An Automatic Method for Vine Detection in Airborne Imagery Using Wavelet Transform and Multiresolution Analysis

Thierry Ranchin, Bernard Naert, Michel Albuisson, Gilbert Boyer, and Pär Åstrand

Abstract

The problem of automatic vine detection from airborne Infrared Color (IRC) imagery is addressed. An automatic method was designed, based on a separate modeling of the textural and spectral information extracted from the data. A multiresolution analysis associated with a wavelet transform allows the separation of spectral and spatial information. After a description of the vine detection problem, the automatic method is described. An example application is proposed and a quantitative evaluation of the results achieved is presented. The analysis of the results demonstrates the efficiency of the method. The square system of planting is the main source of errors. But this growing technique is now nearly abandoned in France due to mechanization. Thus, this method may help photointerpreters in the updating or definition of agricultural registers of vineyards as defined by the European Commission.

Background

The automatic characterization of heterogeneous environments with regular structures are of interest for cultures such as orchards, vineyards, and market gardens, and is of tremendous importance for the establishment and the survey of national or European registers. The diversity of objects that compose these environments (plants, soil, shadow, grass, stones, and organic residues) makes it a very complex process. This paper focuses on automatic vine detection. This problem is representative, at an easily accessible scale in the field, of the complexity of these environments. Only a few studies have been conducted in the field of remote sensing for vine detection (Riom, 1992).

Boissard (1972; 1973) has shown that the textural and structural elements in a vine parcel can be accessed by the Fourier transformation of airborne photographs. These elements lead to the characterization of the stocks of vine and of their structure (orientation of the rows, distance between the stocks, dimension of the stocks, and leaves). Using spectral and temporal parameters with a very high spatial resolution, Debushe (1975), Josa (1978), Sentex (1984), and Naert (1985) performed comprehensive analyses of some elements of the vine states: physiological states, growing methods, and type of vine. These studies show that the automatic recognition of these parameters can only be achieved when the detection of vine parcels is effective. When spectral information alone is considered, the observed parcels can be confused with non-cultivated soils or fallow soils. Depending on the cultivation technique of the vineyard, confusion is possible with orchards or plantings of asparagus, when only textural information is considered. Hence, effective detection can only be achieved by approaches using jointly texture or structure and spectral information. If temporal information is available, detection will be better. A vineyard is a patchwork of objects whose signatures change with the sun position, the season, the orientation of the rows of vines, the type of vine, and the growing method. For a spectral and temporal study and for characterization of the vines, the detection of vines is essential.

As proposed by Boissard (1972; 1973), the use of the Fourier transform was tested by the present authors. But, even if fast algorithms exist, the use of directional filtering for detection of rows of vines in the Fourier domain of images is very demanding in computational resources. The Fourier transform makes some strong assumptions regarding the original image. The image needs to be periodic, to represent stationary phenomena, and, for computational reasons, to be preferably a power of 2 in size. But an image is neither periodic nor stationary, and the power of 2 in size limits the application of the Fourier transform. Nevertheless, the Fourier transform was successfully applied to images. The following procedure was applied to perform a directional filtering of the image for line detection:

- a Fourier transform is applied to the original image (Figure 1);
- the filter is designed manually (Figure 2) on the amplitude spectrum, by selecting the frequencies to preserve (Figure 3);
- this first filter is converted into an optimal filter which is applied to the amplitude spectrum of the image; and
- the inverse Fourier transform is applied to the filtered spectrum and the filtered image is reconstructed (Figure 4).

This method is efficient but, in addition to the previous restrictions, it should be stressed that the design of the filter is done by the user, which strongly influences the results. This point prevents the automation of the method. Due to these different remarks, this method was not further employed and an alternative one was designed.

More flexible mathematical tools were chosen: the wavelet transform (WT) and multiresolution analysis (MRA). These

T. Ranchin and M. Albuisson are with the Groupe Télédétection & Modélisation, Centre d’Énergétique, Ecole des Mines de Paris, BP207, 06904 Sophia Antipolis cedex, France (thierry.ranchin@cenerg.cma.fr).

B. Naert and G. Boyer are with the Laboratoire INRA, Maison de la Télédétection, 500 rue Jean-François Breton, 34903 Montpellier cedex 5, France.

