10 Experience in Application of Hand-held GPS in Projects in Ethiopia

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1. Background

The objective of this paper is to evaluate the relevance of the use of hand-held GPS for cadastral purpose or, to know if hand-held GPS are accurate enough for cadastral mapping. The first step is therefore to estimate what the minimum requested accuracy level for cadastral surveying purpose should be.

The first section of this paper introduces few facts about the GPS technology and its accuracy. The second part describes more precisely the hand-held GPS instrument based both on our own experience as professional land surveyors and on measurements conducted for this particular assignment. Based on the findings, a brief discussion is outlined to determine whether the use of hand-held GPS is suitable for a cadastral survey, and if not, which other means could be proposed as an alternative.

Based on our experience both in Europe and Ethiopia, existing cadastral maps are not always very accurate. This is mainly due to the fact that a cadastral work is often a mix of different maps, such as title deed, cadastral map, master plan, etc., all prepared at different times with different accuracies. The result is that when one has to reconcile these documents, for a land sale or new land division for instance, adjustment is always necessary. In our opinion, such discrepancies should always be less than one meter. Indeed, beyond that figure, conflicts can be such that the buyer and seller might not be in a position to reach to a mutual and fair agreement. Additionally, cumulative errors of that range, on adjacent plots, will considerably affect the quality of the general cadastral map, finally making it completely inadequate. Consequently, a measurement method that will not afford at least better than one-meter accuracy, should not be considered as relevant in a cadastral survey.

2. GPS Is a Satellite Navigation System

GPS is funded by and controlled by the U. S. Department of Defense (DOD). While there are many thousands of civil users of GPS world-wide, the system was designed for and is operated by the U. S. military. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position and velocity.

2.1 Space Segment

The Space Segment of the system consists of the GPS satellites. These space vehicles (SVs) send radio signals from space. The nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours (See Fig.1).

Fig. 1 Satellites that orbit the earth.

The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day). There are six orbital planes, with nominally four SVs in each, equally spaced. This constellation provides the user with between five and eight SVs visible from any point on the Earth.

