PIONEERING A GPS METHODOLOGY FOR CADASTRAL SURVEYING: EXPERIENCE IN ALBANIA AND BELIZE

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1. Introduction

The formalization of property rights within land administration projects and programs typically involves the spatial definition and description (survey and mapping) of individual parcel boundaries. In many cases informal property rights have arisen because of overly expensive, slow and complex surveying methods. As countries such as Albania move towards a private property system, boundary definition of millions of parcels is required. In countries like Belize, surveying has fallen behind the demand for registering freehold rights and state land leases, with the result that the formal record lacks an adequate spatial definition of parcels. In both cases, there is a crucial need for a surveying methodology that is quick, inexpensive and within the reach of the existing surveying professionals.

Over the past ten years GPS has emerged as a major tool for undertaking precise surveys. More recently, it has made inroads in those applications requiring lower precision surveys and is fast becoming a primary technology for acquiring data for input into geographical and land information systems (GIS/LIS). So-called "sub-meter" GPS receivers can provide coordinates which are sufficiently accurate for cadastral purposes in rural areas. More importantly, these receivers offer an opportunity to significantly lower the cost and time typically required for cadastral surveys.

Cadastral surveying is the branch of Surveying dealing with the definition, measurement, relocation and mapping of land parcels to which registerable land rights are attached. It involves the application of legal boundary principles, as well as measurement theory and techniques. Boundary principles are used to assess boundary evidence in the form of measurements, historical records, verbal testimony from landowners, physical monuments and accessories. In this sense (and also because it affects people's legal rights to land), it is far more complex than merely mapping ground features or land-use boundaries.

In designing and testing a GPS methodology for cadastral surveying we have prioritized the following criteria:

- speed (must significantly outperform current approaches)
- cost (must significantly reduce current unit survey costs)
- appropriate (must be within the reach of local surveyors)
- realistic accuracy (match real needs)
- simple field operation (data collection must be simple to allow for variable field conditions)

In the past cadastral standards in developing countries, and elsewhere, have tended to be designed to achieve the highest accuracy that the technology can deliver with little consideration for time and cost. We have attempted at all times to avoid this "supply" driven approach and to apply a "demand" driven approach based solidly on the cadastral needs of developing countries.

This paper will describe the performance of the GPS technology under the controlled conditions of the UF test site. It will also summarize the cadastral conditions and results of the field tests undertaken in Albania and Belize. This experience was used as a basis for developing standards, specifications and procedures for a new GPS-based approach to cadastral surveying, which is described in the latter part of this paper.

2. Performance of GPS Technology under Controlled Conditions

2.1 Control Tests at UF Test Site

With any new technology it is essential to understand how it performs under the different types of conditions in which it will be applied. The performance claims of the manufacturers should be regarded as optimistic and in many cases their tests may not take into account conditions which apply to a specific application area, such as cadastral surveying. For this reason, a number of control tests were undertaken at a cadastral test site on the UF campus.

The test site consists of 49 monumented points which are set out so as to form 28 small parcels or polygons. Coordinates for all these points were determined to a very high degree of accuracy using geodetic GPS receivers and total stations. For the purposes of our tests, they can be regarded as "true" coordinates. In order to test the GPS technology for the demands of cadastral surveying in developing countries, the following tests were carried out:

- Investigation of positional accuracy vs baseline distance (2-200 kms)
- Investigation of positional accuracy vs occupation time (15-60 seconds)
- Performance of Geodetic vs 12-channel sub-meter receiver as base station
- Utilization of second base station for improving accuracy and data authentication
- Performance of different processing software (MCORR300 vs MCORR400)

In addition to the tests site points, other geodetic control points at varying distances from the control site were used for these tests. The coordinates of these control points are known to a very high degree of accuracy as they are part of the Florida High Accuracy Reference Network (HARN). The geodetic control points are situated at the following distances from the test site: 2km, 32km, 68 km, 87km, 107km, 148km, 178km, 235km. For all tests these points were occupied by the base station receiver (Trimble 4000SE or 12 channel Pathfinder ProXL) and the test sites by the rover receiver (Trimble Pathfinder ProXL). The base stations were used to determine the differential corrections that were applied to the rover positions.

