

SPOT 5 Cadastral validation project in Izabal, Guatemala

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Commission VII, Working Group VII/4

KEY WORDS: Remote sensing, surveying, SPOT, identification, land, orthoimages, accuracy.

ABSTRACT:

Due to the resolution of the former generation of sensors, the use of satellite imagery in the surveying field has been limited to the construction of pre-cadastral solutions in rural areas. The project principal objective is to establish the potential use of SPOT 5 imagery - with its spatial resolution of 2.5m - as a main source for parcel identification in surveying activities. It was carried out by the UTJ-Protierra, the Guatemalan project in charge cadastral implementation. The different areas of study were selected by their distinct geographical features and cadastral interest. Two types of data were integrated to provide the database; namely SPOT 5 orthoimage and measurements of parcels with total station and GPS equipments. The evaluation was made by comparing the resulted digitised data from traditional measurements and the one from the image identification. The variation of surface between the two datasets was considered very low for extended and medium estates. The variation of the distance between vertices was less than two pixel resolution. Yet, properties in rugged terrain, small agricultural estates and peri-urban properties presented a considerable variation of area and the difference between vertices was less than 10m. The use of the orthoimages as an input for indirect methodology for cadastral projects is adequate for latifundium properties presenting low variation of topography, medium extensions and for planning cadastral activities. In the case of urban centres, steep gradient areas, regions' presenting an elevated density of parcel and dense vegetation fences, the use of SPOT orthoimage is limited.

1. INTRODUCTION

Digital analysis of remotely sensed data has become an important component of a wide range of land studies. However, due to the resolution of the former generation of sensors, the use of satellite images in the surveying field has been limited.

A cadastre is a methodically arranged public inventory of data concerning properties within a certain country or district, based on a survey of their boundaries. Properties are identified by direct or indirect methodologies such as total stations or aerial photographs. The outlines of the properties and the parcel identifiers are normally shown on large-scale maps which, together with registers, may show for each separate property the nature, size, value and legal right associated with the parcel. In some developing countries, cadastral systems do not exist yet or they are old and general, therefore new inexpensive operations and approaches have to be established.

Lately, with the launch of new sensors with higher resolutions, better capability to acquire derived DEMs, as well as a wider availability of remote sensing imagery, from the internet for instance, it is expected that satellite imagery will allow the acquisition of primary data for surveyor's interests and specifications. Nevertheless, few examples exist of applications on high-resolution images such as SPOT 5.

Satellite images do not allow obtaining exhaustive cadastral information such as legal status for instance, yet it is a global and synthetic instrument that has a significant impact on mapping primary data.

This paper explores the potential use of SPOT 5 XS imagery for parcel delimitation with cadastral specifications in Guatemala. First, traditional parcel delimitation are exposed as well as SPOT new characteristics are briefly explained. Second, a concise explanation of the data and the study area are explored. It is followed by different analysis of the potential use of SPOT

5 imagery and its cadastral delimitation accuracy. Finally the results are summarised and discussed.

2. BACKGROUND

Several methodologies of cadastral parcel delimitation exist, in general they can be divided in direct and indirect methods. The principal objective of the direct methodologies is to locate the relative position of points, so distance can be estimated later on. Depending on the accuracy needed for the cadastral study distinct techniques are employed, among the most used are theodolite, total stations or GPS (Elayachi et al. 2001, Nabil Nassif, 2002) and a combination of them. Yet, Mohd Said (2003) reported that performance of GPS cannot be said on its capability under certain vegetation as tropical canopy.

On the other hand, in the indirect method, surveyors use aerial photographs to delimitate parcel boundaries. The polygons are digitized in a second step of the study. Gavish and Doytsher (2002) mentioned that the use of indirect techniques is no less accurate than direct terrestrial measurement. Nevertheless, as noted by Juppenlatz (1991) conventional aerial photogrammetric method, the production of air photos and the resulting maps are so costly that certain cadastral budgets can neither raise money nor justify such expenditures.

Different parameters defined the use of those methodologies, for example in areas with elevated density of parcels like villages, it is more recommended to use direct methodologies with the use of theodolite or total stations. Where the density of parcel is not elevated, surveyors usually use orthophotos. Though, in rural areas, depending on the vegetation cover, the parcel density and local factors, the two options can be selected. Remote sensing with its utility for surveying large areas in a time and cost effective manner, is considered as a possible

solution for mapping in general and cadastral surveying in particular (Harvey and Hill, 2001).

