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Consistency of GPS Handheld Navigator and Total Station for Producing Cartographic Maps

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Abstract

Global Positioning System (GPS) has been used to establish national geodetic control networks, to measure inter-plate tectonic movement, for mapping and GIS data collection, for construction site setting out and for cadastral boundary demarcation. In this study GPS handheld navigator is used to produce a cartographic map for relatively a big area by using GPS point positioning method in order to reduce efforts, time and cost.

The obtained accuracy from using GPS personal navigator is in order of 3-5m. GPS point positioning method provides an excellent way for producing cartographic maps of scale 1:25000 or smaller. Moreover, in urban area intermingled with buildings, over 95% of the observations on cadastral property boundary and corners surveyed have good correspondences with the results obtained by total station technique.

Keyword: GPS handheld navigator; cartographic maps;

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1. Introduction

Surveying and navigation methods have undergone a revolutionary change over the last twelve years with the progressive deployment of the Global Positioning System (GPS) navigation satellites. The GPS is a collection of satellites owned by the U.S. Government that provides highly accurate, worldwide positioning and navigation information, 24 hours a day. GPS works in any weather conditions, anywhere in the world, it is made up of more than thirty-three NAVSTAR GPS satellites, which orbit 20,200 km above the Earth, constantly transmitting the precise time and their position in space [1].

GPS has become the preferred positioning technology for geodetic control and mapping surveys. However, for a number of reasons, including the high capital cost of the technology and its comparatively low productivity, GPS has not been generally used for engineering surveys. Hence it has not been a familiar surveying technology for private, professional surveyors. However, over the last few years manufactures have been overcome those GPS technology constraints that were considered to be unnecessarily restrictive for engineering surveying. Present state-of-the-art GPS systems are:

- Able to be used even when the receiver is moving.
- Require comparatively short observation times.
- Capable of real-time operation through the provision of a communication link between two GPS receivers.
- Capable of producing cartographic maps by comparatively short time.

GPS uses triangulation of electromagnetic signals from the satellite to determine locations on the Earth. Distances from GPS satellites can be determined by using the travel time of a radio message from at least 3 or 4 satellites to the receiver. GPS satellites have four highly accurate atomic clocks on board. They also have a database of the current and expected positions for all of the satellites that are frequently updated from Earth. When a GPS receiver locates one satellite, it can download all satellite location information, and find the remaining needed satellites much more quickly [2, 3].

2. Cartography and Digital Mapping Technology.

Cartography is the art and science of drawing maps and plans for large, intermediate and small scales graphics, which portray the detail (for example, topography, surface features, boundaries, etc.) by using symbols, colors, variable lines, dots, etc. [4].

Digital mapping applications to engineering surveys began in the early 1970s. At that time, the use of these techniques was confined to few large organizations which had the financial resources available to meet the cost of acquiring and operating the very expensive computer hardware and associated peripherals. Also, it had volume of work to justify and realize the benefits of the very large capital investment required. Since then, both the technology and the methodology have developed space. The number of organizations employing digital mapping methods was increased as a result of the dramatic reduction in cost and the increased computational power of the new technology [5].

In 1988, with the availability of inexpensive microcomputers, powerful graphics workstations and the widespread knowledge for using these devices in a fairly sophisticated manner, there are few organizations engaged in survey work for engineering purposes which do not employ computer-based methods of processing the survey data and delivering it to the client in graphic or digital form [5].

The reasons for adopting digital mapping techniques vary widely from one Organization to another, but there are certain objectives which are shared. The first is to speed up the process of map production in order to shorten the period between the initial data collection in the field or in the photogrammetric machine, and the availability of the resulting map in digital or hard copy form for use by engineers, architects or planners. Another declared objective for adopting digital techniques is the reduction in the cost of map and plan production. In practice, this has been very much harder to achieve than the increased speed of map production, especially if high accuracy is required. Furthermore, highly trained specialist personnel capable of operating, programming and maintaining the equipment need to be acquired and retained within the surveying or engineering organization [6].

Closely associated with these considerations is the desire to reduce or even eliminate much of the tedious yet demanding cartographic work, such as compilation, drafting, scribing, mask-cutting, lettering and symbol generation and placement, which requires highly skilled personnel who are often difficult to find. It is obvious that cartography technology and digital mapping techniques are now established in a wide range of surveying and mapping organizations. Closely linked to these developments are those concerned with the Global Positioning System GPS.

3- Map production using Global Positioning System (GPS)

The GPS is a collection of satellites owned by the U.S. government that provides highly accurate, worldwide positioning and navigation information, 24 hours a day. It is made up now of more than thirty-three NAVSTAR GPS satellites, which orbit 20,200km above the Earth, constantly transmitting the precise time and their position in space. GPS receivers on (or near) the earth's surface collect the information from three to twelve satellite to determine the precise location of the receiver [4]. GPS satellite has four highly accurate atomic clocks on board. They also have a database of the current and expected positions for all of the satellites that are frequently updated from earth. Accordingly, when a GPS receiver locates one satellite, it can download all satellite location information, and find the remaining needed satellite much more quickly [2, 3].

The use of GPS is now being adopted and used by the surveying profession. Traditionally, GPS has been used for high precision geodetic survey, but increasingly it is being used for cadastral surveys. GPS has recently become an important survey and mapping tool to supplement and, in many cases, replace conventional techniques because of its accuracy, efficiency and cost effectiveness [7].