2.2 Summary of Test Results

The results of the control test are summarized in Figure 1 (variable baseline distance and dual base station tests) and Figure 2 (variable occupation times). Additional details are given in Barnes and Eckl (1996).

2.3 Conclusions and Implications

The following conclusions can be drawn from these tests:

a) Sub-meter results can be achieved (but not consistently) for baseline distances of up to 150 kms when using the older processing software (MCORR300), but positional accuracy decreases as baseline distance increases (see Figure 1);

b) Sub-meter results can be consistently achieved for baseline distances of up to 150 kms when using the more recent processing software (MCORR400) with no apparent decrease in positional accuracy as distances increase (see Figure 1);

c) No significant difference in results was detected between rover occupation times of 15, 30, 45 and 60 seconds (see Figure 2);

d) Including a second base station and computing a weighted (inverse of distance) mean of the rover coordinates determined from the two base stations improves the results and provides a check (not independent) on the final result (see Figure 1);

e) The more recent release of the processing software (MCORR400) significantly improves the positional accuracy of the resulting coordinates (see Figure 1);

f) It is impossible to process Trimble ProXL observations when the rover unit receives signals from a specific satellite which, due to obstructions, are not visible from the base station.

The implications of these conclusions for the design of a GPS-based cadastral surveying methodology can be summarized as follows:

a) The GPS technology tested can produce sub-meter results with very short occupation times (60 seconds or less), therefore offering significant efficiency advantages over traditional methods, provided this level of accuracy is acceptable;

b) A geodetic control network with a spacing of around 150 kms will be adequate for supporting a GPS-based cadastral surveying approach, thereby significantly reducing the need for control densification (with corresponding reductions in times and funds required for this task);

c) Property corner coordinates should be computed from at least two base stations, with the final solution being based on a weighted mean;

d) If the Trimble ProXL is used for the rover receiver, it is crucial that base stations be established in unobstructed locations so that all satellites visible at the rover receiver are also visible at the base station;

e) If improvements in processing software continue as they have done in the past two years, the GPS methodology described in this paper could soon be applicable in all cadastral environments in both developed and developing countries.

3. Cadastral Conditions in Albania and Belize

2.1 Cadastral Surveying in Albania

Unlike many other less developed countries, Albania has a dense network of geodetic control points (approximately 4 Km density) which in many instances are clearly demarcated by means of tall tripod signals. Provisional tests using GPS (MSI 1992) confirm that this network has been surveyed to a high degree of accuracy.

Albania is fortunate to have a relatively high number (estimated at around 300) of well educated surveyors who have graduated from the 5-year surveying program at the Polytechnic University of Tirana. There are also a number of survey technicians who have specialized in surveying at the Middle School level (equivalent to high school in the US). The number of people with these qualifications is estimated at 500. In previous years all surveying work was done through the government and there is no private sector surveying industry.

The substantial set of maps that currently exist in Albania, especially at larger scales (1:500 - 1:10,000), provides a valuable base of land information on which to build an effective cadastre. The cadastral surveying approach that is currently being followed is to enlarge the 1:5,000 base maps to a scale of 1:2,500. The individual land parcels are then mapped relative to topographic map features with the aid of taped field distances. Very few monuments are used to define parcel boundaries and for the most part small water furrows or crop lines are used to differentiate adjacent parcels. Further details on the cadastral environment in Albania are given in Barnes et al (1994), Barnes et al (1995) and Barnes et al (1996).

Perhaps the most challenging aspect of the Albanian situation is the minute size and fragmentation of land holdings. In many instances villagers (families) have been allocated between one to four parcels of land (up to seven parcels are allowed by law). These individual parcels may be several kilometers apart and involve agricultural land as well as pasture and land containing olive trees (defined in terms of the number of trees). From a surveying and mapping perspective this fragmentation presents a complex environment in which to identify cost-effective solutions.