The current and upcoming high spatial resolution satellite imagery is expected to have a significant impact on mapping applications of primary data acquisition, especially on attending surveyor's interests and accuracies. Spatial resolution of multispectral data was reduced from 20m to 5m for SPOT products in less than two decades. The use of panchromatic products improved with the launch of high resolution commercial satellite like IKONOS and Quickbird, and the production of accurate terrain model is a big success mainly for developing countries (Bernard and Munier, 2003).

Few cadastral projects have used satellite imagery to delimitate parcel boundaries. SPOT images (SPOT 4) have been used in Argentina and Nicaragua fiscal and physical cadastral pilot projects, yet because of its spatial resolution it was concluded that it was not possible to produce accurate boundary maps for cadastral purpose (Axes, 2004). In general, because of the specification of the images, high resolution satellite imagery can be used for pre-cadastral projects as an analysis instrument for the delimitation process, also as a support in the procedure and methodology decisions process (GDTA, 1997; Axes, 2004). Descriptions of area of study, creation of cadastral maps, less expensive updates, multifunctional cadastral data as land value maps via remote sensing and GIS techniques (Nisanci and Yomrahoglu, 2002) are some of the potential use of the satellite imagery in cadastral projects. The combination of pre-cadastral data from satellite images and traditional surveying techniques allows an execution of cadastral projects in only 20-50 months (Lebeau, 1999; Axes, 2004). The significant reduction of costs is one of the most important attractiveness of the use of satellite images for cadastral projects (Garcia, 2001); in Guatemala the cost of 1/30 000 aerial photographs for a nearby region was US\$ 30/Km² (Kadaster, 2001) compared to US\$ 4/Km² for the orthoimage used in this study.

SPOT 5 was designed to improve the geometric performance of its previous models. SPOT 5 data is constituted of panchromatic band, visible infrared and shortwave infrared band with a swath width of 60 Km. Stereopairs of 5m spatial resolution are acquired systematically from across track solutions, allowing the production of 2.5m orthoimages by a resampling algorithm. As Bernard and Munier (2003) reminded, this production will prove interesting and efficient maps for rural cadastre where the accuracy needed is not less than the orthoimage spatial resolution.

3. DESCRIPTION OF THE STUDY AREA AND DATA

3.1 Study area

The study area is located in the department of Izabal, Guatemala (figure 1). Located in the northeast region of the country, this tropical area includes a number of plains and low rugged mountain ranges. Generally the study area was chosen for its diverse set of terrain features. The flood plains, characterized by rich deposits, are occupied by rice, banana plantations and cattle breeding. Bare soil, scrub, survival plantations and forests cover the rugged areas.

3.2 Database

Two types of data were integrated to provide the database used in this study; namely SPOT 5 orthoimage and field data. The

image processing systems used for this project were ERDAS Imagine 8.3, AutoCAD 2000 and ArcView 3.2.

Ground control points were provided to SPOTIMAGE to relocate the image to 2.5 m accuracy. Field data included the measurement of 669ha. with total station and GPS equipments for rural and urban properties. Sub-areas were divided depending on the extension and topography, by this, large extensions in flat terrain, medium and small estates in rugged topography as well as peri-urban and urban properties were surveyed and identified on the orthoimage.

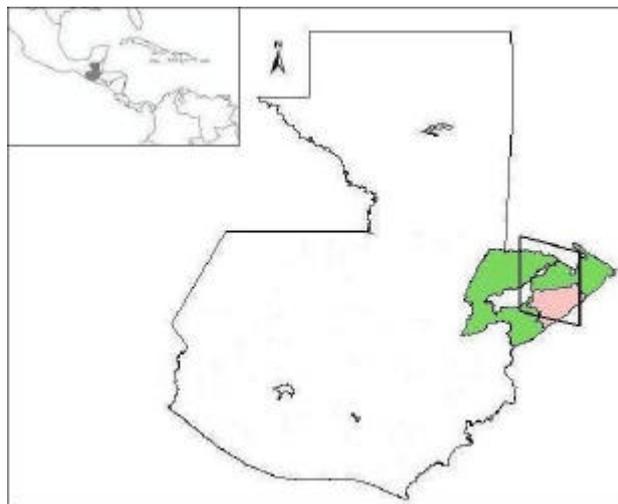


Figure 1. Map of Guatemala, the image extension is indicated with a rectangular box.