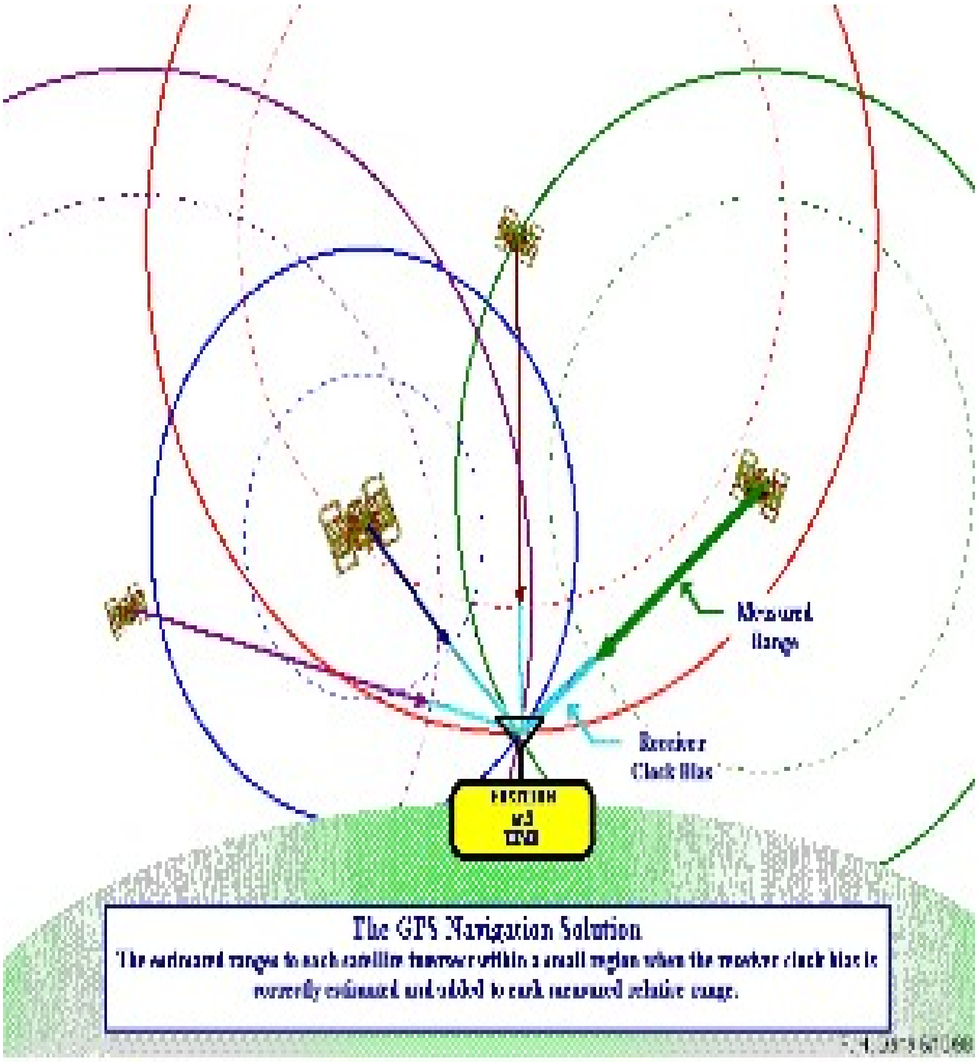
2.2 Control Segment

The Control Segment consists of a system of tracking stations located around the world with the Master Control facility located in Colorado (US). These monitor stations measure signals from the SVs and compute precise orbital data (ephemeris) and SV clock corrections for each satellite. Uploads of ephemeris and clock data to the SVs are made each hour. The SVs then send these data to GPS receivers over radio signals.

2.3 User Segment

The GPS User Segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity, and time estimates. Four satellites are required to compute the four dimensions of X, Y, Z (position) and Time. The correct location will be at the intersection of the four spheres centered on each satellite (see Fig. 2)

Fig. 2. GPS receivers.



GPS receivers are used for navigation, positioning, time dissemination, and other research. Navigation in three dimensions is the primary function of GPS. Navigation receivers are made for aircraft, ships, ground vehicles, and for hand-carrying by individuals. Precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning data for remote receivers. Examples include, surveying, geodetic control, and plate tectonic studies.

2.4 Predictable Accuracy

- 22 meter Horizontal accuracy
- 27.7 meter vertical accuracy

2.5 Receiver Position

Position in XYZ is converted within the receiver to geodetic latitude, longitude and height above the ellipsoid. Latitude and longitude are usually provided in the geodetic datum on which GPS is based (WGS-84). Receivers can often be set to convert to other user-required datums, here in Ethiopia Adidan Datum. Position offsets of hundreds of meters can result from using the wrong datum.

2.6 Receiver Cost

Receiver costs vary depending on capabilities. Small hand-held GPS receivers can be purchased for less than $200, most can accept differential corrections. Receivers that can act as DGPS reference receivers and carrier phase tracking receivers (RTK) cost more (i.e., $2000-15000).

3. Hand-held GPS

3.1 Topographical survey

- Land surveyors use hand-held GPS for the following purpose: It is a great help to find reference points that have no other triangulation data, such as distance and bearing from a known object. These reference points might be National Beacons, provided by the Mapping agency, as well as local Beacons, established at the time of the study.
- It helps also very much for X-section survey to define designed alignment (for instance, new road project or irrigation channel) on the ground. Indeed, this type of work was usually done by a separate crew constituted of one or two skilled persons, using traditional instruments, like compass and wooden sticks. Based on hand-held GPS, the survey crew, without any additional manpower input, can perform an even better job with speed.

3.2 Tentative Test on Accuracy of Hand-held GPS

To generate primary database, a field test has been undertaken for more than two weeks. Measurements were taken using hand-held GPS (Garmin 12) at the same location with known location. True location of the point is:

- East = 479,130.024 m
- North = 997,280.680 m
- Elevation = 2,427.159 m.

A total of 15 GPS measurements with at least five tracked satellites was taken.