The satellite coordinates as given in the broadcast ephemeris refer to the World Geodetic System of 1984 (WGS 84) reference system. Therefore, a GPS user who employs the broadcast ephemeris in the adjustment process will obtain his coordinates in the WGS 84 system also. Some agencies provide the precise ephemeris in various formats such as, the International Terrestrial Reference System (ITRS) and the North American Datum of 1983 (NAD 83) formats.

If the available reference (base) station coordinates are in NAD 83 rather than in WGS 84 then, their origins will be shifted by more than 2m with respect to each other [1]. This shift causes a discrepancy in the absolute coordinates of points when expressed in both reference systems. The largest coordinate difference is in the height component (about 0.5m). The improved WGS 84 and the NAD 83 systems are compatible.

4- Practical study

The proposed research aimed for introducing outline recommended procedures for set up cartographic surveys from survey data files obtained with GPS method with good availability and reasonable accuracy. The objectives of the proposed research are as follows:

- Planning a GPS cartographic survey and finding appropriate solutions for some problems facing the GPS observables.
- Testing of GPS equipment, quality assurance and verification procedures.
- Deduction of transformation parameters to transform the coordinates from WGS84 to local datum and vice versa.

Then, the main goal of this research is to propose a feasibility study on the issues related with introducing a cartographic map using handheld GPS receiver for relatively a big area.

There are previous studies based on GPS dual-frequency receivers to define coordinates of points on the earth (longitude and latitude) , using GPS relative positioning method, the obtained positioning accuracy provided by this process is about centimeters for the horizontal and vertical components, respectively, this accuracy is sufficient and satisfies producing maps of scale 1:100 .

New version of GPS receivers, recently available, can use the advantages of GPS equipments, such as the modernization program which includes the addition of a civil code (C/A-code) on the L2 frequency and two new military codes (M-codes) on both the L1 and L2 frequencies. The availability of two civil codes (i.e. C/A-code on both L1 and L2 frequencies) allows a user with a stand-alone GPS receiver to correct for the effect of the ionosphere, which is major error source, and the autonomous GPS horizontal accuracy will be about few meters. With these types of new receivers, it deserves to try a special researching to produce a cartographic map with simple, easy and quick process, and to determine the obtained accuracy which is expected to be in order of 1-3 meters [8].

The GPS receiver unit which used to carry out this research observations is eTrex H personal navigator from Garmin. This small unit, see Figure (4-1), has a capability to give the point coordinates with an accuracy of order about 3m. This reasonable accuracy can produce a cartographic map with relatively small accuracy at scale 1:25000 and/or 1:50000.

To operate the eTrex there are five main pages we can cycle through them by pressing PAGE. Figure (4-2) shows these five main pages and we illustrate briefly each one of them:

- The sky view page display the GPS receiver status. It also shows the strength of the satellite signals. A READY TO NAVIGATE message is shown when the receiver has gathered enough satellite information to begin navigation.
- The map page shows where you are located, and as you travel, the animated figure leaves a track log. The map also shows waypoint names and symbols.
- The pointer page helps guidance to destination. When navigating towards a destination, the pointer page shows the name, the distance, time of travel and direction arrow in the compass ring.
- The trip computer page contains five data fields to show travel information.
- The menu page is used to access advanced features, create and view waypoints, create route, save and view track logs, or access the system setup features [9].

Position coordinates can be determined either by pressing and hold to mark the location as a waypoint at sky view page, Figure (4.3), and press enter to save it, or press page key to switch to the menu page and select mark (Figure 4.2) and press enter twice to save the way point. The default position format is latitude and longitude in degrees and minutes. The other option is the user position format for custom-designed grid. To change the position format, press PAGE and switch to the menu page, then select SETUP>ENTER, select UNITS> ENTER, select POSITION FRMT> ENTER, select a format> ENTER. The default datum in the eTrex is WGS 84, but the eTrex supports other types of map datum. To change the map datum from the Menu page, select SETUP> ENTER, then select UNITS> ENTER, select MAP DATUMS> ENTER, selecta datum> ENTER [9].

Two selecting buildings E and S are chosen in Cairo city, Egypt, and some known corner points are determined in Egyptian Transverse Mercator (ETM) coordinates format. These buildings were measured by GPS dual frequency receiver from Leica with GPS relative positioning method which gives the best accuracy of GPS receivers. The auto cad drawing for eTrex and leica GPS observations are shown in Figures (4.4) and (4.5) for the two mentioned buildings.

Coordinates of building E of 20 corners are intended to deal with Universal Transverse Mercator (UTM), which is the default system in the eTrex handheld GPS receiver. To accomplish UTM observables process we have to change the eTrex formatting to navigate by UTM system by switching from User Grid to UTM/UPS and choosing MAP DATUM as WGS84 in the UNITS screen in SETUP options. Repeated observations were carried out for each corner by two ways:

a- Repeating observations for each point at 10:00-10:30 am during three days.

b- Repeating observations for each point many times during the day (5 times).

The overlay of building drawn by both repeated observations, by the aid of auto cad program, with that drawn from data collected by total station are compared in order to determine the deviation between the lines configured from the GPS and the total station measurements as shown in Figure (4-6). Considering the total station drawing is the reference, the lines deviation of the other drawing will give the range of accuracy.

