# Aerial Survey Solutions for Encroachments and Informal Settlements: Case Studies in Trinidad and Tobago

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**Key words**: Digital Photogrammetry, Encroachments, Land Monitoring, LiDAR, Squatter Regularisation

## SUMMARY

Monitoring and controlling informal settlements, as well as illegal occupation and use of land have long been difficult tasks for the state and public sector in many developing countries with human resource and economic limitations. The situation becomes increasingly problematic in cases where high valued mineral and other land resource rights are involved as this impacts on fragile economies. It is an ongoing exercise for both the state and private land owners to manage not just the occupation of the land, but activities such as illegal quarrying and mining. Managing the environmental impacts of these activities is also progressively more important for the sustainability of developing countries. While it is sometimes clear that these activities are taking place, the question that arises is exactly how the genesis, extent, and growth of encroachment, and occupation can be ascertained and monitored in a cost effective and timely manner in locations that are either remote or potentially hostile, and in environments where physical safety is of concern.

This paper presents case studies conducted in Trinidad and Tobago, where, through the integration of digital photogrammetric and LiDAR techniques with cadastral surveys and the idiosyncrasies of the local cadastral practice, these concerns are directly addressed. From the results obtained, it can be demonstrated that aerial surveys would not only meet the technical requirements for monitoring occupation and use of land, but when applied in the appropriate context, can provide rapid, cost effective alternatives to several of the challenges in monitoring informal occupation.
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## 1. INTRODUCTION

Monitoring the use of lands and supporting the security of land rights effectively in Trinidad and Tobago have long been difficult to implement. This difficulty is due to the lack of current, comprehensive, accessible georeferenced cadastral information. It is also due to the significant cost, time, and effort needed to acquire sufficient current land use and land cover data. Both sets of data are required for comparison to identify and analyse areas of encroachment, occupation, and use. The cadastral system is incomplete, and is not maintained in a current state. Cadastral plans are not coordinated and are not legally required to be tied to the national grid and this adds to the difficulties in efficiently maintaining current land information systems that must integrate with a cadastral dataset. Cadastral surveys prove to be expensive for private land owners to contract in order to monitor large land holdings on a continuous basis. The state also has great difficulty in managing forest reserves and other protected reserves as well as agricultural and mining leases on state lands. There is considerable informal occupation ongoing on largely state but also private land (Griffith-Charles and Opadeyi 2009; Griffith-Charles 2004) and the state endeavours to stem the initiation of this activity in new areas while trying to regularise and monitor the occupation in long-standing areas. The incidence of spontaneous informal occupation of land, particularly on state land, was stated to be 25,000 households or about 100,000 persons in the 1990s (LSA 2001). Current estimates far exceed this figure, and have been quoted at 250,000 persons or almost 20 percent of a population of some 1.3 million (Trinidad Express 2015). At times land invasions take place, particularly when segments of the population perceive that it is not politically expedient for the government of the day to eject them. An example of this occurred post elections in 2010 (Trinidad Express 2011) and again prior to elections in 2015 (Trinidad Express 2015). These statistics indicate the gravity of the situation and the need for continuous monitoring of this activity for setting land policy and a socially progressive land reform agenda. It is also important to be able to timestamp occupation as dates are used to determine legitimacy of rights in two of the state's land reform programmes. The State Land Regularisation of Tenure Act 25 of 1998 protects squatters from ejectment of their dwelling house from state land if they have been in occupation prior to 1st January 1998. The State Land Regularisation of Tenure Amendment Bill 2015 sought to revise this deadline date to 13th June 2014. This latter Bill has lapsed and has not been enacted but the problem remains and must be addressed.

## 2. BACKGROUND

Current technologies provide ways of comparing digital spatial data to determine changes in times that are quicker than physically occupying for the purposes of conducting topographic and cadastral land surveys. The reduction of the need for human resources onsite also reduces the cost of the exercise where highly skilled and professionally qualified and therefore expensive manpower is required.

Aerial surveying with photogrammetric processing provides for remotely surveying and coordinating positions and can be used where timely data is required and also where accessibility, safety and security are of concern. Current digital airborne cameras are lower in cost and higher in output than previously and are therefore quite versatile for monitoring. They can perform many requirements including creation of DSMs and computation of volumes and can be UAV mounted to reduce costs (Remondino 2011).