2.2 Cadastral Surveying in Belize

Cadastral surveying in Belize is in the midst of a transition from a predominantly government service to one provided by small, private surveying firms. Recently an increasing number of public surveys (i.e. those on national land) have been contracted to private surveyors and in December, 1995, the Government of Belize (GOB) retrenched almost all surveyors in the six District Offices. In three District Offices there is no government surveying capability. In the other District Offices the only surveyor is the District Land Survey Officer. This means that future survey needs will depend almost entirely on the approximately 15 private registered surveyors and a slightly larger group of survey technicians.

The predominant technique currently used for cadastral surveying is traversing. Coordinate control for such traverses may be based on geodetic control stations, minor control stations, previously surveyed property corners (with coordinates), or coordinates of a topographic feature scaled off a 1/50,000 scale map. Although the Survey Regulations specifically forbid "swinging or hanging traverses unsupported by independent checks," this practice appears to be quite common. Main control traverses must close to within 1:10,000 accuracy and all other control traverses used for surveying rectilinear boundaries must close to within 1:5,000. Surveys of curvilinear boundaries (e.g. rivers) must be done to within plotting accuracy.

A review of the history of land in Belize reveals that backlogs in cadastral surveys of national land have on several occasions held up the move to a more complete land registration system (Rogers 1976). These backlogs have caused land to be allocated without the benefit of a survey, giving rise to confusion and tenure insecurity. In order to alleviate this problem, a new registration system was introduced in 1977 which was based on general boundary surveys. Graphic accuracy, defined as "2-3 feet at a scale of 1:2,500)," was required for such surveys. This system was only introduced in certain "declared areas," and even in those areas was not introduced in a systematic fashion. Due to the difficulty of using general boundaries (dense vegetation makes it impossible to identify physical property boundaries), and the long custom of using a fixed boundaries approach, surveyors have continued to use the same techniques both inside and outside declared areas. Once again, this more precise, but time consuming approach has led to a backlog in surveys.

This means that it is crucial that a more efficient method of cadastral surveying be implemented and that the standards, specification and procedures for cadastral surveying give a high priority to speed, cost and an accuracy level that does not jeopardize the effectiveness of the land registration system.

3. Field Tests

3.1 Albania

Field tests were carried out at sites where there was perceived to be a high demand for surveying and mapping to support land registration. Although the earlier focus of the USAID-funded Land Market Development Project had been on rural areas, it became apparent that in the near future the highest frequency of land transactions is likely to be in the urban fringe around the larger cities, particularly the capital, Tirana. As a result of these changing needs, field tests were conducted in both rural and urban areas (Barnes et al 1994).

Two field tests were carried out in the rural villages of Zhurje and Lumthi. Zhurje is located approximately 20 kilometers west of Tirana and is part of the ex-cooperative of Ndroq. This village was selected because it was currently in the process of being surveyed by traditional methods and a direct comparison of the GPS and traditional approaches could therefore be made. Zhurje is a typical example of non-mountainous farmland and had the further advantage of being easily accessible from Tirana. The average agricultural parcel size in the village is approximately 0.25 hectares. Lumthi is situated in the flat coastal plain of western Albania and was one of the first areas to be allocated to individual farmers and surveyed.

In Zhurje we were fortunate to have the services of both a village elder, who had been involved with the original allocation of individual parcels, and the surveyor who was undertaking the survey of the village. A total of 29 parcels were surveyed over a period of 4 hours and 35 minutes (excluding 40 minutes to set up the base station) using the GPS methodology described earlier. In Lumthi a total of 17 parcels were surveyed by GPS in 1 hour and 15 minutes, covering an area of 7.58 hectares (average parcel size of 0.4 hectares). In both cases a base station (geodetic) receiver was set up over an existing control point close to (within 2 kilometers) the test site, and a second base station on the roof of the Land Research Institute office in Tirana was also operated.