4. METHODOLOGY AND RESULTS

A number of display scales were evaluated for the orthoimage identification process. Depending on the region and nature of the area – topography, size of the parcel and image identification utility – the appropriate scale was chosen, providing the clearest visual distinction of boundaries and vertices.

As the quality of the image was considered poor, the identification was held on the image itself and two derived enhanced images – 3x3 and 5x5 windows.

The evaluation was made by comparing the resulted digitised data from the total station or GPS measurements – reference data – and the one from the orthoimage identification – extracted data – for each parcel encountered in the study area. Land surveying analysis are mainly composed of comparisons of areas and distance between vertices among the distinct data as shown in table 1 and figure 4 and 5.

4.1 Rural properties

For large extension in flat terrain, boundaries were easily identified in the enhanced orthoimage as observed in figure 2 and 3. In this case, field borders are trees, live enclosure or fences with presence of vegetation, roads or foot paths and water drainage with the presence of low altitude vegetation. Variation of surface between the reference data and the extracted one is very low (0.14%) and in average the localization of the boundary in the identification process is of 4.3 meters away from the reference data.



Figure 2. Delimitation of large extension parcel on SPOT 5 orthoimage.

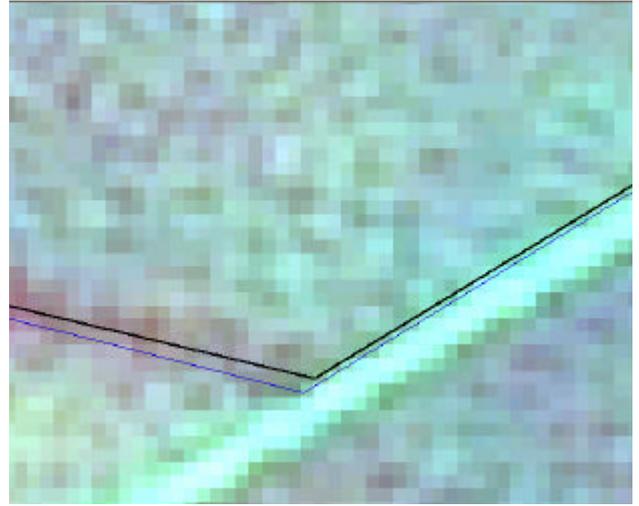


Figure 3. Comparison between surveyed data (GPS in this case) in black and the image identification data in blue. The difference between the dataset is 3.85m

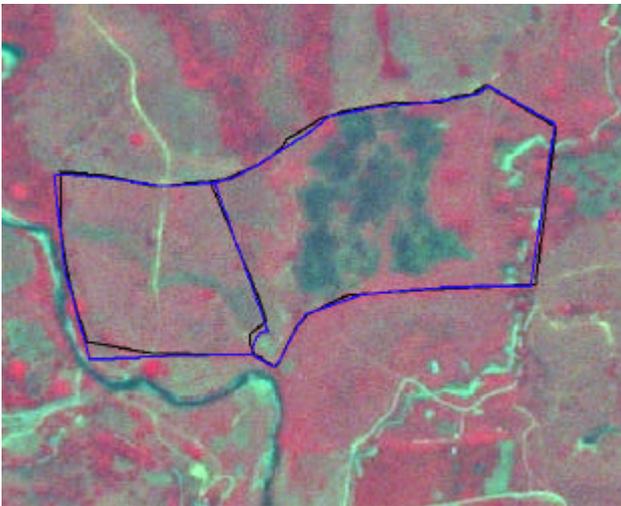


Figure 4. Delimitation of medium parcels on SPOT 5 orthoimage. Reference data in black, extracted data in blue.