LiDAR surveys provide dense quantities of data that can accurately be used in acquiring elevation information and thus can be instrumental for height and volume differencing determination (Means et al. 2000). There are many instances of this application that have produced accurate results depending on the objective of the analysis. While ground based scanning LiDAR produces accurate results as well (Hopkinson et al. 2004), the airborne deployment of the technique allows for faster coverage of large expanses of area as well as safety and security in dangerous and inaccessible situations. The costs of the ground-based configuration can become more expensive if several setups have to be implemented to obtain a holistic view of the objective of the scan.

## 3. METHODOLOGY

This research set out to investigate the applicability of aerial survey techniques to efficiently and effectively capture information on the activity on land that can impact on cadastral rights. There are also safety concerns for state land management staff whose duty it is to monitor and control the burgeoning squatting in densely packed, low-income settlements where crime and violence is commonplace. Remote means of monitoring were therefore important to this assessment. Illegal quarrying on state land has also been a problem in state reserves and this requires, in addition to determining the location and area of occurrence, the computation of the volumes of material removed. While encroachment that can lead to changes in land rights as a result of legal prescription requires long periods of continuous occupation, illegal occupation for the purposes of exploitation of land resources has more immediate impact on land rights and therefore interventions are required to be timely. It was therefore important to assess the speed of these aerial techniques in relation to the conventional field surveying to re-establish boundaries.

Two case studies were therefore planned to represent the different situations where remote methods of quickly determining areas of encroachment, and assessing changes in informal and illegal occupation are required. LiDAR, aerial surveys and photogrammetric processing, and cadastral surveys were performed to compare the differences in time, and manpower required for the different methods. The two case studies are described here and an analysis and conclusion are presented to indicate the applicability of the processes.

## 4. CASE STUDIES

### 4.1 Case Study # 1 Quarry Encroachment

In this application, a 100-acre (40.5 hectare) private land holding in the Tabaquite area of Trinidad and Tobago, as shown in the cadastral index map in Figure 1, was investigated with the main objectives being to assess the extent of any possible cadastral encroachment and to identify potentially illegal quarrying activities that may have been taking place. Additionally, a quantitative assessment of any removed material was also required.

To meet these objectives via conventional survey techniques would typically require a cadastral survey to redefine the parcel or the relevant boundaries and topographic surveys over the affected portion of the 100-acre parcel. The dense vegetation and undulating terrain, along with the size of the site would make this an extremely time and labour intensive exercise, requiring the equivalent of upwards of 13 field days. This is estimated at one field crew comprising one surveyor and two fieldmen over 3 days for redefining the boundaries and 10 additional days for the topographic survey of 40% of the site totalling 13 days or 39 man-days, with additional office computation days. This estimate of time taken for field work is based on experience and cannot be precisely computed. Boundary surveys in Trinidad and Tobago can meet significant delays as monuments are buried and not coordinated. Locating boundary markers that have been lost or destroyed can therefore take additional time for traversing from existing, visible marks at some distance away. The estimate of 3 days for this aspect is therefore a conservative one, assuming moderate difficulty in locating at least one corner marker. Since there are no documented professional standards for time taken in the country, assessment of many similar previous surveys undertaken by the authors and other professionals yielded this figure. Time estimates for topographic surveys are slightly easier to predict for a given set of specific characteristics such as topography, and foliage cover on the site, and precision specifications for the survey, given the objective of the survey. Again, based on many similar surveys undertaken by the authors and other professionals, in greatly undulating areas with foliage cover and moderate survey precisions of 0.5m, approximately 4 acres can be covered in one day. The 40% or 40 acres would therefore take 10 days to accomplish. Three (3) days of office work would be needed to determine the nature and magnitude of the quarry encroachment, and this would include QA/QC checks, draughting work which entails plotting of cadastral boundaries, overlay of topographic layers and final processing including the calculation of the amount of volume removed and identification of encroachment. These processes require both the surveyor and draughtsman, resulting in further 6 man-days. The total for the traditional process in the study would therefore be 45 man-days.

This time frame has significant cost implications which can make an exercise of this nature prohibitive. Professional fees approved by the professional association, the Institute of Surveyors of Trinidad and Tobago, place the cost of an initial cadastral day's work at TT$7,500 and subsequent days at TT$3,250. Topographic surveys are listed at TT$7,000 for the initial day and TT$3,250 for subsequent days. The total cost of the 13 days is therefore TT$50,250 or US$7,824. In addition to the time, cost and manpower considerations, there are also the personal safety concerns that come with surveying in informal settlements and where illegal activities are taking place. These factors were the catalysts to investigate a new approach.