Pär Åstrand is with the Space Applications Institute, MARS sector, Joint Research Center, 21020 Ispra, Italy.

Photogrammetric Engineering & Remote Sensing
0099-1112/01/6701-91S3.00/0
© 2001 American Society for Photogrammetry and Remote Sensing
tools allow a hierarchical description of the information. The textural information is accessed through the use of the WT and MRA, and the spectral information is accessed through a classification scheme.

In the field of the analysis and processing of remotely sensed images, a few works were done using these tools and concerning the analysis of the characteristic scales in geology (Besnus et al., 1993), in the urban domain (Ranchin and Wald, 1993a), or in oceanography (Ranchin and Wald, 1993b). The reduction of speckle in Synthetic Aperture Radar (SAR) imagery was proposed using degradation of the spatial resolution of the image (Proença et al., 1992), by selection and filtering of the most speckled scales (Ranchin, 1993; Ranchin and Cauneau, 1994), by application of the shrinkage method on the wavelet coefficient images (Eldridge and Lasserre, 1995; Horgan, 1998), or through the use of a recursive scheme (Dong et al., 1998).
The restoration of blurred images was studied in the case of airborne images (Bruneau et al., 1991). The benefits of using these tools for data compression were demonstrated from the point of view of performance (Antonini et al., 1992; Singh, 1999) and the European Space Agency has proposed the distribution of a CD-ROM of Meteosat images using such a kind of compression. SAR data compression was also explored with significant good results (Moureux et al. 1995; Parkes and Clifton, 1999). An automatic method for registration of images was proposed (Djoundji et al., 1996). The detection and selection of ground control points (GCP) is done using the WT and the computation of the transformation model is achieved through successive approximations in a coarse to fine approach. This method was deeply improved by Blanc and Wald (1998) by taking into account the local deformation of images.

These tools were used for the analysis of satellite-derived irradiance maps and for the characterization of the spatial and temporal structures in the irradiance fields (Beyer et al., 1995). A characterization of the local roughness of digital elevation models by a wavelet-based estimator (Dautu et al., 1996) and surface determination for digital terrain reconstruction and ortho image formation (Tsay, 1998) were improved by the use of the WT. The scale analysis of surface properties of sea ice (Lindsay et al., 1996) or of sea ice drift (Liu and Cavaliere, 1998) were also investigated. These tools were also applied to the fusion of images and raster-maps of different spatial resolutions by encrustation in the case of the construction of the European solar radiation atlas (Wald and Ranchin, 1995), to the merging of images for updating urban maps (Ranchin and Wald, 1996), and to the merging of SPOT and SAR images (Mangolini et al., 1993). They are the basis of the ARGIS method (from its French name “amélioration de la résolution spatiale par injection de structures”) which is the subject of a patent (Mangolini et al., 1992). This method allows the improvement of the spatial resolution of images up to the best available in a set of images with different spatial and spectral resolutions, and the preservation of the spectral content of original images. In the case of SPOT imagery, this method was shown to give the best available results in terms of preservation of the spectral content of original images (Wald et al. 1997). Thus, the synthesized images can be used for applications where high spatial and spectral resolutions are necessary. The complete description of the implementation for this case is provided in Ranchin and Wald (2000).

Couloigner and Ranchin (1999; 2000) demonstrate the benefits of these tools for the semi-automatic extraction of urban networks. Some potentialities of the WT and MRA were also proposed by Ranchin and Wald (1993a). Ranchin (1997; 1999) explored the benefits of wavelets for environmental modeling, MRA and the WT were also used for the detection of settlements in a water resources management context (Staudenrausch et al., 1999) and for the automatic interpretation of buildings from aerial images (Shao, 1993). Interesting studies on the multiscale properties of images (Hu et al., 1998) and on texture analysis and classification using wavelets (Zhu and Yang, 1998) were also achieved. This list is far from being exhaustive because the recent use of these tools in remote sensing and their potentials provide new applications every day.

An Automatic Method for Vine Detection

The Wavelet Transform and Multiresolution Analysis

The association of the WT and MRA leads to a powerful and comprehensive analysis and processing of remotely sensed images. The concept of MRA introduced by Mallat (1989) derives from the Laplacian pyramids (Burt and Adelson, 1983).