5- Results and analysis

To obtain reliable comparison between the two buildings E and S , Figure (4.4) and Figure (4.5), we intend to navigate the same points (with other corner points) which we have their position coordinates from Leica observations.

Table (5.1) and Table (5.2) show the observables coordinates of two buildings points E and S, and the difference between the coordinates which obtained from Lecia and eTrex Garmin GPS receivers in East and North directions.

There are several ideas we get from this initially study, we can brief as the followings:

1- The difference between the coordinate observations from two GPS receivers; Leica and eTrex Garmin, in North direction are in order of about 20 meters. That means we have to correct the FALSE N option, which we adopted previously. When we switch to User Grid screen to eliminate this difference, the parameters will be corrected when we switch from UTM to ETM systems in User Grid screen.

2- There are odd points coordinates (E7, E15, and E19) in East direction, we have to navigate their observables coordinates again to avoid error resources which cause this problem.

3- The obtained accuracy of building S observations is better than those of building E, because the time of observations of S point's were taken at duration from 10 pm to 12 pm.

4- It is worth mentioning here, that the main goal of this research is to produce a cartographic map in UTM system, but we had the two buildings E and S drawn in ETM system. This does not discrepancy with the aim of taking first look to the eTrex H (GPS receiver) performance, then first experiment gives us a reliability sense to accomplish our research to produce a cartographic map.

To accomplish the repeating observables for each point, we chose building E in the selected area, and tried to repeat observables for each corner of this building by two ways:

- Repeating observables for each point at 10:00-10:30 am for three days.
- Repeating observable for each point at variable time along the day five times.

The mean values of observations for the mentioned two ways are compared with the total station measurements as given in Table (5.3). Linear misclosure error, D , and standard deviation, б , for each corner point are given in Table (5.3) and the corresponding layout for each is shown in Figure (4.6).

Where $D= [(X_{t.s.} - X_i)^2 + (Y_{t.s.} - Y_i)^2]^{1/2}$ … 5.1 and

$б = [б^2]^{1/2}$ … 5.2 ($б^2$: Variance, Mean Square Error).

We conclude from the previous analysis that:

-The accuracy that obtained by using eTrex H personal navigator is about 3-5 m

-The best time to navigate by GPS receiver is at 10-12 pm., to overcome the ionospheric error.

-GPS technology will not replace the existing survey techniques but it will provide another means in carrying out map production, especially in the area where conventional technique is not economical.

-We can produce maps by using eTrex H personal navigator from Garmin (GPS receiver) with scale 1:25000 or less.

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Table (5.1) Observables of building (E) points at (12 am) 9-11-2008

Points	Leica E	Leica N	Garmin E	Garmin N	dE	dN
E1	643355	818914	643358	818893	-3	21
E2			643359	818892		
E3			643355	818895		
E4	643327	818890	643331	818871	-4	19
E5	643317	818899	643321	818878	-4	21
E6	643332	818915	643334	818896	-2	19
E7	643320	818921	643331	818902	-11	19
E8	643310	818905	643311	818885	-1	20
E9	643300	818914	643302	818895	-2	19
E10	643315	818930	643316	818911	-1	19
E11			643314	818919		
E12	643291	818923	643292	818902	-1	21
E13	643281	818932	643283	818910	-2	22
E14			643300	818930		
E15	643284	818953	643294	818934	-10	19
E16	643274	818937	643276	818918	-2	19
E17	643264	818947	643267	818926	-3	21
E18			643288	818946		
E19	643273	818968	643286	818955	-13	13
E20	643286	818977	643289	818960	-3	17

Table (5.2) Observables of building (S) points at (10 am) 11-11-2008

Points	Leica E	Leica N	Garmin E	Garmin N	dE	dN
S1	643198	819125	643199	819104	-1	21
S2			643206	819099		
S3			643207	819093		
S4	643193	819105	643197	819082	-4	23
S5	643223	819078	643227	819058	-4	20
S6			643236	819068		
S7			643246	819060		
S8	643231	819071	643234	819048	-3	23
S9	643212	819073	643215	819050	-3	23
S10	643190	819093	643194	819071	-4	22
S11	643170	819071	643172	819050	-2	21
S12			643196	819031		
S13	643188	819040	643191	819017	-3	23
S14			643183	819006		
S15			643184	819002		
S16			643187	819000		
S17			643195	819000		
S18			643163	819044		
S19			643156	819033		
S20			643148	819033		
S21	643140	819061	643142	819037	-2	24

Table (5.3) Standard deviations and distances between points from three kind of measurements

