEM, timber volume map, classification, etc.) for a better synoptic understanding of areas of interest, or for further data analysis.

**VI. FOREST AND LAND-USE INVENTORY**

Previous remote sensing forestry studies in Indonesia had assessed the thematic complementarity between SPOT-XS and SAR data [4]. This complementarity is also exploited in the study shown.

Indeed, within the cloud-free part of the SPOT image, classification is performed on a dataset formed of mixed SPOT/RADARSAT derived indices. These indices, obtained through Tasseled Cap analysis and SPOT/RADARSAT data fusion are designed to select from the dataset the part of information content that is relevant to the current application [cf. 5].

ISODATA clustering is applied to these indices. The rationale of clustering algorithms is to identify natural groupings (clusters) in the selected feature space through an iterative statistical learning process.

Within the cloudy part of the SPOT scene, classification is performed using the two RADARSAT images acquired at different incidence angles, and the ERS image. The classification method used is the extension to the case of multi-
channel SAR images of the supervised classification method developed by PRIVATEERS N.V. in [6] for the case of mono-channel SAR images. This method, that uses both the radiometric and the textural properties of the thematic classes provides highly accurate results when the thematic classes are appropriately defined.

In a final step, these two partial classifications have simply been merged to produce the final classification. As shown, the merging border is almost invisible and both partial classifications fit satisfactorily to each other.

In this final forest pre-inventory, the following classes are identified: very high yield forest, high and medium yield cutover, low yield cutover and the secondary forest, clearcuts and very low yield areas, bare soils and agricultural surfaces, water bodies. Ground and GIS-based validation shown that results are fully satisfactory.

VII. ESTIMATION OF STANDING TIMBER VOLUME

Timber volume (or equivalently woody standing biomass) estimation is made, using a new method developed [cf. 7] and validated by PRIVATEERS N.V. and TREEMAIL. This method uses both Optical/SAR data fusion technique, and forest structure models [8]. Within the cloud-covered areas of the SPOT image, forest pre-inventory classification results and automatic training in the SAR images based on results obtained within the cloud free areas of the SPOT image compensate for the lack of Optical data.

VIII. VALIDATION OF STANDING TIMBER VOLUME ESTIMATION

Validation of the results has been carried out, by comparing these remote sensing estimations of the standing timber volume, with the database of the professional foresters of the customer (1287 plots of timber volume measurements within the study area),
an industrial timber concession established in Sarawak. Clearly, the two kinds of estimations had been obtained independently, and by totally different techniques. The resulting comparison is presented in the Figure 5 below.

Figure 5 shows that the objectives fixed by the customer in terms of estimation accuracy (less than 15% error) are achieved in 87% of the cases. In an additional 6.4% of the cases, the mismatch between ground and remote sensing estimations remains inferior to 30%, which is still better than what is achieved by concurrent techniques presented in the literature in the case of dense tropical forests.

Figure 5 enables to evaluate the domain of validity of the present technique:
- From 0 m³/ha to 200 m³/ha, this technique gives very satisfactory results. No other technique provides such accuracy in this range of timber volume.
- From 200 m³/ha to 260 m³/ha, this technique still provides useful results (error of the order of 15%).
- Above 260 m³/ha, estimations become erratic and are systematically under-estimated. Therefore, further improvements (forest model, use of different frequencies or remote sensing data) are needed to extend the validity domain of this technique, for standing timber volume over 260 m³/ha.

XI. CONCLUSION AND PERSPECTIVES FOR THE PREVENTION OF FOREST FIRES

The techniques presented above result from PRIVATEERS/TREEMAIL research and development investment initiative. They have already been successfully validated, first within scientific pilot projects granted by the major Space Agencies, then in the framework of commercial application projects. It is noticeable that these techniques often outperform dramatically previous techniques. They open new perspectives for a wide range of forestry applications:

With regard to forest fires in El Niño climatic conditions, these (and any other) remote sensing techniques are useless if applied too late, when giant wild fires already rage. However, among the techniques and applications shown, several are of particular relevance, and can
represent a major asset in the framework of a forest fire prevention project:

- Estimation of forest biomass is important to assess the amount of potential vegetal fuel and evaluate fire risks.
- Identification and monitoring of (regrowing) clearcuts and agriculture areas are an important issue in the assessment of fire risks linked:
  - to the change in drainage conditions and patterns, and the formation of both peat soils (e.g. by drying out peat swamps for agriculture),
  - to the formation of dense but dryer vegetation cover (clearcut, regrowth).
- Knowledge of terrain topography is mandatory to assess the difficulties of access to potentially threatened areas.
- Up to date identification and mapping of the ground communication network (roads and forest tracks) as vector GIS layers ontop of the topographical maps is needed, in order to enable rapid intervention of fire fighters brigades wherever a wild fire breaks out.
- Georeferencing and geocoding of these cartographic products, integrated in a GIS, is mandatory to:
  - locate accurately and without any ambiguities the potentially threats in the prevention phase,
  - assess the difficulties of intervention to burning areas and to manage efficiently the use of fire fighters in critical situations, when a wild fire breaks out.

X. REFERENCES