Urban field tests were undertaken in Selita, Priest Hill and Kamza, all located in the urban fringe of Tirana just outside the "yellow line" which designates the urban boundary of Tirana. Generally, these sites consisted of a mix of old buildings, recently completed buildings, and houses in different stages of construction. The only boundaries that could be construed as property boundaries were the walls built around several of the houses. The corners of these walls, houses, road centerlines, power poles and concrete bunkers were surveyed using GPS. A total of 20 houses and 153 planimetric features were surveyed in all three areas in just under 8 1/2 hours of field observation.

The results of the field tests were very encouraging and showed that this methodology can be employed very effectively. While not much data has been systematically collected on the productivity of the traditional tape and base map approach under different conditions in Albania, we were able to obtain general figures from the managers of this work. When compared with the productivity of the GPS field tests, the GPS methodology was estimated to be 8 times faster in the field and almost 10 times faster in the office. Since our GPS work was done in an experimental mode, and did not include such time consuming tasks as boundary adjudication, one can only draw the general conclusions that the GPS methodology has the potential for

3.2 Belize

In Belize a pilot test area was selected in and around the village of More Tomorrow, situated approximately 9 miles north of the main highway that joins Belize City to the capital, Belmopan. The test area (see Figure 4) comprised seven rural parcels and six small village parcels, with a curvilinear boundary (Belize River) running between these parcels and providing the southern boundary of all rural parcels. The size of the rural parcels varied from 6.5 - 35.2 hectares and the urban from 2000 - 7500 square meters.

The rural parcels were in the process of being surveyed by government surveyors and they had opened lines between the points. However, access to the corners of the rural parcels proved to be quite difficult and in general this site was more challenging than the Albanian test sites. Several of the points were situated under thick vegetation with only partial visibility to the sky. A limited amount of additional cutting was carried out at some points in order to gain access to sufficient satellites.

Base station receivers (Trimble Community Base Stations) were set up at two control points, one on top of the Department of Lands and Surveys building in Belmopan and the other on the Department of Fisheries building in Belize City. The coordinates of these two points had been determined previously in the geodetic surveying phase of the project (see Greening 1996). Two ProXL rover receivers were used to occupy the parcel corners at the test site. Most of the data acquisition was done by members of the Belizean survey team after a very short demonstration and coaching session.

3.3 Problems and Lessons

Several problems were experienced in this test, all of which proved extremely informative in designing procedures for cadastral surveying in this kind of environment.

(i) A full day of observations were lost when battery power to the data collector failed.
(Lesson: download the GPS data as soon as possible, preferably onto a laptop at the end of the day's work)

(ii) An electric power outage at one of the base stations resulted in the loss of 90 minutes of reference data
(Lesson: Operate at least three base stations or ensure that power is constant through the use of an uninterruptable power supply unit)

(iii) On two occasions the rodman operating the data collector did not push the correct button to terminate data collection at a point, with the result that several additional points were collected as he walked away from the point. This "trailing" clearly degrades the accuracy of the mean point position.
(Lesson: It is advisable to occupy all points twice - double occupancy - in order to detect any points affected by "trailing")

(iv) The receiver was configured to accept 2-D solutions in cases where there were insufficient satellites visible for a 3-D solution. The resulting positions proved to be very unstable, especially when moving from a 2-D to a 3-D solution and vice versa, resulting in positional shifts of up to 7 meters.
(Lesson: Rover receiver should be configured to accept 3-D only solutions)

(v) While crossing the Belize River during a reconnaissance of the pilot area, the dugout canoe carrying part of the survey team overturned, dowsing the rover receiver and personnel. The receiver was subsequently inoperable for a day until it dried out. (Lesson: these rover receivers are not waterproof!)

4. Standards and Specifications

4.1 Defining a Standard

In defining a standard, it is extremely important to begin with a clear understanding of the needs and requirements of cadastral surveying and mapping in a particular country. The design criteria listed at the outset of this paper were constantly deferred to in the formulation of the standard, specifications and procedures for GPS-based cadastral surveying.