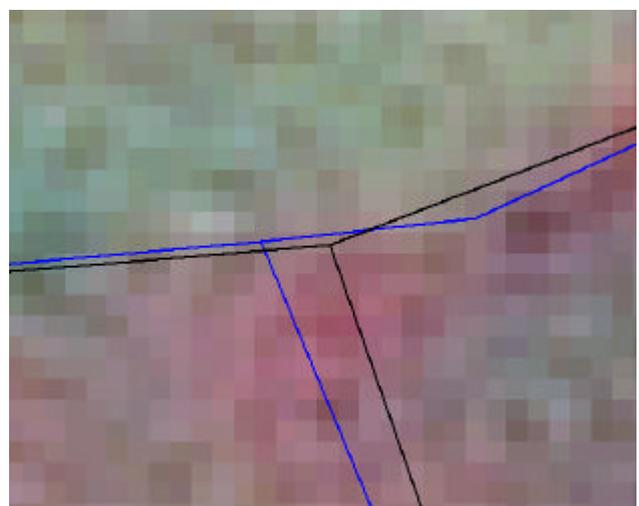


Figure 5. Difference of vertex location. Reference data in black, extracted data in blue.

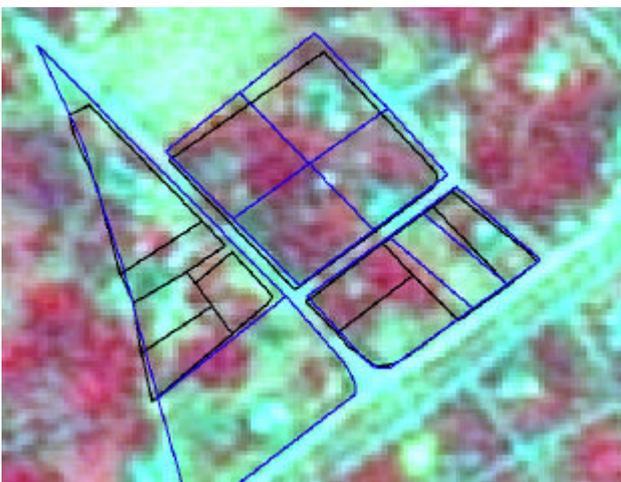


Figure 6. Delimitation of pre-urban parcels. Reference data in black, extracted data in blue. Deformation of shapes can be observed.

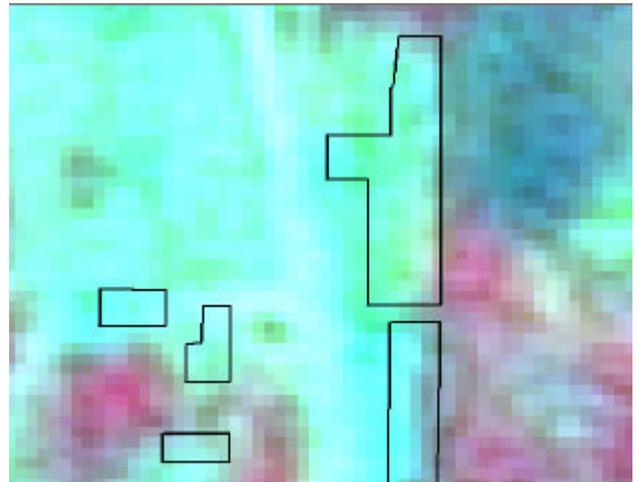


Figure 7. Black polygons represent buildings. They were measured with total stations. As it can be noted, building identification is limited.

Type of parcel	Topography	Scale of the orthoimage	Variation of the area (%)	Mean variation of the distance between the extracted data and the reference data (m)
Rural – Large estates	Flat terrain	1/10 000	0.14	4.3
Rural – medium estates (10 – 20ha)	Rugged terrain	1/5 000	0.22	6.8
Rural – medium estates (5 – 10ha)	Rugged terrain	1/5 000	1.77	8.5
Rural – small estates (smaller than 5ha)	Flat terrain	1/5 000	3.7	3.7
Peri-urban estates	Flat terrain	1/2 500	22.6	4.33
Urban estates	Flat terrain	1/2 500	Do not apply	Do not apply

Table 1. Results obtained for each type of properties.

However some of the vertices have a difference of localization of less than one meter.