Table 1. Hand-held GPS readings (taken from 3 February to 17, 2006)

Date	Time	East (m)	North (m)	Elevation (m)	Deviation from the average (m)		
Feb 3	12:00 am	479132	997280	2436	2	2	1
Feb 4	6:00 pm	479134	997282	2437	0	0	2
Feb 5	6:00 pm	479134	997284	2433	0	2	2
Feb 6	12:00 am	479132	997280	2436	2	2	1
Feb 7	12:00 am	479133	997282	2433	1	0	2
Feb 8	6:00 pm	479134	997281	2436	0	1	1
Feb 9	12:00 am	479132	997280	2433	2	2	2
Feb 10	6:00 pm	479133	997280	2436	1	2	1
Feb 11	12:00 am	479137	997284	2433	3	2	2
Feb 12	6:00 pm	479133	997282	2433	1	0	2
Feb 13	6:00 pm	479139	997281	2438	5	1	3
Feb 14	12:00 am	479133	997284	2437	1	2	2
Feb 15	6:00 pm	479140	997284	2436	6	2	1
Feb 16	12:00 pm	479133	997282	2433	1	0	2
Feb 17	6:00 pm	479133	997281	2438	1	1	3
					Standard deviation (m)		
					2	1	2
	Average	479134	997282	2435			
	True value	479130	997281	2427			
	Difference (m)	-4	-1	-8			

As shown in table 1, the accuracy is better than the one commonly given, which is around 20 meters for both plane and vertical data. Indeed, the average of our measurements is less than five meters far from the true plane values and less than 10 meters far from the true vertical value. It is also important to note that the standard deviation is small and shows coherent and homogeneous results during the two weeks measurement. Even the two highlighted figures, showing the highest differences from one single measurement to the average measurement, do not exceed 10 meters.

The above results confirm, more or less, our general opinion about hand-held GPS accuracy, i.e., 5 - 10 meters. However, even if such accuracy is sufficient for the kind of survey work described in the above, it does not reach the minimum requirement specified in the first introduction paragraph, i.e., less than one meter.

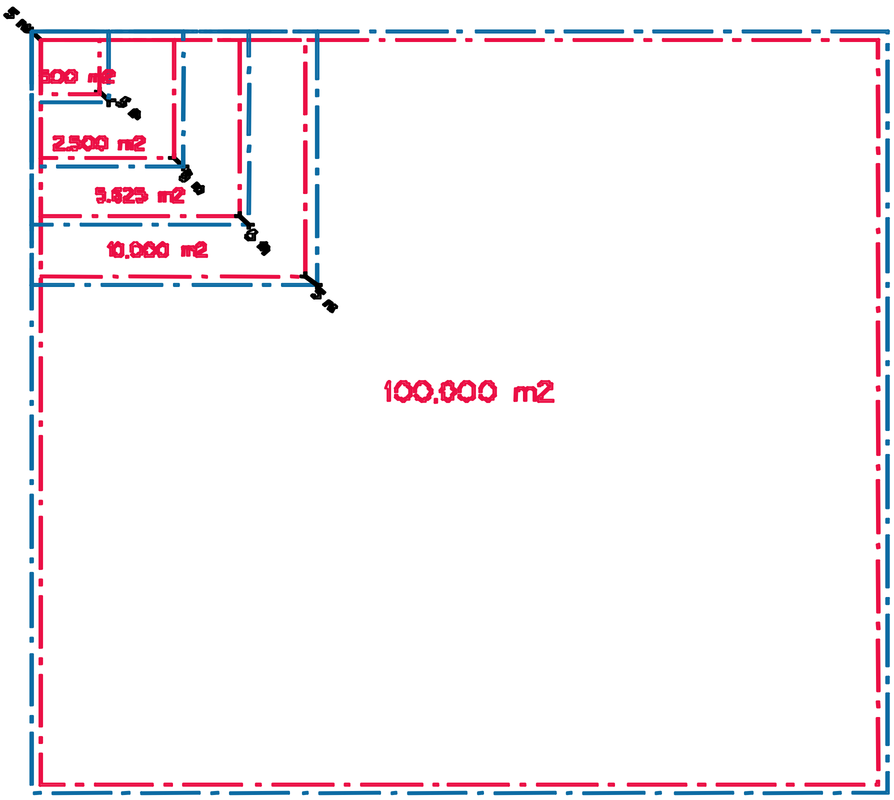
The following example will show how surface calculation is affected with a five meter error on the determination of each corner plot. We have considered different plots with size ranging from 500 m^2 (1/20th of 1 ha) to 100,000 m^2 (10 ha). The schema of the plot sizes is shown in table 2.