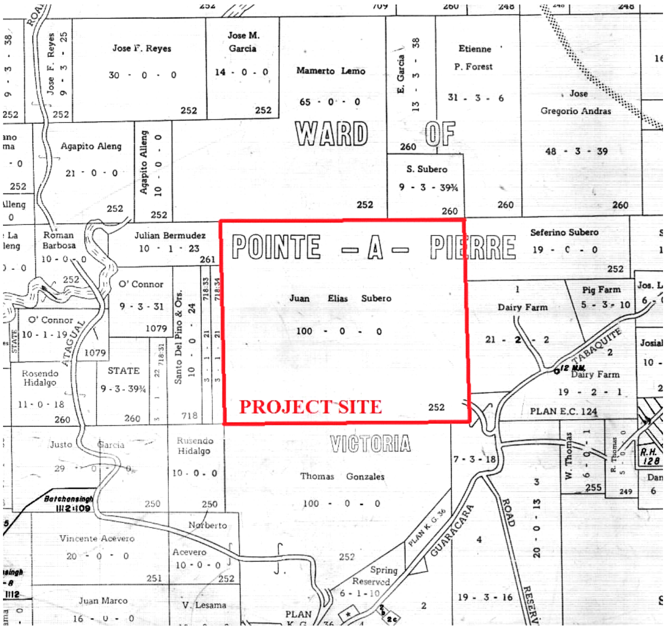


*Figure 1 – Cadastral index map indicating project site*

An integrated cadastral, photogrammetric and LiDAR methodology was used to complete the survey. The survey started on August 5th and was completed on September 10th, delivering all of the required objectives. To illustrate the potential time and resource use this approach provided, a total of 3 days was spent on site by the field crews, consisting of one surveyor and two chainmen, performing the cadastral survey boundary redefinition and control and verification exercises resulting in a total of the equivalent of 9 man-days which would be the same as the traditional techniques. Mapping and LiDAR activities were conducted simultaneously by separate crews, in approximately half of the man days of the traditional topographic data acquisition. Additional office time was used in data processing, analysing and presentation activities utilising the surveyor for processing of GPS data, the draughtsman and the data processor. This LiDAR processing took an additional 5 days. The total was therefore 34 man-days, which is less than the 45 days of the traditional method.

The project began with a cadastral survey to redefine the boundaries of the 100 acre parcel. As cadastral boundaries were relocated they were simultaneously coordinated. It should be noted that at this stage, all of the cadastral boundaries need not be found to complete all of the objectives of the project since the parcel had been surveyed previously. Once sufficient boundary markers were found to verify the location and orientation of the parcel, the other boundaries could be generated if necessary from the distance and bearing information from the existing cadastral plans. However, only a survey of the boundaries encroached on was relevant to the exercise. This gives a coordinated outline of the parcel which can be overlaid on the georeferenced image and LiDAR data. This was an additional consideration as some of the areas of the site carried particular safety concerns related to the hazardous topography.

The topographic data were collected via LiDAR surveys and photogrammetry. The photogrammetric and LiDAR flights were conducted using an Optech Orion M-300 scanner and an 80MP high resolution Optech CS-10000 digital camera. Ground control was established to georeference the photographs. A georeferenced mosaic was produced and the cadastral data were overlaid on it to identify any possible occupation or activities on the site. Figure 2 shows the cadastral plan prepared showing redefined boundaries and the occupation of the parcel.

