

Assessment Study of Using Online (CSRS) GPS-PPP Service for Mapping Applications in Egypt

Research article

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Abstract:

Many applications in navigation, land surveying, land title definitions and mapping have been made simpler and more precise due to accessibility of Global Positioning System (GPS) data, and thus the demand for using advanced GPS techniques in surveying applications has become essential. The differential technique was the only source of accurate positioning for many years, and remained in use despite of its cost. The precise point positioning (PPP) technique is a viable alternative to the differential positioning method in which a user with a single receiver can attain positioning accuracy at the centimeter or decimeter scale. In recent years, many organizations introduced online (GPS-PPP) processing services capable of determining accurate geocentric positions using GPS observations. These services provide the user with receiver coordinates in free and unlimited access formats via the internet. This paper investigates the accuracy of the Canadian Spatial Reference System (CSRS) Precise Point Positioning (PPP) (CSRS-PPP) service supervised by the Geodetic Survey Division (GSD), Canada. Single frequency static GPS observations have been collected at three points covering time spans of 60, 90 and 120 minutes. These three observed sites form baselines of 1.6, 7, and 10 km, respectively. In order to assess the CSRS-PPP accuracy, the discrepancies between the CSRS-PPP estimates and the regular differential GPS solutions were computed. The obtained results illustrate that the PPP produces a horizontal error at the scale of a few decimeters; this is accurate enough to serve many mapping applications in developing countries with a savings in both cost and experienced labor.

Keywords:

Assessment Study • CSRS-PPP • Mapping Applications

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1. Introduction

Most users of GPS data use the differential technique due to its higher accuracy. However, there are some limitations in relative GPS technique: two or more receivers are required to be available, and the true coordinates of the reference station should be known. Moreover, increasing the distance between the two receivers causes a decrement in the quality of positioning. A new technique

in GPS positioning known as precise point positioning (PPP) shows that a user with a single receiver can attain positioning accuracy at centimeter or decimeter level, as compared to differential technique. PPP is very cost-effective since there is no need for observations from local or regional reference stations.

In recent years, a number of free online GPS processing services that provide the user with GPS positioning results have been established. These services are available for unlimited access and do not require detailed knowledge of the processing software. These services are therefore useful for GPS users who do not have an experience in GPS processing software packages.

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The motivation behind this paper is the need for free GPS processing tools for use with a single receiver that do not require detailed knowledge of or experience with processing software packages; these tools should offer accurate results for land title definitions and mapping applications such as preliminary city planning. This research aims to assess the Canadian Spatial Reference System (CSRS) Precise Point Positioning (PPP) (CSRS-PPP) service supervised by the Geodetic Survey Division (GSD), Canada. Single frequency static GPS observations have been collected from three points covering different time windows of 60, 90 and 120 minutes. These three points form three baselines with lengths of 1.6, 7 and 10 km, respectively. These observations were processed by using the two methods (the differential technique and the CSRS-PPP service) which were then compared to one another. The attained results show that the PPP produces a plane error at the level of a few decimeters.

2. GPS positioning techniques

The determination of a GPS user's position can be categorized in two modes: absolute positioning and relative positioning. Relative positioning (differential positioning) employs two receivers that track the same satellites simultaneously, one as reference station and the other as a rover (estimated) station. Some error sources can be eliminated by calculating the difference between the estimated and the known coordinates for the reference station and then employing corrections for the unknown station. The differential technique is used in surveying applications that need high accuracy. However, there are limitations to using differential mode, such as the dependence of the accuracy on the distance between the reference and rover stations. In addition, the need for at least two simultaneously operating receivers during data collection complicates field procedures and adds a great deal of expense.

Absolute positioning, also known as standalone, autonomous, or single point positioning, involves a single GPS receiver in non-differential mode. This receiver tracks four or more GPS satellites in order to determine its position relative to the reference frame of the known satellite orbits (usually GPS broadcast frame WGS84). It is possible to improve the accuracy of single point positioning with the availability of precise ephemeris and clock products from (IGS) and other organizations, the usage of both carrier-phase and code range measurements, and other corrections such as satellite antenna offset, ocean tide loading, atmosphere loading and site displacement effect. This technique is known as precise point positioning (PPP). PPP leads to positional accuracy at the centimeter or decimeter scale.

3. Elements of precise point positioning

The undifferenced observation equations for the measured phase and code are given in formulas 1 and 2 respectively [Farah, 2004]:

$$\lambda\phi_i^j = \rho_i^j + c(dt_i - dt^j) - \lambda\Delta^{iono} + \lambda\Delta^{tropo} - \lambda N + \varepsilon \quad (1)$$

$$R_i^j = \rho_i^j + c(dt_i - dt^j) + \Delta^{iono} + \Delta^{tropo} + \varepsilon \quad (2)$$

Where variables are as given in Table 1. From the previous expressions, we can see that there are important factors that affect the performance of precise point positioning (PPP). These are explained below.