There is a significant difference of result depending on the size of the property. Medium properties between 10 and 20ha presented a variation of surface of 0.22%, yet estates of 5–10ha presented a variation of 1.77%. The difference of vertice location between the datasets was of 6.8m for properties of 10–20ha. and of 8.5m for properties of 5 to 10 hectares. Field borders in rugged topography presented a very low density of vegetation, making the identification on the image more difficult (figure 4). When the border is under dense vegetation, the distance variation between the digitized border and the one survey can be as high as 11m (figure 5). In the case where no physical border exists the difference can be as high as 13m. Adding to this case, when there is no land use change, it is almost impossible to identify the border; the surveyor can only estimate the location of the vertice.

For small estates in flat areas the variation of the area detected was of 3.7% and the average variation of the distance between the borders identified in the image and the survey one was of 3.78m.

4.2 Urban properties

By peri-urban parcel, we consider properties of 500 – 1600m² with a combination of residences and survival cultures. Area variation was of 22.6% and the variation between borders was 4.33m. Most of the cases presented no physical boundaries, only 'legal invisible' fences. The presence of fruit trees, make the identification less accurate as we had to generalize the location of the vertice under dense canopy.

Where land consolidation is present, a variation of 1.48m of length is obtained.

Urban identification on the orthoimage was limited as it can be observed on figure 6 and 7. The areas of the buildings surveyed were smaller than 500m². The borders were barely identifiable in the orthoimage, making the delimitation of boundaries almost impossible. We have to note that building forms are highly changed between what can be identified in the image and the real aspect of the building as we can observe in figure 7. This is mainly due because of similar spectral response of the building and its entourage, where no contrast is identified the accuracy of image identification drops. Details of 8m of length could not be identified in the satellite image data.

5. ANALYSIS AND DISCUSSION

As the area covered by the orthoimage is elevated and the use of digital data presents some advantages, different preliminary work can be done with the image. In this particular case, the use of satellite images can be implemented since the beginning of the cadastral activities, for example in:

- planning activities,
- preliminary analysis for the selection of methodologies to be used,
- preliminary definition of cadastral polygons and municipality boundaries,
- to update the cartography, and
- for land-use/land-cover studies and general studies of the region surveyed.

Nowadays in Guatemala, the planning of cadastral activities is made with outdated cartography, 1/50 000 maps and in many cases without any previous field supervision. The design of cadastral polygons is completed using official cartography and photogrammetric products from the 80' and adjusted as the cadastral mapping advances. The delimitation of municipalities, which cadastral polygons cannot surpass, is done in a preliminary step with invalid maps and is adjusted on the field inspection making the planning step costly and time consuming. SPOT 5 orthoimage brings better elements than the ones used at the present.

Eight GCPs were provided to relocate the image to a 2.5m spatial resolution of the orthoimage. Ideally a GCP should be as small as a single pixel and an appropriate number should be well distributed in the study area (Campbell, 1996, Korgaja *et al.*, 2003). In tropical woodlands, steep topography and for distant regions, to obtain appropriate GCPs is a challenging task. The nature of the study area will influence the georeferenciation of the orthoimage and the resulted accuracy border identification.

The image used in this study presented some limitations, the presence of clouds and haze restricts the area of utility and the identification of parcel borders is more complex. It is recommended to work with enhanced images, as boundaries are most of the time linear, more easily identified. Depending on the average size of the properties, an adequate scale was chosen. Yet, as the image quality for cadastral mapping was not the most adequate one, most of the scaled images presented only the area of interest (cfr. Table 1). We cannot suggest an appropriate scale for preliminary or definitive cadastral plans, as the election of this one will depend on the nature and size of the properties – latifundium, medium and small estates, peri-urban and urban properties –, topography, atmospheric effects and precision needed. However, in this study we obtained more accurate results for medium scales (1/20 000 to 1/5 000) than for small ones (1/2 500), this is mainly due to the resampling method applied to the stereopair images of 5m spatial resolution to obtain a 2.5m orthoimage.

As we can observe, the variation of the parcel area between the referenced data and the one derived from the image interpretation depends directly of the size and topography of the property. The variation of area was considered very low for latifundium estates with no topographic variation and for medium estates of 10 – 20ha. However, properties in rugged terrain, small agricultural estates and peri-urban properties

presented a considerable variation of the surface. Important variation of the surface can have significant consequences in land development planning and legal aspects.