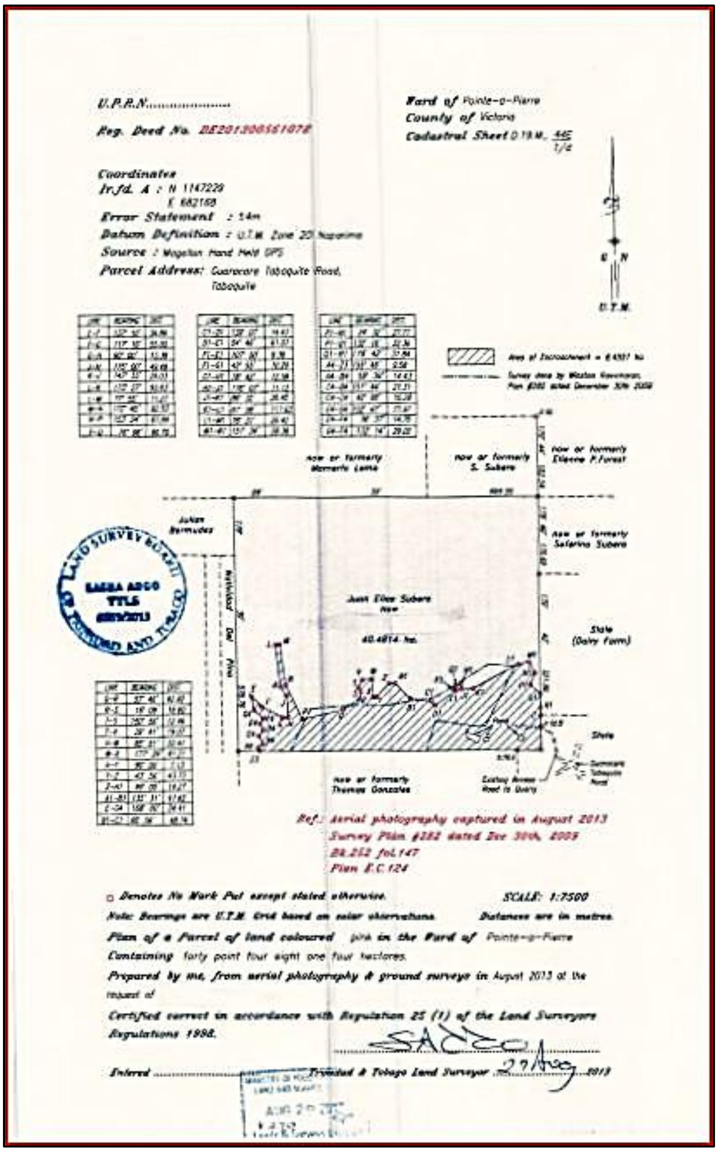


*Figure 2 – Cadastral plan showing redefined boundaries and the occupation of the parcel.*

Figure 3 shows the cadastral information overlaid on the georeferenced mosaic. The highlighted portions show areas of potentially unauthorized quarrying activities on the site.