Defining a standard became a challenge of determining what accuracy was appropriate given the need for low costs, greater efficiency, simplicity and appropriateness. The cadastral surveying profession in many countries has adopted accuracy standards which were based primarily on what the equipment could deliver. A secondary role was given to assessing the accuracy actually required or affordable by the end-user. As a result, cadastral surveying in these countries has required unrealistically high accuracy levels and has become unaffordable, particularly by the poorer sectors of the population. In many instances the cost of surveying a small piece of land is higher than the value of the land itself. This issue has already been addressed in Belize in the context of land registration with the requirement of graphic accuracy surveys to support land registered in terms of the Registered Land Act of 1977.

In addressing the question of whether or not graphic or meter-level accuracy would suffice for cadastral surveys, it is essential to refocus on the purpose of coordinate information. Coordinate information on property corners serves three major purposes, namely:

- to relocate the physical monument that demarcates the corner position
- to replace a missing corner monument in the event that it has disappeared
- to describe the land parcel (usually graphically) for transaction purposes

These may be regarded as the relocation, replacement, and description functions of a coordinate.

The accuracy required to support the replacement and description functions will depend on several factors, including the parcel size, land value, land capability and relationship between neighbors. The standard, specifications and procedures developed here aimed at small to medium sized parcels in rural areas. Typically, these parcels are on the low end of the land value and capability continuums. An accuracy of less than 1 meter was regarded as appropriate when considering size, value, capability and other factors in rural Belize. In Albania it was regarded as adequate for defining blocks of parcels, particularly in areas where there are no base maps.

Perhaps the most important factor to consider with respect to accuracy is that in most cadastral systems the monument is the most important indicator of the corner position and the coordinates and other survey measurements are merely a means of perpetuating that position. The coordinate, and other measurement data, is therefore of secondary importance in defining the location of a parcel corner. If the coordinate allows a surveyor to relocate the physical monument, it has fulfilled its replacement function. In the Albanian context, this means that serious consideration must be given to physical monumentation where there are no clearly identifiable general boundary features (e.g. water canals).

Based on the accuracy required to fulfill the relocation, replacement and description functions, a positional accuracy of less than 1 meter was accepted as being appropriate for small to medium sized rural parcels in Belize, and for blocks of rural parcels in Albania. Since the reference datum adopted for a coordinate system affects accuracy (see Greening 1996 for more details), it must be incorporated in the standard statement. The standard can therefore be expressed as follows:

THE ABSOLUTE POSITION OF A PROPERTY CORNER IN RURAL AREAS SHALL BE DETERMINED TO WITHIN ONE METER (<1 METER) OF THE TRUE VALUE ON THE ITRF94 (EPOCH OF 1996.0) DATUM.

4.2 Specifications

In order to meet the standard for cadastral surveying as stated above, certain specifications with respect to equipment, measurement tolerances, field survey, and office computations must be followed. These are summarized in Table 1.

5. Procedures for GPS-based Cadastral Surveys

5.1 Calibration of GPS Unit

(a) Calibration Network:

A calibration network, consisting of 10 or more points, should be established to enable government and private surveyors to calibrate their GPS units (receivers, antennae, firmware and software) by providing a set of accessible points with accurately known coordinates. This provides the basis for a standard test that can be applied to all GPS receivers. This kind of test will become increasingly important as private surveyors embrace GPS technology and the GPS market expands. In Belize a network of ten monumented points was established in Belmopan in the vicinity of the Department of Lands and Surveys.

(b) Calibration Requirements:

All GPS units (including receivers, antennae, firmware and software) used for cadastral surveying must meet the specified accuracy standards. Therefore, prior to any cadastral fieldwork with a particular GPS unit, it must be calibrated against the calibration network. Further calibration of a receiver is required when:

- processing software is changed (new version)
- firmware is changed (new version)
- different antenna type is to be used with the receiver

Results of the calibration tests should be submitted to the Department of Lands and Surveys, or appropriate government department, which will certify the GPS receiver and maintain a record of all certified receivers.