Table 1. Variables for equations (1) and (2).

Symbol	Meaning
ϕ_i^j	measured phase between satellite and station,
R_i^j	measured pseudorange between satellite and station,
ρ_i^j	true range between satellite and station,
N	integer ambiguity,
λ	carrier wavelength,
c	velocity of light,
dt^j	satellite clock error,
dt_i	receiver clock error,
Δ^{iono}	ionosphere delay,
Δ^{tropo}	troposphere delay,
ε	noise and multipath.

3.1. Satellite position and clock corrections

The quality of GPS orbits and clock information affects the derived estimates of PPP. The precise GPS orbits and clock products are available in SP3 format from IGS after 13 days latency, and are known as IGS-final.

3.2. Geometric strength

Factors influencing geometric strength are the number of accessible satellites, distribution of accessible satellites, elevation mask angle and length of time span of carrier phase observations.

3.3. Antenna information

PPP determines the height, latitude and longitude of the antenna phase centre (APC) realized by the processed observations. To compute the position of the ground point, the vertical distance between the ground point and the antenna reference point (ARP) as well as the distance between ARP and the APC must be known.

1. ARP to the marker:

This is the vertical distance between the ground point and the antenna reference point (ARP), which is relevant for the installation of the antenna. This distance should be entered in the H component of the antenna delta H/E/N in the RINEX header.

2. ARP to APC:

The distance between the ARP and the APC is a function of the electronic properties of the antenna as well as the elevation and azimuth of the incoming satellite signal. This distance is determined by laboratory or field calibration and its value remains constant for any given model.

3.4. Ionospheric delay

The ionosphere is a layer of ionized atmosphere surrounding the earth extending from 50 km to 1000 km above the surface. The ionosphere is a dispersive medium for the frequency bands used by global navigation satellite system (GNSS) signals. The impact of the ionosphere decreases with the reciprocal square of the frequency of the signal. The ionospheric delay is proportional to the total electronic content (TEC). In order to eliminate the ionospheric bias, it is possible to use an ionosphere-free code and carrier phase combination by using dual frequency observations.

3.5. Tropospheric delay

The troposphere is the bottom layer of earth's atmosphere. Its thickness varies from 8 to 16 km between the poles and the equator. The tropospheric delay is based on temperature, pressure, humidity, and water vapor and is a function of elevation and latitude of the receiver. Tropospheric models are used to mitigate the tropospheric effects about 92% to 95% and the remaining part can be removed by using a short baseline differential technique [Wells et al., 1999].

4. On-line gps processing services

In recent years many organizations have introduced online GPS tools that provide unlimited numbers of GPS processing estimates to the user free of charge. The user sends a file in Receiver Independent Exchange format (RINEX) to the service and the position of the user's receiver will be sent back within a short timeframe not to exceed several minutes. An outlined comparison between these services is presented here [for more details, see Ghoddousi-Fard, 2006 and Dawod et al. 2007].

4.1. AUSPOS service

The Geoscience Australia [formerly the Australian surveying and Land Information Group's (AUSLIG)] Online GPS Processing Service (AUSPOS) was officially launched in late 2000. The AUSPOS service has the following advantages: an easy to use web site, dual frequency GPS data processing ability, quick turn back of results, global availability, and results that are referenced either to the International Terrestrial Reference Frame (ITRF) system or to the GDA94 for Australian users. The AUSPOS solution uses differential GPS to the nearest three International GNSS Stations (IGS) and in

addition uses IGS precise orbit products. This service is available at <http://www.ga.gov.au>.

4.2. CSRS-PPP service

The Geodetic Survey Division (GSD) of Canada developed the Canadian Spatial Reference System (CSRS) Precise Point Positioning (PPP) service. This service provides a single-point positioning solution for users in static or kinematic modes. The CSRS estimates are processed from carrier phase or code range observations of both single and double frequency receivers. PPP coordinates are referred to the North American Datum (NAD 1983) as well as to the (ITRF) system. PPP results are based on precise GPS orbits and clock products. Results can be improved through the use of better user-end equipment, and through the dynamics and duration of the observations. This service is accessible at <http://www.geod.nrcan.gc.ca>.