Figure 5 is a very convenient description of MRA and more generally of pyramidal algorithms.

The base of the pyramid is the original image. Each level of the pyramid is an approximation of the original image computed from the original one. When climbing the pyramid, the successive approximations have coarser and coarser spatial resolutions. The theoretical limit of an MRA is one pixel representing the mean of the original image. Due to some physical constraints, this limit is never reached. The base of the pyramid can also be considered as an approximation of the landscape measured by the sensor.

Associated with MRA, the WT allows the description of the differences existing between two successive approximations of the same image (i.e., of two successive levels of the pyramid, by its wavelet coefficients). If the process of MRA is inverted, the original image can be exactly reconstructed, from one approximation and from the different wavelet coefficients. These tools allow a hierarchical description and modeling of the information contained in the image. The present method uses the “atrous” algorithm (Dutilleux, 1967). For each iteration, one context image and one wavelet coefficient image are computed. They have the same number of pixels as the original one, and can be compared pixel by pixel to the original one. The wavelet coefficient image represents the characteristic scales of the original image with no privileged direction.

The Proposed Strategy

Figure 6 describes the strategy for the automatic detection of vines. The strategy is as follows:
The richness of the details of high spatial resolution imagery enables the detection of individual stocks but prevents the effective detection of the parcel of vines. On the one hand, the high spatial resolution imagery is necessary for accessing the texture of vine areas. On the other hand, such images are too blurred at zero and present high spatial resolution imagery is necessary for accessing the spectral signature of a vine parcel. The wavelet coefficients images have histograms that are centered on the district of Villeneuve les Maguelone (Hérault, France). It comprises the Viticultural Experiment Station of INRA, called "Domaine du Châpitre," surrounded by representative and exhaustive samples of the languedocian vineyard. In 1984, this station exhibited structures of plantations that are still (i.e., rows 2 m apart with a distance of 1.2 m between stocks, 2 m by 1.3 m, and 2.5 m by 1.2 m) in bush vines (goblet-pruned vines) or lateral cordon-constrained and trellised vines with numerous different varieties of vines. Around the experiment station, the parcels are not homogeneous. Many of them are planted in bush-vines with a square system of planting (1.5 m by 1.5 m or less); a path exists every three or four rows, for the treatment tractors. The image was acquired using an IRC (infrared color) emulsion, at a scale of 1:5000 on 16 October 1984 and is composed of urban area (more or less diffuse), vineyard (the "Domaine du Châpitre" represents 20 hectares of the vineyard), fallow land, asparagus, and orchards.

Plate 1 presents an example of application of the complete strategy. The inter-row distance of vines is between one and two meters. Then, the line detection algorithm has been applied to the wavelet coefficients image describing the information between one and two meters. The spatial resolution of the approximations (computed by application of MRA) used for the spectral description of the area is 8 meters in this case. The masking was applied to the results of the classification. The surfaces of the resulting parcels are then compared to the reference surfaces. If the individual difference for each parcel is lower than 25 percent in area, the parcel is classified as vine. If the difference is greater than 25 percent, the parcel is classified as non-vine. In the next section, the results for the whole image are summarized using error matrices and indexes.

**Results and Discussion**

The evaluation of the results was first achieved for each parcel. In order to obtain an indicator for the whole process, the approach proposed by Congalton (1991) was used. An error matrix was computed for the image. It contains two classes—

---

(1) The original infrared color (IRC) image is decomposed into conventional red, green, and blue layers. According to the usual processing of airborne photographs (Naert, 1977), the vegetation is mostly enhanced in the green layer which contains the infrared information (Bourreau and Naert, 1985). MRA using the WT is applied to this layer.

(2) Line detection is applied to the wavelet coefficients image representing the structures to be detected. The choice of this image depends on an *a priori* knowledge of the distances between the rows of vines, and can easily be tuned.

(3) A textural index is derived from the results of this line detection.

(4) Approximations of the original data computed through MRA and the textural index are used to derive a supervised classification of the whole image.