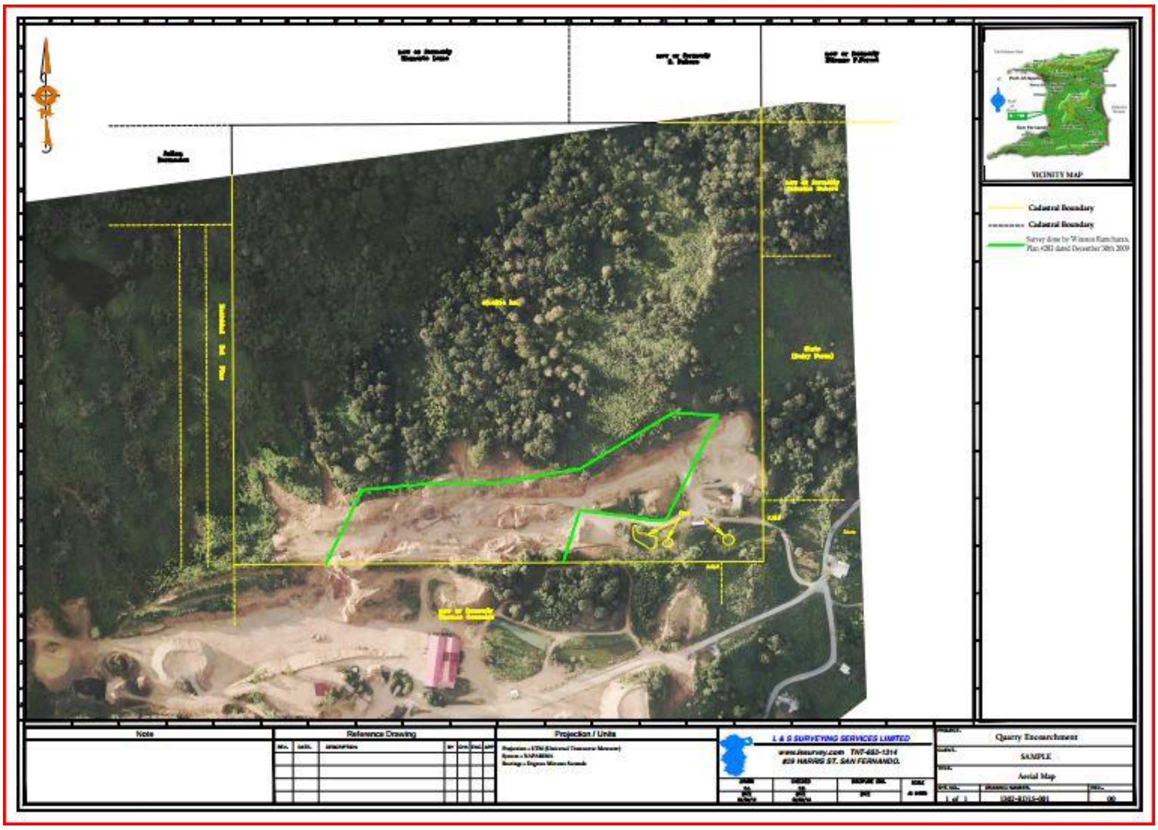


*Figure 3 – Mosaic of site with cadastral overlay showing areas of possible unauthorised activity on the site*

A digital surface model (DSM) for the site was extracted from the acquired LiDAR data. This is generated from the LiDAR reflections with the vegetation and other structures removed (see Figures 4 and 5). Corresponding elevation data were acquired for the site from the 1994 topographic dataset from the Lands & Surveys Division. The 1994 model was used as base data and, using the cadastral limits to clip the boundaries, the two surface models were overlaid and differenced to assess the change in the topography of the land. The total volume of the difference between the two surfaces represents the amount of material that was removed from the parcel during the period circa April 1994 when the 1994 photography was flown to August 2013 when the LiDAR data were acquired. It was determined from this volumetric calculation that a total of approximately 231,129 $m^3$ was removed from the site for that period. This provided a total volumetric change over the entire site using the parcel boundary as the limits. A clip boundary could also be generated using the areas identified as unauthorized quarrying activity from the cadastral overlay of the mosaic. The precision of the current dataset is higher than the precision of the previous data acquired from

1:25,000 scale aerial photography so this would impact on the precision of the final determined volume.

*Figure 4 – Colorised LiDAR data depicting project area*

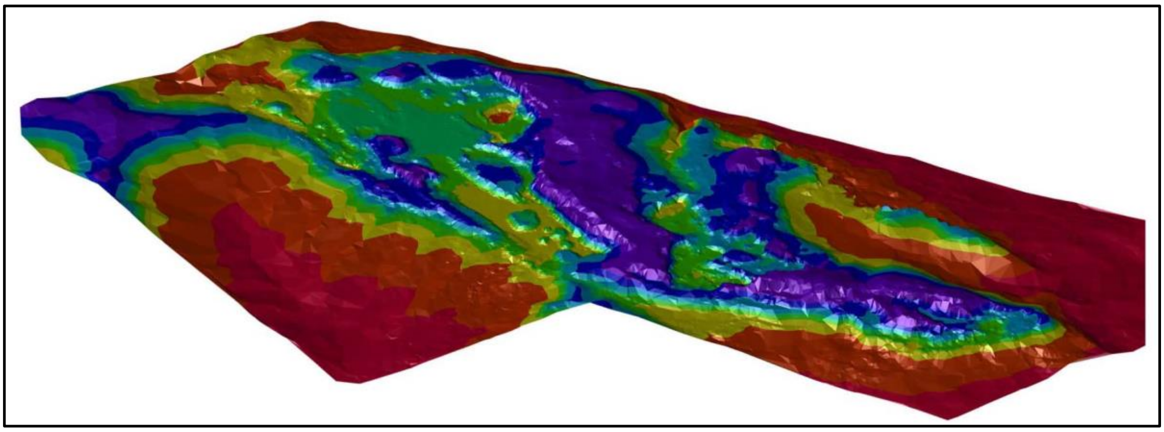

*Figure 5 – LiDAR reflections with vegetation removed to obtain DSM*

### 4.2 Case Study # 2 Informal Settlement Assessment

In this application, a rapid assessment was done of an informal settlement in Santa Rosa combining photogrammetric and cadastral techniques. A survey of the area was conducted in 2009 which provided base data for the lotification and building assessment. The objective of the survey was to map the change in built environment between 2009 and 2013.