4.3. SCOUT service

The Scripps Coordinate Update Tool (SCOUT) was developed by the Scripps Orbit and Permanent Array Center (SOPAC). The coordinates of this service are given in reference to the nearest three IGS stations. However, the service permits the user to choose up to four reference stations. The service uses GAMIT processing software. The service's website is <http://sopac.ucsd.edu>.

4.4. OPUS service

The United States' National Geodetic Survey developed the On-line Positioning User Service (OPUS). The results of OPUS are computed from three Continuously Operating Reference Stations (CORS). The CORS sites are chosen not according to closest proximity but according to compatibility between the user's data and the CORS site. There is also an option that allows the user to choose the CORS stations to be used. The service's website is <http://www.ngs.noaa.gov>.

4.5. Auto-GIPSY service

This is an e-mail/FTP interface to the GPS Inferred Positioning System (GIPSY) developed by JPL. This service performs single point positioning and it is not dependent on CORS/IGS data. The FTP address of user's data should be submitted by email to: ag@cobra.jpl.nasa.gov. This service was replaced by JPL's new Automatic Precise Positioning Service (APPS), available at <http://apps.gdgps.net/> on August 15, 2009 [Auto-GIPSY, 2011] and has become accessible for dual frequency observations.

4.6. Comparison between on-line services

There are general aspects to be considered in the assessment of each service such as the approach of sending and receiving data, time delay in receiving results, accessible options and the service's limitations. An overall evaluation of each service is illustrated in Table 2.

As can be seen from Table 2, the most suitable service for the single frequency receiver data used in this experiment is the CSRS-PPP service, and so subsequent sections of this paper will focus on that service.

5. Basics of online (CSRS-PPP) GPS processing service

The Canadian Spatial Reference System (CSRS) Precise Point Positioning (PPP) service provides post-processed position solutions via the Internet from GPS observation files submitted by the user. Precise solutions are given in reference to the CSRS standard North American Datum of 1983 (NAD83) as well as to the International Terrestrial Reference Frame (ITRF). Precise position estimates are computed for users operating in static or kinematic modes using precise GPS orbits and clocks.

5.1. Accessibility of precise orbits and clocks

The CSRS-PPP service uses the ephemeris available at the time of sending GPS data (broadcast ephemeris). However, the longer period in submitting data for processing leads to more accurate CSRS-PPP solutions. This due to the fact that IGS final orbits and clock products are available after 13 days.

5.2. Accepted minimum and maximum duration of GPS data set

There is no minimum length for a GPS observation session. However, the quality of a PPP computed position will not be optimal until the carrier phase ambiguities have converged. For short data sets, the effective calculation of a position uses only the code pseudo-range observations. Longer data sets make it possible to resolve the ambiguities required to recover positions using the more precise carrier phase observations [CSRS-PPP guide, 2004].

The CSRS-PPP service can process up to six days of observation data and a RINEX file up to 100 Mb. Submission of a file exceeding 100 Mb will result in an unsuccessful job termination [CSRS-PPP guide, 2004].

5.3. Antenna information

The online CSRS-PPP service uses the antenna phase centre calibration value published by the International GNSS Service (IGS) and by the National Geodetic Survey (NGS) through certain antenna model identification, found at <http://www.ngs.noaa.gov/ANTCAL/> [GSRS-PPP guide, 2004]. The antenna type must be recorded in the header of the RINEX file. Therefore if there is no information about

APC or if the antenna model does not exist in the IGS model, there will be unexpected solutions in the height component [CSRS-PPP guide, 2004].

5.4. Solutions of ionospheric delay

The (CSRS-PPP) service uses ionospheric maps produced at 2-hour intervals in IONEX format by IGS in case of L1 observations. The L1&L2 processing uses the L1&L2 ionospheric-free combination of the code and phase observations [GSRS-PPP guide, 2004]. For more details about IONEX format, see [Schaer et al., 1998].

5.5. Solutions of tropospheric delay

CSRS-PPP total tropospheric zenith delay estimates are now based on the Global Mapping Function (GMF) derived from the European Centre for Medium-Range Weather Forecasts numerical weather model along with default surface meteorological data and an elevation mapping function. These serve to correct the along-path tropospheric delay [Kouba et al., 2008].

6. Results of the previous studies

In order to make a background review about online PPP services and their solutions, results of previous studies are mentioned and compared here. [Ghoddousi-Fard, 2006] submitted different data sets varying in time and location to different online PPP services and then compared their results. The findings reveal 1 cm differences in horizontal direction and a few cm-level in height for 8-10 hr lasting data sets of dual frequency receivers. In addition, the AUTO GIPSY and PPP services are not based on the location of the site, while SCOUT and AUSPOS use the nearest three IGS stations. However these stations are not distributed uniformly around the world. The AUTO GIPSY service provided the coordinates closest to the truth while the results of the other services vary about 4 cm after 8 hr time spans.

