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UTILIZATION CSRS-PPP SOFTWARE FOR RECOVERY AIRCRAFT'S POSITION

Summary. The PPP method is applied in aeronautical navigation as a new technique for determination of aircraft's position. In this paper preliminary results of recovery aircraft's position were presented. The raw GPS observations from Topcon dual-frequency receiver were utilized to position obtained with temporal resolution 1 second. Service on-line CSRS-PPP was used for estimation vehicle coordinates and receiver clock, troposphere delay and ambiguity term also. Preliminary results of aircraft's position show that accuracy of horizontal coordinates is about 3 cm and less than 7 cm for vertical coordinate, respectively. The high level accuracy of coordinates is assured by using precise products such as GPS ephemeris and clocks.
Keywords: GPS, PPP method, positioning accuracy

1. INTRODUCTION

Implementation GPS technology in civil aviation is very important for aircraft's position accuracy improvement. Especially, GPS technology has got major role during landing procedure on the airport, without ILS system. New possibilities of GPS receivers, which can register and collect code and phase observations from triple frequency (L1, L2 and L5), are really in this process. Utilization code and phase information in GPS positioning find out references in Precise Point Positioning (PPP) method. Moreover this strategy is very popular on the world and also was using in many tests of kinematic positioning. In paper [1] NovAtel dual-frequency GPS/GLONASS receiver was used in the experiment. Rover receiver was installed on the roof of car and additionally reference station from University of Calgary was

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utilized for determination of kinematic position in Double Difference (DD) solution. Preliminary results from PPP method are very similar to DD estimation. RMS values for PPP solution are less than 0.161, 0.056 and 0.357 m, for east, north and up coordinates, respectively. In paper [2] NovAtel DL-v3 dual-frequency receiver was used as a rover station in the vehicle. Computation were executed in RTKLIB software. Kinematic test shows that RMS value for PPP solution is between 1 and 1.8 m for each coordinates, while RTK solution (using DD technique) is between 0.2 and 0.3 m. In paper [3] Septentrio PolarRx2 dual-frequency GPS receiver was used in airborne test. The PPP solution from few softwares (e.g. CSRS-PPP, GAPS, APPS and magicGNSS) was compared with differential estimation. Preliminary results present that mean difference between PPP and DGPS solution is less than 15 cm with standard deviation about 0.4 m. In work [4] three experiments were realized, using NovAtel OEM3 and Ashtech dual-frequency receivers. Aircraft's position in both studies was estimated in CSRS-PPP and GrafNav softwares. RMS value of GrafNav solution is less than 10 cm and for CSRS-PPP about 13 cm, respectively, in comparison with truth aircraft's position. In paper [5], airborne test was realized in Toronto area in the Canada. In the experiment, two receivers were used: Trimble NETR5 (As a base station) and Trimble BD960 (as a rover station in aircraft). The aircraft's trajectory was recovery in two softwares, e.g.: the RTX-PP and the TBC. Mean difference between both solutions are -1.5 mm, 5.7 mm and 10.1 mm, for north, east and up component, respectively. The RMS term equals to 8.6 mm, 10.3 mm and 23.5 mm for north, east and up coordinates, respectively. In work [6], two airborne experiments were realized. The aircraft's position was estimated in two PPP softwares: P3 and Gipsy-Oasis. In first test, whereas speed of aircraft was less than 300 km/h, mean offset between P3 and Gipsy-Oasis solution was less than 5 cm for all coordinates with RMSE error equals to 8 cm. In second test, whereas speed of aircraft was less than 800 km/h, mean offset between P3 and Gipsy-Oasis software was nearly to 50 cm for all coordinates with RMSE error about to 53 cm.

In this paper, CSRS-PPP software in kinematic mode was used for solved aircraft's position. The PPP method as a mathematical formulation was utilized in computations. Observations from Topcon TPS HIPER dual-frequency GPS/GLONASS receiver was taken in computations, with sample rate 1 s. Firstly results from CSRS-PPP for presented study are so optimistic. Accuracy of position is about 3 cm for horizontal coordinates and less than 7 cm for vertical component.

2. MATHEMATICAL FORMULATION FOR DETERMINATION AIRCRAFT'S POSITION

The CSRS-PPP software is on-line free service, available since 2003 at website: http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php?locale=en [7]. The CSRS-PPP is tool for precise processing of GPS/GLONASS observations in kinematic and static mode. Currently, application enables for determination, e.g.: user position, receiver clock, troposphere delay and ambiguity term. The CSRS-PPP operates as a web interface with limit of data transfer less than 100 MB [8]. Input data in CSRS-PPP is RINEX file and should be send at website, together with information about user's e-mail. Additionally mode of positioning (kinematic or static) should be choice and horizontal (NAD83 or ITRF) and vertical (CGDV) frame should be mark (see Fig. 1). Moreover, after few minutes CSRS-PPP tool returns report data on private e-mail address [9]. Report include 4 files:

- „*.sum”− text file with processing summary,
- „*.pos” − text file with results of precise processing of kinematic data,
- „*.csv” − text file with coordinates values for each measurements epoch,
- „*.pdf” − pdf file with graphical presentation of results.