Conventional surveying would require new cadastral and topographic surveys to determine the extent of the site and the location of buildings built since the 2009 baseline. Again, based on surveyors' experience, the cadastral survey of the boundaries of the site, with moderate difficulties in locating boundary markers, can be 3 days at TT$7,500 for the initial day and TT$3,250 for 2 subsequent days. Topographic surveys would be needed to acquire data on horizontal positions of structures with no elevations required. However, as a result of the close proximity of the houses surveying their positions would require several more observation stations than an open field. It is estimated that a field crew can acquire the topographic data over the number of buildings in 1 field day at a cost of TT$7,000. An additional 2 man-days would be required for computations and plotting.

In February 2013, a Cessna 162 light aircraft was used to fly over the area and a GoPro Hero2 camera with wide angle lens was used to capture images of the site as shown in Figure 6 (b). The image was processed, corrected and geo-referenced to UTM Naparima 1955. The original survey lotification information and topographic data was super-imposed onto the recently captured image using physical data collected on the original cadastral plan. Figure 6 (a) shows the image of the same location from Google earth also accessed in the month of February. This imagery is dated 2006. In this exercise, one field crew at an approximate cost of TT$7000 was utilised for one day to provide ground control for the flights, but no additional cadastral or topographic work was required. Two days were spent in the office utilising the surveyor for processing and the imagery and the draughtsman to digitise the changes.


*(a) Google Image 2006* *(b)Aerial Image 2013*

*Figure 6 – Santa Rosa site showing Google (a) and Aerial (b) images of location*

Figure 7 shows the cadastral and topographic data obtained in 2009 overlaid on the newly acquired 2013 image. This illustrates the cadastral boundary lines and the structures that were present prior to 2009, allowing all the changes in occupation that have occurred since the initial survey, and additional structures to be easily identified using this technique. Changes can be digitised and quantified to assess the growth in the area over a specified epoch and this result can be date-stamped at the time of data capture to indicate the period within which occupation began, particularly in instances of spontaneous land invasion or for land reform purposes. For areas where spontaneous invasion is of particular concern, periodic monitoring and mapping of changes can be carried out, with the dates of the imagery providing a basis for assessment of rates of occupation and development.

This is a simple method that can be used if a connection from a surveyed boundary to some physical detail is surveyed on the original cadastral plan. Otherwise an initial cadastral survey is required to do this. It can be recommended that cadastral plans contain this information in future or that some points are coordinated. Since this is not currently a requirement, discussions with the surveying profession can result in the introduction of this rule for the benefit of the cadastral system in Trinidad and Tobago. Since this method is not software dependent, costs and capacities are minimised. The cost of the light aircraft can also be compared with an alternative such as the use of an Unmanned Aerial Vehicle (UAV).


*Figure 7 – Cadastral boundaries and structures pre and post 2009*

## 5. DISCUSSION & POTENTIAL APPLICATIONS

In both of the case studies, the use of the aerial methodologies allows for several advantages. These advantages include:

- The ability to acquire data quickly supports efficient and effective land management
- The ability to identify and monitor new or unauthorised structures on a periodical and continuous basis
- The ability to eliminate ground policing or drive through thereby reducing safety concerns for ground teams
- The ability to capture information on structures that can be hidden from view from the ground by fences
- The ability to gather information and produce client specific results very quickly

- Lower cost as compared with traditional ground survey techniques for data capture
- The ability to create time series maps indicating the changes over the years which can be used for further trend analysis to aid in sustainable planning and development

Table 1 indicates the potential time savings earned by aerial over conventional methods in the case studies. While savings of time can occur, the difficulties in coordinating the cadastral data with the topographic data sometimes reduce these savings. Costs of aerial methods can be considerably more than the conventional methods. Overall, the benefits stated previously, including the safety elements, are the main attractions to this method.