(c) Calibration Tests

The process for calibrating the GPS unit is summarized in Figure 3. The first two calibration tests focus on evaluating the precision of the GPS unit. These tests are termed the "multiple baseline test" and the "multiple occupancy test." In the multiple baseline test coordinates corrected relative to BS1 and BS2 are compared. The coordinate differences should be less than 1 meter in all cases. In the multiple occupancy test the coordinates of each point determined at different occupation times are compared. The coordinate differences should be less than 1.4 meters in all cases. The test for systematic error (bias) involves comparing the mean coordinate values from all occupations with the known calibration values. These mean values should fall within 1 meter of the known position

5.2 Office Planning and Preparation

Office planning and preparation should include identifying which two base stations will be used for differential correction and, if necessary, notifying the managers of the base station of the observation dates and times. Once several base stations are operating on a regular schedule (e.g. 6:00 am- 7:00pm), this notification will no longer be necessary.

Our proposed field procedure calls for the occupation of two known control points at the start of the project (pre-survey control check) and again at the end of the project (post-survey control check). In Belize a pair of control these control points were established at every district capital. The coordinates of these points must be known relative to the International Terrestrial Reference Frame (ITRF) and not simply in relation to the local datum. The coordinates for these points, as well as any other relevant cadastral data from previous surveys should be acquired prior to any fieldwork.

Achieving the standard required for rural cadastral surveys with GPS is only possible under specific operational conditions. Parameters such as logging interval, elevation mask, PDOP mask, and SNR (Signal to Noise Ratio) mask should be configured in the rover receiver prior to measurement. The specified values for these are included in the specifications listed in Table 1. It is particularly important to set the rover masks (elevation, PDOP, and SNR masks) so that they are more restrictive in the rover receiver. This is to insure that the rover receiver does not track a satellite that is not being tracked by the base receiver.

While occupying a parcel corner or some other feature, attribute data such as the point name and description should be acquired. The GPS processing software generally enables a user to create a data dictionary which provides a structure for the data collection process. Each dictionary consists of a list of features, a list of attributes for each feature, and values for each attribute. Once the data dictionary has been created, it is uploaded from the computer to the datalogger for subsequent use in the field.

5.3 Field Procedures

A thorough reconnaissance is an essential part of any cadastral survey, but this is especially true for GPS surveying. The area to be mapped must be identified and the parcels drawn in a field sketch to facilitate the systematic identification of all parcel corners. These procedures enable the measurement process to be optimized and the results to be organized in a logical fashion.

The GPS methodology described here utilizes a technique know as 'Differential Pseudo-Range Positioning'. A minimum of three GPS receivers, two base and one rover, are required for this technique. The strategy in Belize is to develop a system of six base stations located at the five District Lands and Survey (DL&S) Offices and the central office in the capital. The central office will disseminate the reference data to surveyors as needed. Individual surveyors would therefore only require a relatively inexpensive rover unit to carry out cadastral surveys using GPS.

Before proceeding to the survey site, the surveyor should occupy two known control points. This provides a general check that the GPS receiver as configured is delivering the required accuracy (sub-meter). Once survey points or monuments have been identified (this may be part of an adjudication exercise), they should be occupied for at least 60 seconds resulting in 12 positions (at 5 second intervals). All points should be reoccupied at least one hour after the first occupation as an independent check on the coordinates. A fieldbook should be kept to record the names and order of the points visited, unusual circumstances (e.g. difficulties in obtaining a 3-D fix due to obstructions), potential multipathing situations, a graphic plan of the parcel layout with associated corner identifiers, dates, times, etc.

At the end of the surveying project, the pair of known control points should be reoccupied to check that the receiver is still delivering the required accuracy.

5.4 Post-Processing

(a) Backing up Field Data:

At the end of each day in the field the rover data should be downloaded to a personal computer and archived on a removable diskette prior to any processing. This ensures that a back-up copy of all raw data is maintained in case the data becomes corrupted in the post-processing stage.