For large extensions in flat terrains and peri-urban parcels, the variation of the distance between the surveyed border and the extracted data was less than the pixel resolution – 5m – of the images from which the orthoimage was deduced. Although for rugged terrains, the difference was less than 10m. This variation depended on the nature of the fence, vertices under live linear enclosure were easily identified although the ones located under dense vegetation and large canopy were identified with less precision. It was also the case when non-physical boundaries existed – only agreements between neighbours or legal invisible boundaries – as presented mainly in peri-urban areas and parcel presenting survival cultures (corn or bean plantations).

The variation of surface and distance also depended on the number of vertices; in this study most of the parcels surveyed presented squared shapes, reducing the number of vertices. The identification on the orthoimage of parcels presenting curved boundaries, as it is the case when the border is a river, will be less accurate. If this condition is combined with topographical accidents, parcels of reduced size as well as a dense vegetation cover, the use of SPOT 5 orthoimage for cadastral purpose will be limited.

The use of SPOT 5 orthoimages as a tool for the indirect method for cadastral projects seemed interesting for latifundium properties presenting low variation of topography and for medium extensions. Nevertheless, small rural properties, peri-urban and urban estates were not well identified presenting an important variation of their surface as well as a deformation of their shape as it was the case for parcels smaller than 500m² and urban buildings. In the case of urban centres, steep gradient areas, regions' presenting an elevated density of parcel and dense vegetation fences, the use of SPOT 5 orthoimage is limited. Even if it is not feasible for collecting regional data or data requiring continual validation because of the cost and logistical difficulties in tropical areas, Harvey and Hill (2000) estimated that aerial photographs make a very useful data source due to their textural feature and superior spatial resolution. Still, because of the cost of acquiring data and the time involved in analysing large data sets in aerial photographs, where the required information can be extracted from high resolution satellite imagery – latifundium estates for example or extended non agricultural areas – it appears to be the most feasibly technology to adopt in land surveying projects. And where the use of the image presents its limitations, a combination of direct surveying methodologies and orthoimage identification can be made.

As noted previously, the average difference between the identified border and the reference data varied between 3.7 and 8.5m. The tolerance varies depending on the type of cadastre, different types exist depending on the information provided and the use of it. For example physical cadastre considers only the measurement of the parcels. A legal cadastre consists of the measurement of the parcel and the legal rights of this one. Fiscal cadastre defines the parcel as the base for land taxes. Polyvalent cadastre or multi-purpose ones is a combination of the distinct types of cadastre. In Guatemala where a cadastre for legal purpose is considered, the tolerance for urban parcels is 0.3m and for rural properties is 1m. In Colombia, the tolerance varies on the land tenure; in the Netherlands the difference of 0.28m for urban parcel is accepted and of 0.57m for rural properties. Wilcox (1984) noted that the rural tolerance in the US varied between 0.1m and 0.6m, and 0.3m for urban and suburban areas. This study demonstrated that the difference of distance surpass the established national tolerance

making inadequate the use of the orthoimage for delimitation purpose in Guatemala. Nevertheless, the use of SPOT 5 orthoimage as an input for indirect methods for land surveying can be considered in countries having fiscal and physical cadastre, where the accuracy of identification is not as strict as Guatemalan cadastral norms.

6. CONCLUSION

High-resolution satellite imagery with its utility for surveying large areas in a time and cost effective manner, was considered as an interesting input for indirect land surveying methodology. The principal objective of this paper was to investigate the potential use of SPOT 5 orthoimage for cadastral surveying.

Maps (1/50 000, 1/25 000 and 1/10 000) constitute useful tools as they bring important technical elements assisting the established cadastral activities. For countries like Guatemala, where planning cadastral activities are prepared with outdated topographical maps, SPOT 5 imagery brings a significant support to cartography.

Comparisons between data from total stations – GPS measurements and orthoimage identification for different types of parcels were evaluated. Good results were obtained for large and medium extensions; although it presented its limits for identify accurately small parcels, peri-urban and urban estates. The accuracy of identification depends directly on the size and shape of the property, the topography of the area, the type of fences and vegetation coverage present on the study area as well as the scale of the orthoimage used in the identification process. SPOT 5 orthoimage is considered an interesting alternative input for indirect methodology for latifundium and medium estate with low topographical variation. However for small properties, urban cadastre and building identification it is recommended to use traditional surveying methods. Even if in this study, the difference between identified vertices and the ones located with traditional methods surpassed the Guatemalan cadastral tolerance, the use of SPOT 5 orthoimage as an input can be consider in countries regarding cadastre with less strict precision.