Points	Points of total station Measurements(T.S.)		Points of GPS Observables (c) at 10:00- 10:30 am		Points of GPS Observables (V) at Variable times		Linear misclosure error D		Standard Deviation б			
	$X_{t.s.}$	$Y_{t.s.}$	Mean X_c	Mean Y_c	Mean X_v	Mean Y_v	D (t.s.:c)	D (t.s.:v)	б (X_c)	б (Y_c)	б (X_v)	б (Y_v)
1	335689.75	3328945.36	335688	3328949	335688	3328949.8	4	4.78	2	1.53	1.41	1.14
2	335759.37	3328882.40	335761	3328882	335761	3328881.8	1.78	1.83	0.41	0	1.92	1.61
3	335749.43	3328871.42	335748.67	3328873	335748.6	3328874	1.69	2.7	0.58	0.41	1.58	1.81
4	335745.92	3328874.59	335745	3328875.67	335744.8	3328876.8	1.5	2.5	1	1.29	1.67	1.14
5	335731.03	3328858.12	335731.33	3328860	335731	3328860	1.92	1.89	0.91	0.58	0.95	1.58
6	335721.17	3328867.25	335720	3328867.33	335718.2	3328867	1.04	3.07	1.15	1.47	2.04	2.02
7	335735.91	3328883.64	335735	3328885.33	335733.2	3328885	1.89	3.12	1.15	0.91	1.98	2.12
8	335729.15	3328889.72	335729	3328892	335728.2	3328891	2.28	1.66	1	1	1.46	2.08
9	335714.41	3328873.32	335715	3328875	335714.8	3328875.8	1.81	2.46	1	1.53	1.61	1.92
10	335704.34	3328882.36	335705	3328883.67	335703.2	3328884	1.29	2.06	0.58	1.29	1.78	1.89
11	335718.58	3328898.56	335718.67	3328900	335719.2	3328900	1.32	1.55	1.73	1.15	1.69	2.14
12	335709.42	3328906.83	335710.67	3328907.67	335711.2	3328908	1.65	2.05	1.29	0.58	1.39	2.23

Table (5.3) Standard deviations and distances between points from three kind of measurements(Cont.)

Points	Points of total station Measurements(T.S.)		Points of GPS Observables (c) at 10:00- 10:30 am		Points of GPS Observables (V) at Variable times		Linear misclosure error D		Standard Deviation б			
	$X_{t.s.}$	$Y_{t.s.}$	Mean X_c	Mean Y_c	Mean X_v	Mean Y_v	D (t.s.:c)	D (t.s.:v)	б (X_c)	б (Y_c)	б (X_v)	б (Y_v)
13	335695.04	3328890.93	335694	3328892	335693	3328891.4	1.49	2.19	1.53	1.53	1.82	1.55
14	335685.25	3328900.12	335684	3328900	335683.2	3328899	1.26	2.42	1	0.41	1.12	1.76
15	335699.7	3328916.19	335699.67	3328917.33	335697.2	3328919	1.21	3.83	1.29	0.91	1.74	2.02
16	335693.07	3328922.16	335692.33	3328923	335691.2	3328923	1.08	2.14	0.91	0.41	1.46	1.94
17	335678.33	3328905.76	335677.33	3328907	335676.2	3328907	1.54	2.57	1.47	1	2.04	1.32
18	335668.48	3328915.02	335667	3328915.33	335665.2	3328915	1.37	3.37	0.41	0.91	1.98	1.48
19	335683.02	3328931.19	335683.33	3328934.33	335681	3328931.6	1.27	1.97	1.47	1.47	2.02	2.16
20	335679.67	3328934.22	335677.67	3328937.67	335676.8	3328938.6	4.13	5.19	0.58	1.29	1.67	1.58