*Table 1 – Time savings for aerial vs conventional methods*

| | Case Study 1 Conventional | Case Study 1 Aerial | Savings in Aerial method | Case Study 2 Conventional | Case Study 2 Aerial | Savings in Aerial method |
|---|---|---|---|---|---|---|
| Cadastral time (man days) | 9 | 9 | 0 | 9 | 3 | 6 |
| Topographic time (man days) | 30 | 15 | 15 | 3 | 0 | 3 |
| Office time (man days) | 6 | 10 | -4 | 2 | 4 | -2 |
| ***Total*** | ***45*** | ***34*** | ***9*** | ***14*** | ***7*** | ***7*** |

Since cadastral surveys are not generally coordinated in Trinidad and Tobago, field work is still necessary in most instances to ensure that the location of the boundaries is positioned accurately with respect to the physical features that evidence encroachment or occupation. Elevation data are also not precise in the official database since the data were acquired by the state mapping institution since 1994. However, the speed of the acquisition of data and the ease of remotely determining the information desired outweigh the need for tighter precisions at this time.

## 6. CONCLUSION

Developing countries can face human resource and economic challenges in attempting to monitor illegal and detrimental land use and occupation. Land rights in both private and public spheres need to be monitored to preserve security of those rights. Some of the newer remote imaging technology can be combined with conventional survey technology and practice to improve on the monitoring and analysis in a timely and cost-effective manner. While the precisions attainable from remote methods are not as high, in some instances, as those attainable from direct methods as a result of inadequacies of previous and existing cadastral and topographic datasets, higher efficiencies are achieved. If the limitations in accuracy of the results obtained are taken into consideration, the improvement in timeliness and cost still justifies the use of the remote techniques. Refining these methodologies and standardising them can result in more effective land administration and management

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## BIOGRAPHICAL NOTES

**Dexter Davis**

Dexter Davis PhD (Newcastle-upon-Tyne) is currently a lecturer in geomatics with the Department of Geomatics Engineering and Land Management, Faculty of Engineering, University of the West Indies. Since 1998, he has worked in various teaching and research roles as well as Geomatics consultancy at the University of Newcastle-upon-Tyne, UWI and UTT as well as the private and public sectors in the Caribbean. He also serves as a Geomatics Consultant and on the Board of Directors for L & S Surveying Services Ltd. He is an active member of the Institute of Surveyors of Trinidad & Tobago (ISTT) and the American Society for Photogrammetry & Remote Sensing (ASPRS). Some of his current areas of research and expertise include sea level rise monitoring in the Caribbean and disaster relief mapping.

**Charisse Griffith-Charles**

Dr Charisse Griffith-Charles Cert. Ed. (UBC), MPhil. (UWI), PhD (UF), FRICS is currently lecturer in Cadastral Systems, and Land Administration in the Department of Geomatics Engineering and Land Management at the University of the West Indies, St. Augustine, where her research interests are in land registration systems, land administration, and communal tenure especially ‘family land’. Dr Griffith-Charles has served as consultant and conducted research on, inter alia, projects to revise land survey legislation in Trinidad and Tobago, assess the impact and sustainability of land titling in St. Lucia, address tenure issues in regularizing informal occupants of land, and to assess the socio-economic impact of land adjudication and registration in Trinidad and Tobago, apply the STDM to the eastern Caribbean countries, and document land policy in the Caribbean. Her publications focus on land registration systems, land administration, cadastral systems, and land tenure and these have been published in Surveying and Land Information Science, Computers, Environment and Urban Systems, Journal of Land Use Policy and Survey Review amongst others.

**Sasha Addo**

Sasha Addo has been a practicing Surveyor since graduating from UWI in 1996. He was awarded a surveying license in 1998 from the Land Survey Board and in 2006 completed his EMBA at Arthur Lok Jack Graduate School of Business. Mr. Addo is a member of the Institute of Surveyors of Trinidad & Tobago (ISTT), serves on the Land Survey Board and is a member of the UWI Industry Liaison Committee for Geomatics.

Mr. Addo has been the Managing Director of L & S Surveying Services Limited since its inception in 2000. L & S is currently the largest Surveying and Mapping Company in the island providing professional and innovative services to the industry including sub-surface surveying, 3D terrestrial and aerial based scanning and land monitoring solutions using locally based equipment and staff.

**Nikita Morris**

Nikita Morris is Project Assistant currently working at L & S Surveying Services Limited. After graduating with a BSc in Geomatics from UWI in 2010, she continued in the Geomatics Engineering and Land Management Department as a member of staff fulfilling research and teaching support roles. She is currently pursuing an MSc in Geoinformatics and some of her current research areas and interests involve GIS, Change Detection and Aerial Mapping

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