[Dawod et al., 2007] have compared the two services AUSPOS and CSRS-PPP by using dual frequency GPS data of a 3.8 hr average time span which has been collected on 10 national GPS stations established by the Egyptian Survey Authority (ESA). The accuracy of the attained PPP results show an average of 0.19 m in the 2D direction and an average of 0.21 m in the 3D direction when compared with the ESA known coordinates. On the other side, the accuracy of the achieved AUSPOS results show an average of 0.23 m in the 2D direction and an average of 0.24 m in the 3D direction when compared with the ESA published coordinates.

[Featherstone et al., 2008] transmitted GPS observations of 46 points of a geodetic network to the CSRS-PPP service and compared the results with coordinates processed by means of the Bernese scientific software V5. The CSRS-PPP estimates agreed with the Bernese solutions to 3.3 mm in east direction, 4.8 mm in north direction and 11.8 mm in height direction.

Table 2. Comparison of online GPS processing services. [Ghoddousi-Fard, 2006]

Name of service	Data transfer method	Available options	Elapsed time to receive results	Restrictions of length of GPS data set	limitations
AUSPOS	Uploading Antenna Via anonymous FTP	Antenna height Antenna type No. of RINEX files (maximum)	> 25 min.	Minimum of 1 hr.	Dual frequency Static
Scout	Via anonymous FTP Upload the file to Scripps FTP site	Antenna height Antenna type Selection of reference stations	> 15 min.	Minimum of 1 hr.	Dual frequency Static
CSRS-PPP	Uploading	Mode of processing Reference systems (NAD83 or ITRF)	< 3 min.	No minimum Maximum 6 days long	
OPUS	Uploading	Antenna height Antenna type	> 4 min.	Minimum 2 hr. Maximum 24 hr.	Dual frequency Static Only available for use in Central and North America
Auto-GIPSY	Via sending the anonymous FTP address	None	< 3 min.	At least 1 hr.	

7. Experimental work

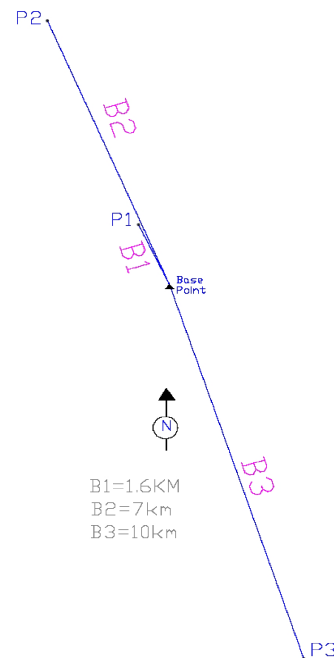
In order to assess the accuracy of the CSRS-PPP service, single-frequency static GPS observations have been collected at three points covering various time spans of 60, 90 and 120 minutes. These three observed sites form baselines of 1.6, 7 and 10 km, where the base point is the same for all these baselines (Figure 1). The processing of this data was achieved by using two methods: 1) use of a differential GPS solution to determine the positions of each unknown point, and 2) use of the CSRS-PPP service.

Two single-frequency GPS receivers (Promark-3 units) were used to survey the three baselines. A 10 degree elevation angle, 10 second sample rate, and GNSS Solution software was used to process the vectors in the differential solution. The processed coordinates of each baseline and its corresponding PPP solution were compared, allowing judgment of the quality of the results of the PPP service.

8. Results and discussions

For differential GPS solution, GNSS Solution software was used to estimate the positions of the unknown points by using precise ephemeris available from IGS after 13 days latency. UTM-36 N map projection system was used to compute the coordinates of surveyed points on metric units. The coordinates of the points are given in Table 3.

For the CSRS-PPP solution, the first stage was to convert GPS observations files from Ashtech format to RINEX format by using RINEX converter utility in GNSS Solution software. Hence, those files were uploaded to the CSRS-PPP website. The files were sent to the CSRS-PPP service 13 days after collecting the observations, when

**Figure 1.** Occupied points.

the IGS-final ephemeris and clock products became accessible. The obtained results are shown in Table 4.

In order to investigate the accuracy of CSRS-PPP solutions, the attained coordinates of each station have been compared with the estimates of differential GPS solution by calculating the difference

Table 3. Processing data for static differential solution.