(5) Results of the classification are analyzed in a GIS environment in order to provide the results on a parcel basis. Then a combination of the parcel shapes and the results of the classification is performed. A threshold is applied to determine if the parcel is a vine parcel. All the parcels with a value in surface detected greater than 75 percent of the reference surface are considered as vine. This threshold was determined empirically from the individual parcel results.

The method of line detection is based on this interpretation of the histogram. Hence, a thresholding of the wavelet coefficients image of the relevant structures will enhance the well-marked structures and show the lines of vines. The threshold was determined empirically to be 0.7 or where er is the root mean square of the wavelet coefficients image between one and two meters of the image. This threshold depends on the application and on the size of the structures to be detected; it should be fitted according to the objectives.

The algorithm of line detection is item (2) of the strategy scheme (Figure 6) and may be described as follows:

- an MRA using the WT is applied to a single channel of the image (usually the channel best representing the vegetation),
- the root-mean-square \( \sigma \) is computed for the wavelet coefficients image comprised between one and two meters,
- all the wavelet coefficients with value lower than 0.7 \( \sigma \) are set to 0, and
- all the wavelet coefficients with value greater than 0.7 \( \sigma \) are set to 255.

A texture index is derived from the line detection image by computing the number of pixels with a value equal to 255 in a moving window of size 9 by 9. This index will be used as one input layer in the subsequent supervised classification.

**Example of Application**

The area of interest is situated on the district of Villeneuve les Maguelone (Hérault, France). It comprises the Viticultural Experiment Station of INRA, called "Domaine du Châpitre," surrounded by representative and exhaustive samples of the languedocian vineyard. In 1984, this station exhibited structures of plantations that are still (i.e., rows 2 m apart with a distance of 1.2 m between stocks, 2 m by 1.3 m, and 2.5 m by 1.2 m) in bush vines (goblet-pruned vines) or lateral cordon-constrained and trellised vines with numerous different varieties of vines. Around the experiment station, the parcels are not homogeneous. Many of them are planted in bush-vines with a square system of planting (1.5 m by 1.5 m or less); a path exists every three or four rows, for the treatment tractors. The image was acquired using an IRC (infrared color) emulsion, at a scale of 1:5000 on 16 October 1984 and is composed of urban area (more or less diffuse), vineyard (the "Domaine du Châpitre" represents 20 hectares of the vineyard), fallow land, asparagus, and orchards.

Plate 1 presents an example of application of the complete strategy. The inter-row distance of vines is between one and two meters. Then, the line detection algorithm has been applied to the wavelet coefficients image describing the information between one and two meters. The spatial resolution of the approximations (computed by application of MRA) used for the spectral description of the area is 8 meters in this case. The masking was applied to the results of the classification. The surfaces of the resulting parcels are then compared to the reference surfaces. If the individual difference for each parcel is lower than 25 percent in area, the parcel is classified as vine. If the difference is greater than 25 percent, the parcel is classified as non-vine. In the next section, the results for the whole image are summarized using error matrices and indexes.
Plate 1. Example of the strategy for automatic vine detection. The upper left corner is an extract of the reference image. The pixel size is 0.25 m and the image was acquired using an infrared color emulsion at the scale of 1:5000. The upper right corner is the result of the line detection algorithm using the wavelet transform. The lower left corner is the superimposition of the original image and the parcel information. The lower right corner is the combination of the results of the classification scheme and the parcels information.

Table 1 presents the error matrix computed for the whole image and Table 2 presents the calculated statistical indices.

The overall accuracy has to be considered with the "producer's accuracy" and the "user's accuracy." The overall accuracy for the whole image is close to 82 percent. It excludes the omission and commission errors. The producer's accuracy indicates that approximately 74 percent (26 percent omission of vine) of the vines are well-classified and that approximately 95 percent of the non-vines are well-classified. The user's accuracy indicates that approximately 96 percent (4 percent commission or mix-up of vine) of the vine parcels are actually vine and that approximately 68 percent of the non-vine parcels are actually non-vine parcels. The KAPPA parameter is a measure of how well the classification agrees with the reference data, and takes into account the omission and commission errors. This parameter is usually considered as the one reflecting the global quality of the classification. For this image, it reaches approximately 64 percent. This is a fairly good result compared to the usual results obtained by photointerpretation.