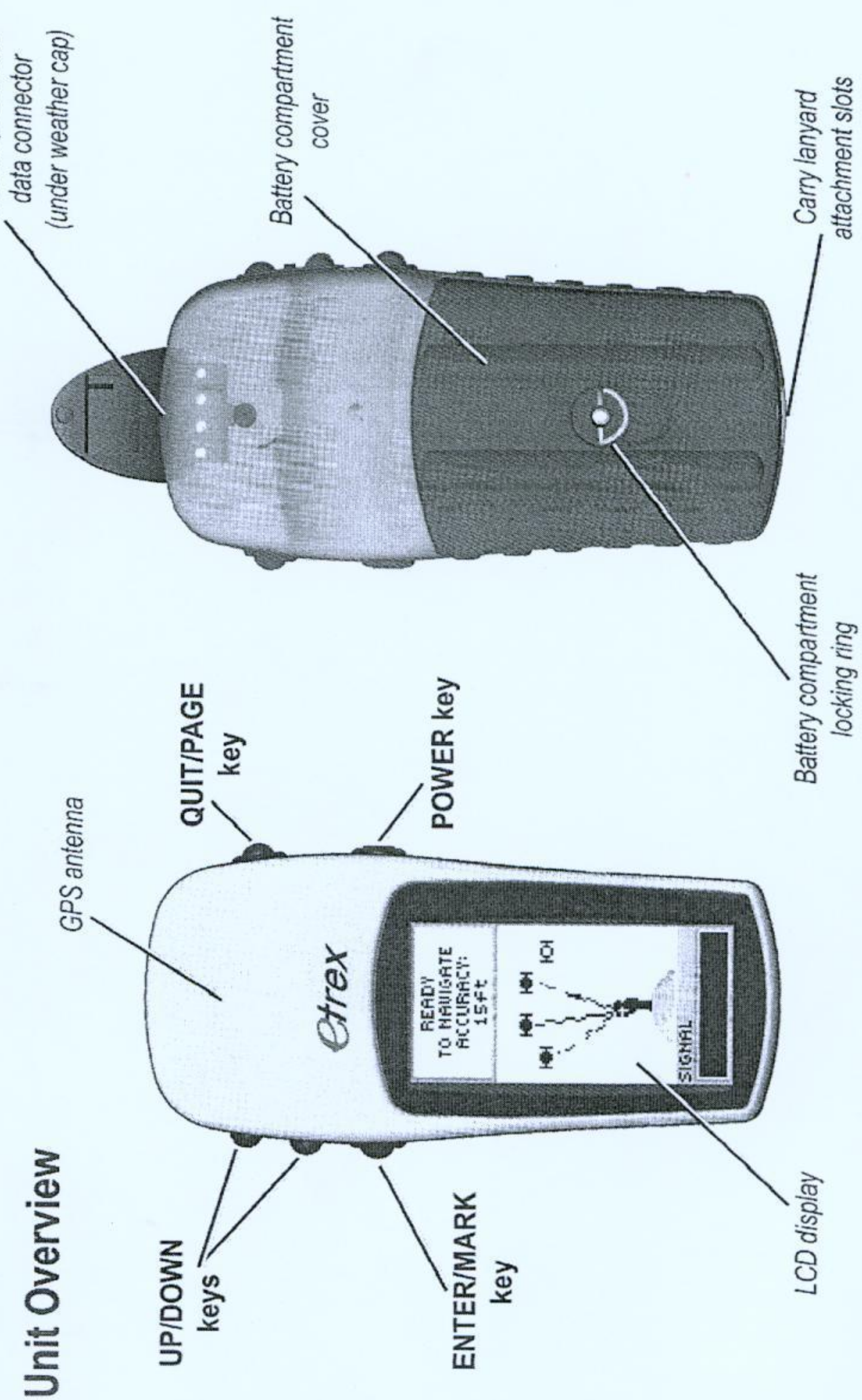

Figure (4.1) The front and back faces of eTrex H personal navigator unit

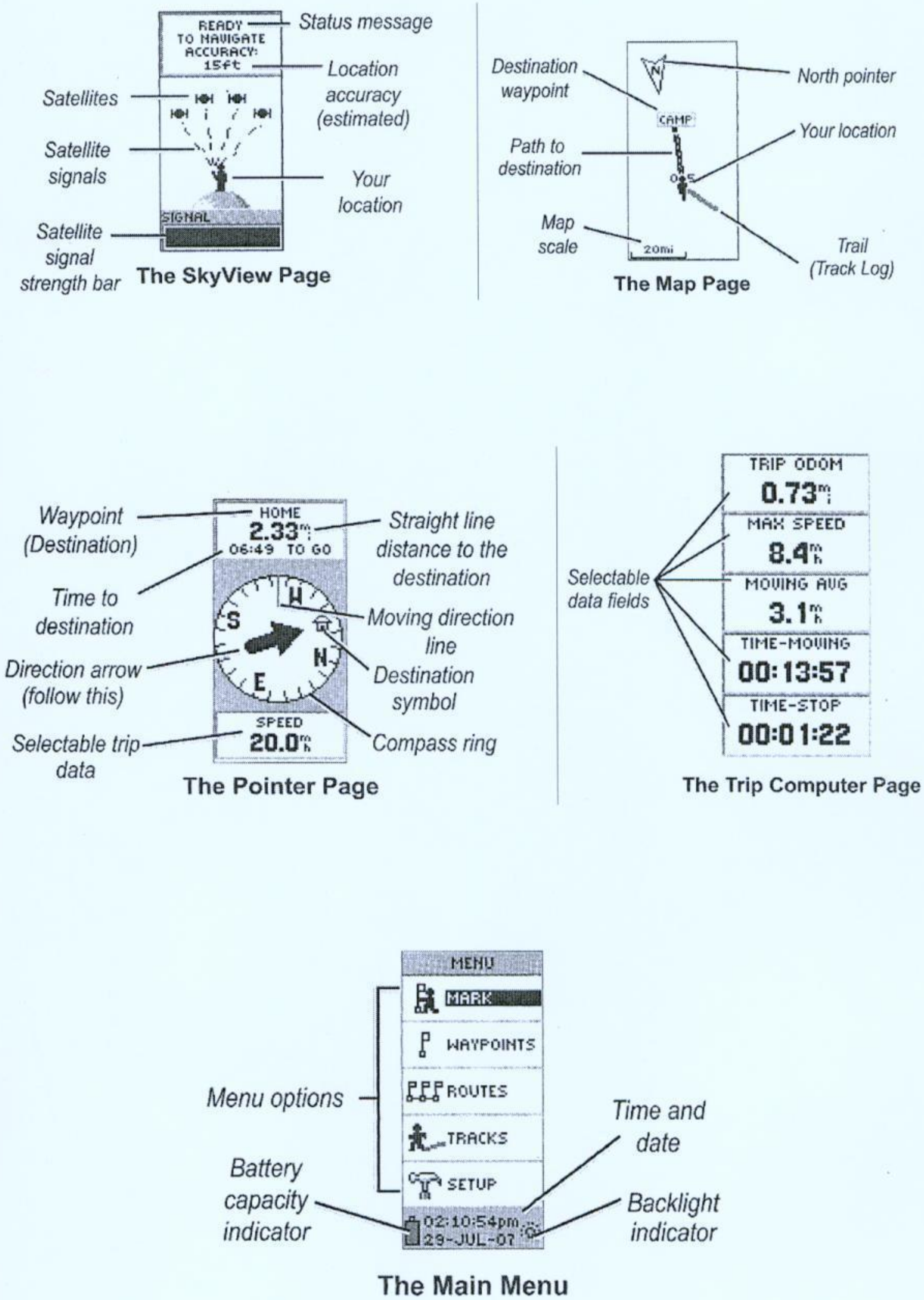