Base line	Time span	UTM coordinates		PDOP
		Easting (m)	Northing (m)	
1.6 km	60 min	489110.031	2669890.564	1.5
	90 min	489110.031	2669890.565	1.5
	120 min	489110.031	2669890.565	1.4
7.0 km	60 min	487125.296	2674847.438	1.5
	90 min	487125.295	2674847.441	1.5
	120 min	487125.295	2674847.443	1.5
10 km	60 min	492712.978	2659341.036	1.9
	90 min	492712.978	2659341.037	1.8
	120 min	492712.980	2659341.037	1.5

Table 4. Processing data for static CSRS-PPP solution.

Base line	Time span	UTM coordinates	
		Easting (m)	Northing (m)
1.6 km	60 min	489110.074	2669890.843
	90 min	489109.885	2669890.348
	120 min	489109.885	2669890.348
7.0 km	60 min	487125.427	2674847.125
	90 min	487125.385	2674847.152
	120 min	487125.394	2674847.205
10 km	60 min	492712.879	2659340.681
	90 min	492713.012	2659340.737
	120 min	492713.040	2659340.801

(Equation 3). As a measure of accuracy, the plane difference vector (2D) is computed using Equation 4. The results are listed according to different base line length and various time windows in Table 5. Figure 2 illustrates the differences between PPP and differential solutions at different time spans.

$$\text{Difference}(\delta) = \text{Differential solution} - \text{PPP solution} \quad (3)$$

$$\text{Horizontal error (2D)} = \sqrt{\delta_E^2 + \delta_N^2} \quad (4)$$

The previous results demonstrate the following:

Table 5. Differences between CSRS-PPP and differential solutions.

Base line	Time span	Differences in coordinates (m)		Plane error (m)
		δ_E	δ_N	
1.6 km	60 min	-0.044	-0.279	0.282
	90 min	0.146	0.217	0.261
	120 min	0.146	0.217	0.261
7.0 km	60 min	-0.131	0.313	0.339
	90 min	-0.090	0.289	0.303
	120 min	-0.099	0.238	0.258
10 km	60 min	0.099	0.355	0.3699
	90 min	-0.034	0.300	0.302
	120 min	-0.060	0.236	0.244

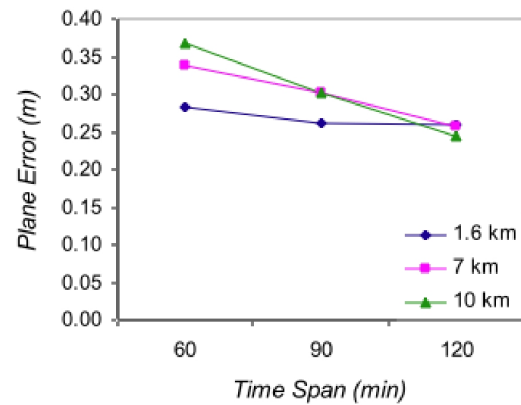


Figure 2. The plane difference between CSRS-PPP solution and differential solution.

- For 60 minutes time span, the horizontal error (2D) ranges from 28 cm to 37 cm.
- For 90 minutes time span, the 2D error vectors range from 26 cm to 30 cm.
- For 120 minutes time window, the horizontal difference ranges from 24 cm to 26 cm.
- As the observation period increases, the plane error decreases.
- The overall plane difference between PPP solution and differential solution is at the scale of a few decimeters.
- This level of accuracy is based on the observation time span, multipath, quality of introduced orbits and clocks products, ionospheric-model, tropospheric model and type of observations' (single or double frequency) carrier phase or code range.
- The results acquired from CSRS-PPP service can be used in producing a cadastral map at 1:1000 scale.
- The obtained accuracy of the coordinates provided by CSRS-PPP service can be used in some engineering applications such as preliminary city planning, for a cadastral map with scale 1:1000.

9. Conclusions

In recent years, a number of free online global positioning (GPS) processing services have become available that provide the user with GPS processing results. These services are accessible via the internet without requiring detailed knowledge of the employed processing software.

In order to assess one of these services (namely the CSRS-PPP service), single-frequency static GPS observations have been collected

at three points building base lines with different lengths of 1.6, 7 and 10 km within time frames of 60, 90 and 120 minutes. These observations were processed by using two different processing methods: a differential technique, and the CSRS-PPP service. The final results of both processing lines were compared. The attained results show that the PPP produces a horizontal error at the scale of a few decimeters. The quality of CSRS-PPP service depends on the observation time span, the quality of introduced orbits and clocks products, the ionospheric model, the tropospheric model, and the type of observations' (single or double frequency) carrier phase or code range.

The obtained accuracy provided by CSRS-PPP service is sufficient for some mapping applications for a cadastral map with scale 1:1000. In addition, this service allows for a tremendous savings in cost and experienced labor.

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