In order to analyze the contribution of the different growing methods, extended error matrices were computed and the producer's accuracy indexes derived first for different types of planting (Table 3) and vine-growing methods (Table 4 and 5). This area comprises two main types of planting existing in this area: the tying up types composed of stocks growing on wires, for which the leaves of the different stocks constitute a continuous line, and the bush or goblet pruning which corresponds to stocks planted individually without any physical link as wire in the tying up mode. Depending on their inter-rows distance, the leaves can give an impression of continuity in lines. There are two modes of planting for goblet pruning. Figure 8 displays the square system of planting and the usual goblet pruning. The differences are in the inter-line and inter-row distances.

Table 1: Error Matrix for the Image with a Pixel Size of 25 cm and Processed Using the Proposed Strategy

<table>
<thead>
<tr>
<th>Detected areas</th>
<th>Ground Truth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vine</td>
</tr>
<tr>
<td>Vine in square meters in number of parcels</td>
<td>320735</td>
</tr>
<tr>
<td></td>
<td>65</td>
</tr>
<tr>
<td>Non vine in square meters in numbers of parcels</td>
<td>112798</td>
</tr>
<tr>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Total in square meters in number of parcels</td>
<td>433533</td>
</tr>
<tr>
<td></td>
<td>98</td>
</tr>
</tbody>
</table>

Table 2: Accuracy Indices Derived from Table 1

<table>
<thead>
<tr>
<th></th>
<th>Vine</th>
<th>Non vine</th>
</tr>
</thead>
<tbody>
<tr>
<td>User's accuracy indexes</td>
<td>0.96</td>
<td>0.68</td>
</tr>
<tr>
<td>Producer's accuracy indexes</td>
<td>0.74</td>
<td>0.95</td>
</tr>
<tr>
<td>Overall accuracy index</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>KAPPA parameter</td>
<td>0.64</td>
<td></td>
</tr>
</tbody>
</table>

In January 2001
very close to a classical row system of planting. But the distance between two successive rows is 3 m. The algorithm was tuned to detect vines spaced of between one and two meters. Hence, the omission of more than 54 percent, is due to this tuning. One way of detecting this type of growing method parcels is to process the wavelet coefficients image representing the corresponding characteristic scales. The omission decreases from 54 percent to 49 percent when the number of missing rows decreases. With the different spacing due to missing rows, the algorithm is able to detect the rows, but the masking leads to a surface occupation inferior to 75 percent. The part of the parcels covered by vines is well detected but no connection is made between these sub-parcels. One way of resolving this problem can be an adaptation of the algorithm by the computation of another textural index focusing on the characteristic scales of this process.

Conclusions and Perspectives

In this paper, an automatic method to detect the vine/non-vine areas on aerial infrared photographs was described. The developed method allows detecting the vine areas in the test district with a Kappa coefficient of 0.64 in the case of a 1:5000-scale airborne IRC image. The pixel size of 50 cm seems to be a limit to properly detect the vines planted in squares. However, this technique of culture has been abandoned due to mechanization. The proposed method is able to detect the two or three rows of planted vines but has difficulty to link them through the grass lines.

Other tests have also been achieved with 1:20,000-scale images and a pixel size of 50 cm and over different vineyards in Spain (panchromatic 1:40,000-scale image, pixel size 50 cm), Italy (panchromatic 1:40,000-scale image, pixel size 1 m), and France in the area of Bordeaux (IRC 1:25,000-scale image, pixel size 60 cm). The results obtained, without any modification of the method, on these images show a lower accuracy. This emphasizes the need for an adaptation of the method to fit the imagery, the type of vine growing method, and the inter-row distance present in the area under study.

This method is fully automatic. Its applicability to the detection of vines parcels was demonstrated for a 1:5000-scale IRC image. The level of detection of the vine/non-vine parcels is fairly good (Kappa parameter equal to 64 percent). The choice of the wavelet coefficients image to process permits an easy adaptation of the method to the available image and to the characteristics of the vineyard.