(b) Acquisition of Base Station Data:

Differential data should be acquired from the two base stations identified earlier, preferably those closest to the area of survey. How the dissemination of this data to private surveyors is carried out will depend on the available channels. Only in rare instances can this be done in developing countries via such sophisticated mechanisms as the InterNet or satellite. Modem transfer may be viable in countries with a reliable telephone system. A more workable solution in most developing countries is to make the data available on diskette, perhaps from a centralized office to which local base station offices send their data on a weekly basis.

(c) Differential Correction:

Once data from the data collector has been backed up and base data acquired, the rover data can be differentially corrected. It is extremely important to ensure that the reference coordinates, coordinate system and datum of the reference base station are correctly set in the processing software. All processing should be done in the GPS datum (ITRF94 or WGS84). This means that the reference coordinates for the base stations must be relative to ITRF94 or WGS84 and the reference elevation should be a height above the ellipsoid (not above mean sea level).

Differential correction essentially involves the determination of corrections (in X,Y,Z) by comparing the pseudorange position of the base station point with its known position. These corrections are then applied to all pseudorange positions determined at the rover receiver location. This effectively removes pseudorange errors (due to clock, orbital, atmospheric and selective availability errors) from the rover positions. It is only through such differential correction that sub-meter accuracies can be achieved.

(d) Export GPS Data to Spreadsheet:

Most post-processing software handles data in its own format. In order to use other software on the data, it is necessary to convert the differentially corrected positions and the attribute data to a format that conforms with that software. The data should be converted to an ASCII format so that it can be imported into a spreadsheet program (e.g. Quattro Pro). Spreadsheets are ideal for managing the data and manipulating it for the quality control tests described below. Most GPS processing software provides a capability to export data files in a number of different GIS formats, including ASCII and DXF.

(e) Multiple Base Station Test:

Coordinates for all occupied points must be determined from at least two base stations. This will produce at least two sets of differentially corrected data (termed set BS1 and set BS2). Each corresponding point in set BS1 and set BS2 is compared and tested against the specified tolerance (<1 meter). If the point passes the multiple base station test, the mean of each corresponding point is computed. If any point fails the multiple baseline test (i.e. differs by more than 1 meter in position), it should be reoccupied.

(f) Multiple Occupation Test:

The high correlation implicit in the dual baseline test (observations are taken at exactly the same time so atmosphere and satellite configuration are the same) means that additional, more independent tests need to be included in the cadastral survey quality control. For this reason, all points are required to be occupied at least twice with a minimum of 1 hour separating occupations. In the multiple occupation test the difference in the position of each point from one occupation to the next is compared. The differences should be within 1.4 meters. If all points pass the test, the mean position for each point is computed. If any point fails the multiple occupation test (i.e. differs by more than 1.4 meters in position), it should be reoccupied.

(g) Computation of Final Coordinates and Export to AutoCad:

Once a point has passed both the multiple baseline and multiple occupation test, the mean coordinates from all occupations of that particular point are computed and regarded as final. In order to present the GPS data in a graphical form and compute parcel dimensions and areas from the GPS coordinates, the data should be exported to a software package such as AutoCad. This will typically require a conversion of the data from an ASCII to a DXF format. This conversion can be done using Surveying software or AutoCad add-on software.

(h) Presentation of Survey:

The presentation of the results of a survey is extremely important as the survey records provide the historical evidence that is crucial to all subsequent surveys. In a resurvey of a parcel, cadastral surveyors usually abide by the principle of "following in the footsteps of the original surveyor." The survey records provide these footsteps for future surveyors and future surveys. If these records are submitted and maintained in an organized and structured manner, it will facilitate their subsequent use by other surveyors.

We propose that the survey records be composed of the following components:

- Report
- Field Notes
- Computations
- Cadastral Plan

Details of the proposed components of each of these documents are given in Greening and Barnes (1996).

(i) Quality Control Procedures:

In addition to any other existing procedures, surveys done by means of GPS should be checked for compliance with the specified tolerance for multiple base station test,
with the specified tolerance for multiple occupation test, and with specified tolerances for the pre- and post-survey checks.