REFERENCES

- Axes, F., 2004. Spot 5 imagery as a tool for land management and agriculture monitoring, towards the accession to the European Union. SPOT Image.
- Bernard, M., and Munier, P., 2003. FIG Working Week "Evolution in the use of space imagery, trends and challenges". Paris, France.
http://www.ddl.org/figtree/pub/fig_2003/PS_3/PS3_1_Bernard_Munier.pdf (accessed 20 Jan. 2004)
- Campell, B., 1996. *Introduction to Remote Sensing*. 2nd edition, Taylor and Francis Ltd, London.
- Elayachi, M., Salimi, H., Souhaili, S., 2001. FIG International Conference New technology for a new century "GPS_DAO – application to use GPS for topographic and cadastral plans", Seoul, Korea.
<http://www.ddl.org/figtree/pub/proceedings/korea/full-papers/pdf/session14/elavachi-salimi-souhaili.pdf> (accessed 20 Jan. 2004)
- Garcia, M., 2001. *Feasibility evaluation of the SPOT satellite for parcel boundaries identification*. Thesis presented to obtain

the Professional Master degree in Geoinformation, ITC, Enschede, The Netherlands.

Gavish, Y., and Doystsher, Y., 2002. FIG XXII International Congress “Analytical Cadastre in Israel: restoring land boundaries based on photogrammetric tools”, Washington DC, USA, http://www.fig.net/pub/fig_2002/Ts7-10/TS7_10_gavish_doytsher.pdf (accessed 14 Jan.2004)

Groupement pour le Développement de la Télédétection Aérospatiale GDTA, 1997. *Kit cadastre rural en Amérique latine, Système d'informations cadastrales et apport de l'imagerie SPOT*. GDTA, Paris, France.

Harvey, K.R., and Hill, G.J., 2001. Vegetation mapping of a tropical freshwater swamp in the Northern Territory, Australia: a comparison of aerial photography, Landsat TM and SPOT satellite imagery. *International Journal of Remote Sensing*, 22(15),pp.2911-2925.

Juppenlatz, M.,1991. Urban environmental surveys: information gathering, low cost aerial photography and town management. *Cities*, no data

Kadaster, 2001. Informe final proyectos pilotos catastro Zacapa-Chiquimula. Guatemala, Guatemala.

Kargaja, A., Melnikova, I., Liba, N., Kall, T., and Veermets, T., 2003. “About quality and using IKONOS satellite image in Estonia”. Paris, France. http://www.fig.net/pub/fig_2003/TS_12/PP12_2_Kargaja_et_al.pdf (accessed 16 Apr. 2004)

Lebeau, J.R., 1999. *Le cadastre rural au Nicaragua*. Thesis presented to obtain the Engineering degree, ESGT, Paris, France.

Mohd Said, S., 2003. FIG Working Week “Evaluation of GPS RTK performance under tropical trees Canopy”. Paris, France.http://www.ddl.org/figtree/pub/fig_2003/TS_19/PP19_5_MohdSaid.pdf (accessed 20 Jan. 2004)

Nabil Nassif, E., 2002. FIG XXII International Congress “A radical solution for cadastre problem in Egypt Using Integrated GPS-GIS System”, Washington DC, USA. http://www.fig.net/figtree/pub/fig_2002/JS2/JS2_nabilnassif.pdf (accessed 20 Jan. 2004)

Nisanci, R., and Yomrahoglu, T., 2002. International Symposium on GIS “Creating land value maps via remote sensing and GIS techniques” , Istanbul, Turkey. http://www.fig.net/com_3_istanbul/PDF/R.Nisanci1.pdf (accessed 14 Jan.2004)

Wilcox, D.J., 1984. Proposed map accuracy standards for a multipurpose cadastre. *Comput. Environ. Urban Systems*, 9(2/3), pp.203-207.

ACKNOWLEDGMENTS

This work was supported by SPOT Image and UTJ-PROTIERRA. The authors are grateful to Luis Victorio, José Ignacio Puertas, TETRA group and Fondo de Tierras for providing their permission to measure their properties.