Table 2. Error involved in area estimation of different plot sizes

Plot	True surface (m^2)	Hand-held GPS surface (m^2)	Error (%)
P1	500	866	42
P2	2,500	3,257	23
P3	5,625	6,735	16
P4	10,000	11,464	13
P5	100,000	104,517	4

The second column of table 2 shows the true surface area of these plots, while the third column shows the surface measured using hand-held GPS with a given error of 5m (see Fig. 3 below). The fourth column expressing the error in percentage on the surface calculation, compared to the actual size of each plot.

Fig. 3. Surface measured using hand-held GPS.



Errors with more than 40% are observed on plots with less than 500 m^2, of land. This clearly demonstrates that such kind of measurement is not acceptable for cadastral purposes.

4. Differential GPS Measurements

4.1 General Definition

As explained above, neither the accuracy of 20 meters (given one) nor the accuracy of five meters (tested one) is acceptable for many applications, cadastral one for instance. Fortunately, a method, call it differential measurement, has been developed to reduce errors and enhance the accuracy. That method takes the advantage that the errors due to the satellite clock, the satellite orbit, the ionosphere, the troposphere affect receivers, not too far from each other, the same way and with the same magnitude. If the exact location of one receiver is known, that information could be used to calculate errors in the measurement of that location and then these errors (or correction values) could be reported to the other receivers so as to compensate their measurements. The differential mode will thus remove most errors involved in enhancing the accuracy.

Historically, the differential mode with code phase (the less accurate phase broadcasted by the satellite) has been called **DGPS,** and with carrier phase (the most accurate phase broadcasted by the satellite) called ***Stop&Go*** and ***Real-Time Kinematic (RTK)***.

4.2 DGPS

In many countries, for example in the USA or in the EU, DGPS can be operated with simple hand-held GPS to reach accuracy generally better than one meter. Indeed, these regions are covered by both ground base stations, with some 100 km range, and by additional satellites (EGNOS for Europe and WAAS for North America) that will, in real time, correct the GPS errors. *Since neither EGNOS nor WAAS systems are reaching Africa and because there is no ground base station that exists here, there is no way to perform DGPS measurement here in Ethiopia.*

4.3 Stop&Go and RTK

Here, accuracy better than one centimeter can be reached. Nevertheless,

- It needs at least one known reference point on the ground (from a national mapping authority, for instance);
- The range is limited to a few km, less than 10;
- Equipment cost is drastically higher;
- Nearby obstacles such as trees and buildings will often not allow measurement;
- Computer post-processing is needed for the Stop&Go method;
- Skilled operators are required for both field surveys and office computation.

5. Conclusions and Recommendations

- Even where DGPS technology is available, hand-held GPS should be used only for rural cadastral purpose and never considered accurate enough for urban cadastral tasks.

- RTK technology is widely used for any survey purpose, including cadastral mapping, all over the world.
- To implement RTK survey, the first step will be to establish a grid of reference points, with a density of one reference each 50 $km^{2.}$ This is an ideal density where all features are in a range to be surveyed using RTK Technology. But it is to be noted that the GPS equipment suitable for RTK is also appropriate to perform Static GPS Measurement. Therefore, even if the Reference Point is further than 10 km from the field to be surveyed, it is possible to establish a temporary Reference Point in the vicinity of the proposed site to be surveyed. As a Static GPS measurement can afford a centimeter's accuracy within a range of 30 km, the density of the primary Reference Points could be one for every 1,000 $km^{2.}$
- The cost of that canvas of reference points might be shared with other agencies, such as a national mapping authority, as it could be useful for any other topographical survey.

Even if RTK measurement is much more precise, secure and faster than any other measurement performed with optical instrument, like Total Station, part of the work, especially in urban areas will have to be done using optical means because of obstacles.