The present results are less satisfactory than those usually obtained by photointerpretation. This method is a first step to

### Table 3. Extended Error Matrix and Producer's Accuracy Index Based upon the Type of Plantation Information for the Image Processed with the Proposed Strategy

<table>
<thead>
<tr>
<th>Rows</th>
<th>Young or badly maintained</th>
<th>No information</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine in m² in parcels</td>
<td>197131</td>
<td>79104</td>
<td>7134</td>
</tr>
<tr>
<td>Non vine in m² in parcels</td>
<td>7489</td>
<td>60714</td>
<td>44595</td>
</tr>
<tr>
<td>Total in m² in parcels</td>
<td>204620</td>
<td>139877</td>
<td>51729</td>
</tr>
<tr>
<td>Producer's accuracy index</td>
<td>0.96</td>
<td>0.57</td>
<td>0.14</td>
</tr>
</tbody>
</table>

### Table 4. Extended Error Matrix and Producer's Accuracy Index Based upon the Detailed Type of Vine-growing Method for the Plantation in Rows

<table>
<thead>
<tr>
<th>Tying up</th>
<th>Bush or goblet pruning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine in m² in parcels</td>
<td>157219</td>
</tr>
<tr>
<td>Non vine in m² in parcels</td>
<td>7489</td>
</tr>
<tr>
<td>Total in m² in parcels</td>
<td>164708</td>
</tr>
<tr>
<td>Producer's accuracy index</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Figure 8. (a) Usual bush or goblet pruning. (b) Square system of planting.

### Table 5. Extended Error Matrix and Producer's Accuracy Index Based upon the Detailed Type of Vine-growing Method for the Plantation in Squares

<table>
<thead>
<tr>
<th>Square, 1 row/2 missing</th>
<th>Square, 1 row/3 missing</th>
<th>Square, 1 row/4 missing</th>
<th>Square, 1 row/6 missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vine in m² in parcels</td>
<td>37093</td>
<td>12726</td>
<td>1513</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Non vine in m² in parcels</td>
<td>11112</td>
<td>15133</td>
<td>6758</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total in m² in parcels</td>
<td>48204</td>
<td>27899</td>
<td>8276</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Producer's accuracy index</td>
<td>0.77</td>
<td>0.46</td>
<td>0.18</td>
</tr>
</tbody>
</table>

96 January 2001

PHOTOGRAFMETRIC ENGINEERING & REMOTE SENSING
an efficient automatic method for vine detection. It constitutes a good framework and will be improved by further investigation of the different ways of representing the textural information of vines.

This method can presently be used as a support for photo-interpretation, allowing a first step in the processing of vine detection. The photo-interpreters can then focus on the parcels that are not detected as vines. The detection of changes in the use of parcels through time can also be conducted through comparison of results computed on different dates.

Acknowledgments
This study was partly supported by the Joint Research Center of Ispra, through the VINIDENT project. The authors thank ONVIN and the Regional Statistics Department of the Languedoc-Rousillon (S.R.S.E.A.) for the statistical description of the France vineyards, the INRA team of the “domaine du Châpitre” for the description of the growing techniques, and the GUTLAR for furnishing the airborne photographs. The authors want to thank the anonymous reviewers for their fruitful comments.

References


---

CALL FOR PAPERS
PE&RS Special Issue on Geospatial Information Technology in KOREA

In December 2001, the American Society for Photogrammetry and Remote Sensing will devote its issue of Photogrammetric Engineering and Remote Sensing (PE&RS) to Geospatial Information Technology in KOREA.

Authors are encouraged to submit manuscripts on “cutting edge” research underway in KOREA in the following areas

- Photogrammetry • Remote Sensing • LIDAR
- Radar • GIS • GPS • Biological & geological applications
- All aspects of geospatial information technologies

All manuscripts must be prepared according to the “Instructions to Authors” published in each issue of PE&RS and on the ASPRS web site at www.asprs.org. Papers will be peer-reviewed in accordance with established ASPRS policy. Manuscripts must be received by March 31, 2001 to be considered for publication.

Please send completed manuscripts or direct inquires to:
Dr. Woosug Cho, Guest Editor
Department of Civil Engineering, Inha University
253 Yonghun-Dong Nam-Gu, Inchon, 402-751, KOREA
FAX: +82-32-873-7560, wcho@inha.ac.kr

PHOTOGRAHMETRIC ENGINEERING & REMOTE SENSING