Figure (4.2) The five main pages in eTrex H software,

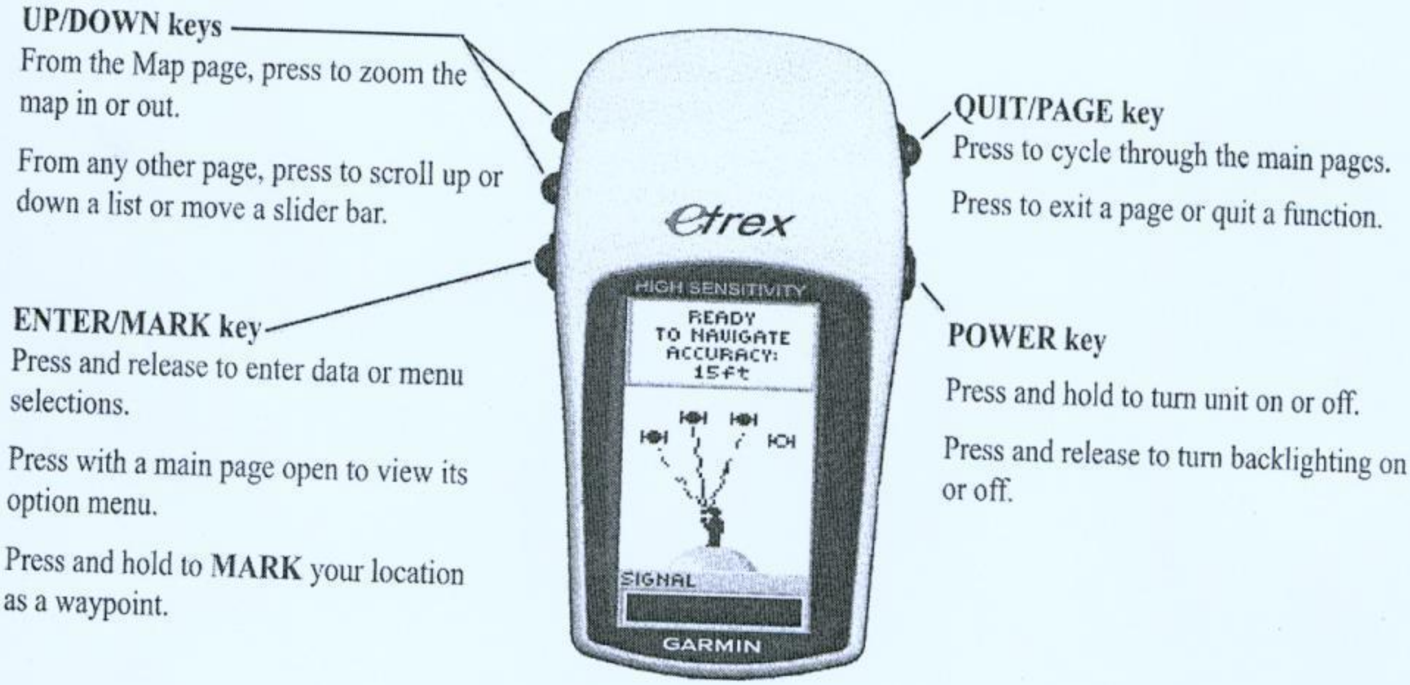

Figure (4.3) Key functions of eTrex H, [37].