6. Conclusions

The methodology described in this paper has been field tested in two extremely different environments and a standard, specifications and procedures developed for its implementation. In our research we have not discovered any other such procedures, although GPS-based cadastral surveying is being implemented on an experimental basis in several different countries (see Jones and Abidin 1996, for example). A recent Circular from the Surveyor-General of Victoria (Australia) stated that "at the time of writing there are no accepted procedures to determine the legal traceability of GPS to the standard of measurement of length." (State of Victoria 1995) The concern appears to be the problem of calibrating a GPS unit. The procedures for both calibration and field checks which we have proposed offer a solution which we feel offers legal traceability and quality control checks. Once again, it is important to remember that the coordinate values are merely evidence as to the "legal" position indicated by the original physical monument.

One of the shortcomings of the proposed GPS methodology is that it cannot easily be used for setting out new points at predefined locations. This may be overcome by using a real-time approach. However, the resulting trade-off is that broadcast constraints would limit the baseline distances to 20-40 kilometers. Since in most developing countries the demand is primarily to survey existing informal parcels, setting out was not perceived to be of secondary importance.

Greater accuracies can be achieved by using carrier phase receivers, but this generally means an increase in the receiver cost (vs code receivers), longer occupation times, and greater complexity in field operations. Tests in Indonesia reported serious problems with integer ambiguity and the need for initialization periods of up to 30 minutes (Jones and Abidin 1996).

We believe the proposed methodology meets the design criteria (speed, low cost, appropriate technology, realistic accuracy, simple field operation) listed at the start of this paper. It therefore offers a very viable alternative to cadastral surveying approaches, such as aerial photography or total station techniques, typically adopted in large scale land administration, titling and registration projects.

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TABLE 1. Specifications for GPS-Based Cadastral Surveying

COMPONENT	**CRITERION**
Equipment:	
1. GPS receiver, antenna, firmware and software	=> Must satisfy standard by passing calibration test
2. Base Receiver Configuration	
• PDOP mask	=> 6
• elevation mask	=> 10 degrees
• SNR mask	=> 6
• logging interval	=> 5 secs
• minimum no of satellites	=> 4 (3D solution)
• time interval of individual base files	=> 1 hour
3. Rover Receiver Configuration	
• PDOP mask	=> 4 or 6 (depending on vegetation)
• elevation mask	=> 15 degrees
• SNR mask	=> 6
• logging interval	=> 5 secs
• minimum no of satellites	=> 4 (3D solution)
• minimum no of positions per occupation	=> 12

TABLE 1 (Continued)

Calibration Test:	
1. Calibration Network	=> At least ten calibration points must be used for calibration
2. Field Procedure	=> All ten points must be occupied in 3 consecutive circuits in the morning and in 3 additional circuits in the afternoon
3. Verification of Precision	=> Positions for all occupations must be computed with respect to two base stations (excluding closest base station => Difference in positions processed from two (min.) baselines must be <1 meter => Difference in positions from two or more occupations must be <1.4 meters
4. Test for Systematic Error (bias)	=> Mean position of each calibration point from two baselines and six occupations must be <1 meter different from known positions
Field Survey:	
1. Pre- and Post-Survey Checks	=> At least two control points must be occupied
2. Multiple Occupation Test	=> At least I hour must be allowed between occupations => Every point must be occupied at least twice
Office Computations:	
1. Differential Correction	=> At least two base stations must be used
2. Reference Coordinates	=> Entered to 0.001" if Latitude and Longitude or to 0.01m if Easting and Northing => Referenced to WGS84 or ITRF94 & GRS80 => Height above ellipsoid (GRS80)
3. Reference Elevation	=> Entered to 0.1m
Tolerances:	
1. Pre-Survey Control Check	Processed position (mean) must be <1 meter from known position
2. Post-Survey Control Check	Processed position (mean) must be <1 meter from known position
3. Multiple Baseline Test	Difference in positions processed from two (min.) baselines must be <1 meter
4. Multiple Occupation Test	Difference in positions from two or more occupations must be <1.4 meters