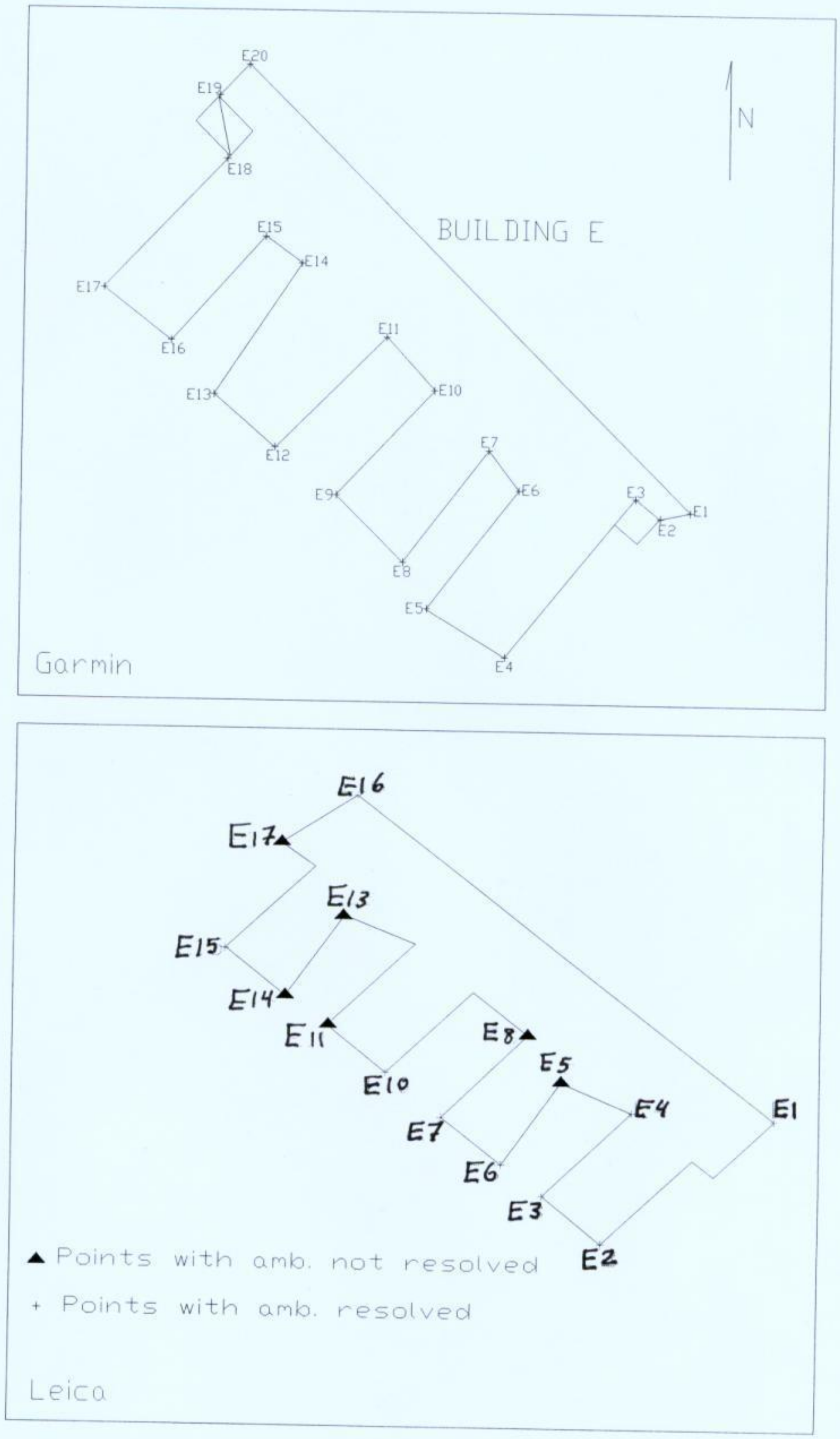

Figure (4.4) Building (E) drawings from eTrex Garmin and Leica GPS observations

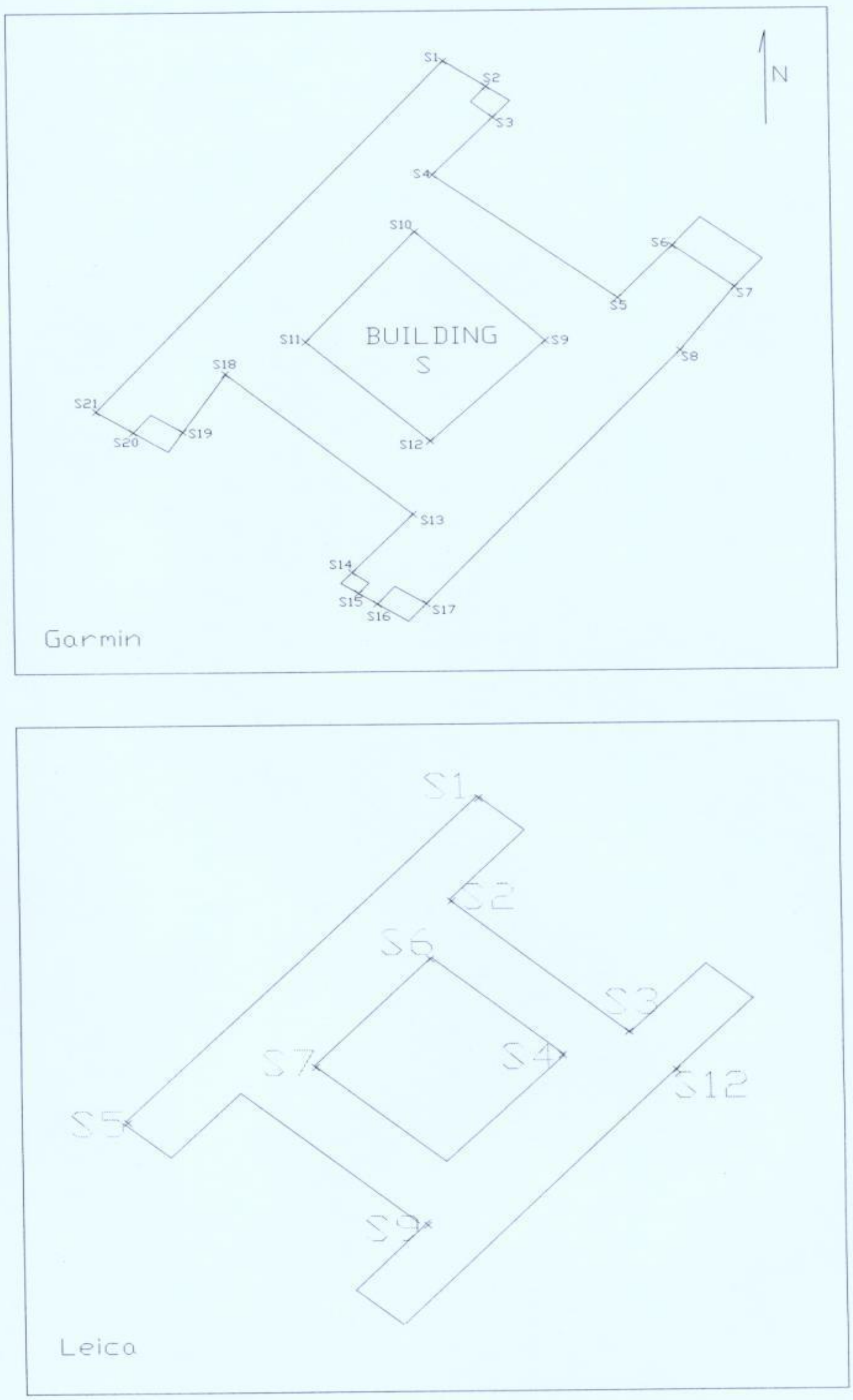

Figure (4.5) Building (S) drawings from eTrex Garmin and Leica GPS observations

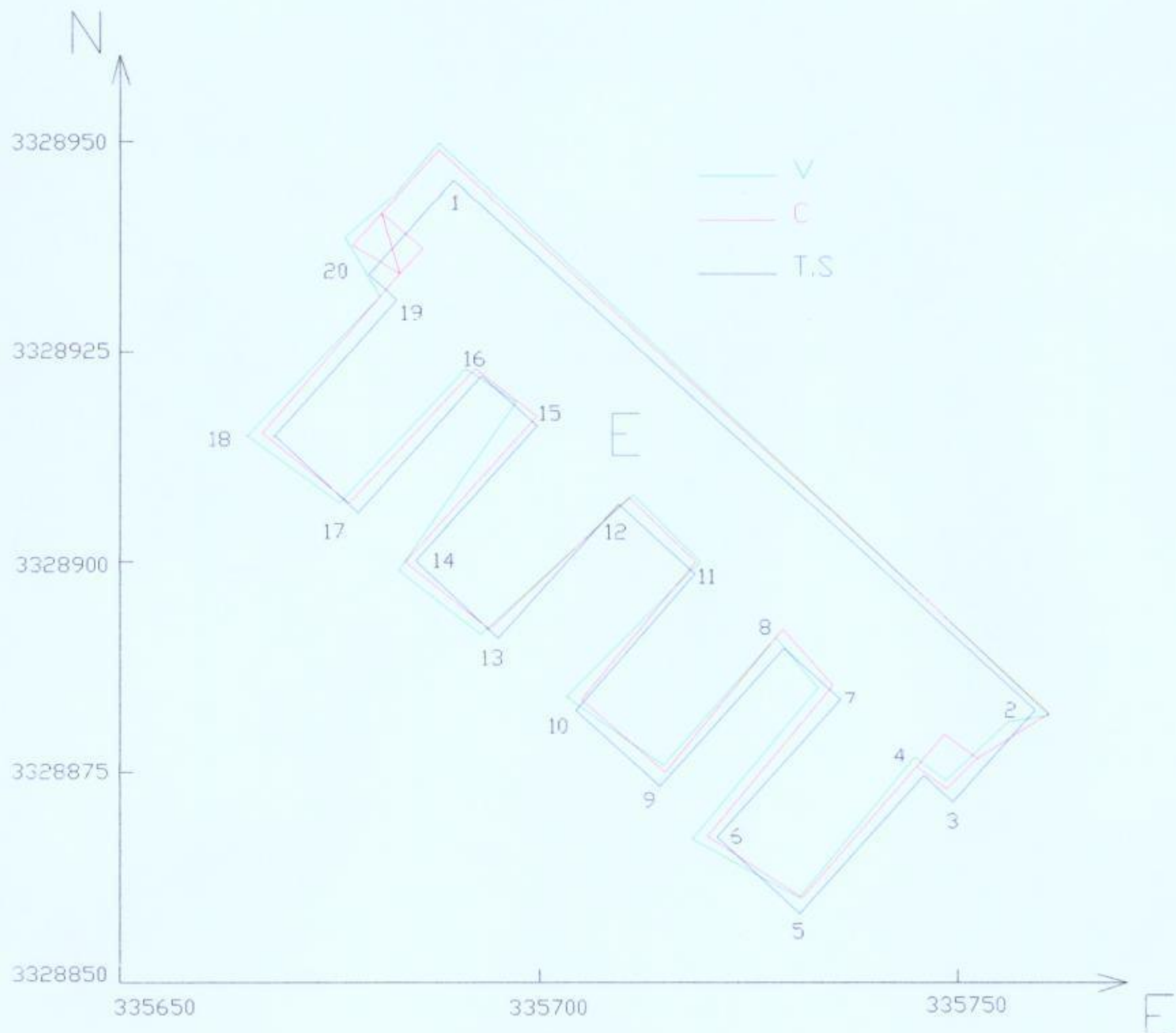

Figure (4.6) Sketch of building E by total station measurements in blue, mean of GPS observables at 10:00-10:30 am in red, and at variable times in green color