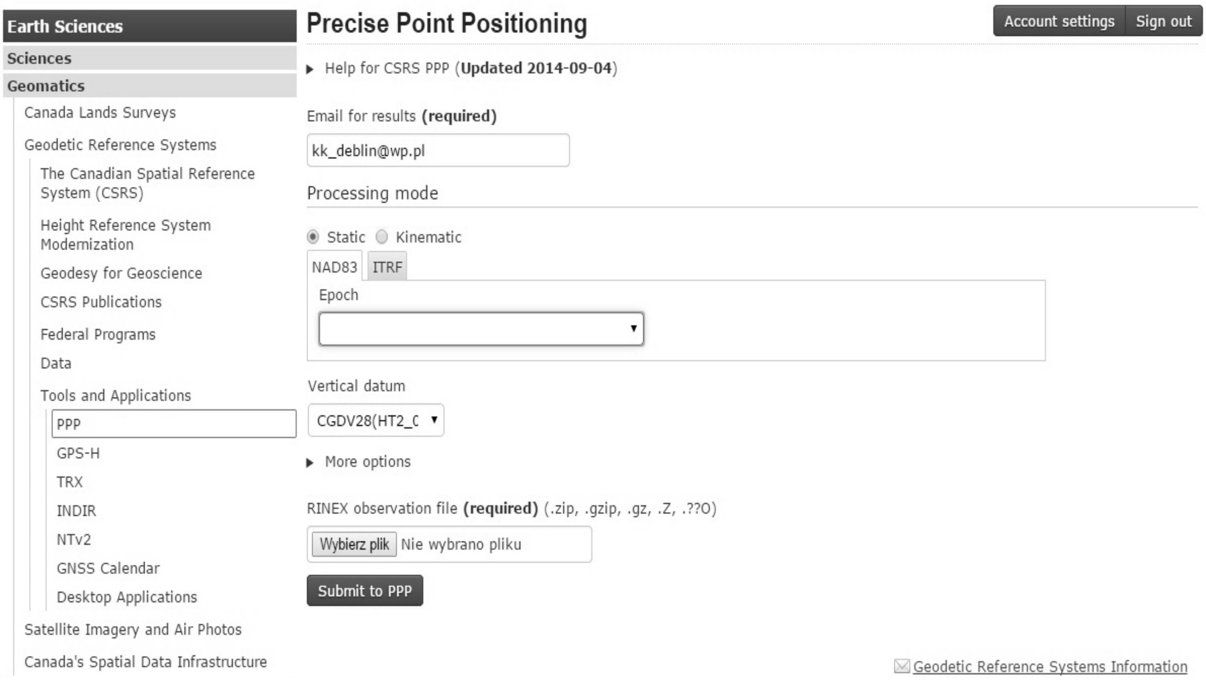

Fig. 1. Interface of CSRS-PPP software [5]

The CSRS-PPP application utilizes PPP method for recovery of user's position. The PPP method based on „Ionosphere-Free", which eliminates ionosphere delay on 1st frequency and instrumental biases DCB from code observations. Moreover, precise information about satellites coordinates and clocks are applied in „Ionosphere-Free" (L3) combination, what cause that this combination sometimes is called PPP technique. From the other side, precise ephemeris and clocks reduce measurements noise in code observations. What is important, PPP method enables to estimation user's position only from single receiver, without additionally data from network reference stations. This approach is quite simple and not requires very high price technical infrastructure [10]. Accuracy of PPP method for static and kinematic mode are very similar to DGPS solution. In the nearest time, differential techniques will be replaced by PPP method.

Basic equations of PPP method are given by [10, 11, 12]:

$$\begin{cases} P_3 = \alpha_1 P1 + \alpha_2 P2 = d + C \cdot (dtr - dts) + T + \mathrm{Re}\,l \\ L_3 = \alpha_1 L1 + \alpha_2 L2 = d + C \cdot (dtr - dts) + T + \mathrm{Re}\,l + \lambda_3 N_3 \end{cases} \tag{1}$$

where:
α_1=+2.546,
α_2=-1.546,
P_3, L_3– linear combinations for code and phase observations,
P1, P2– code observations,
L1, L2– phase observations,
d– geometrical distance between satellite and receiver,

$$d = \sqrt{(x - X_s)^2 + (y - Y_s)^2 + (z - Z_s)^2},$$

(x, y, z) – aircraft position in geocentric frame,
(X_S, Y_S, Z_S) – satellite position in geocentric frame,

C− speed of light,
dtr− receiver clock,
dts− satellite clock,
T− troposphere delay,

T=SHD+SWD,
SHD=MFd·ZHD,
SWD=MFw·ZWD,

MFd, MFw− mapping function for hydrostatic and wet component of troposphere delay,
ZHD− zenith hydrostatic delay,
ZWD− zenith wet delay,
Rel− relativistic effect,
λ_3− wavelength, $\lambda_3 = 10.7$ cm,
N_3− ambiguity term.

The aircraft coordinates, receiver clock, zenith wet delay and also ambiguity term are estimated in sequential process from equation (1). The CSRS-PPP tool set constraints for presented data in numerical computations, as below [7, 9]:
- positioning mode: kinematic,
- precise ephemeris/clocks: applied,
- reference frame: ITRF,
- ellipsoidal frame: WGS-84,
- satellite antenna phase center offset: applied,
- receiver antenna phase center offset: not applied,
- ocean loading correction: not applied,
- primary meteorological data:
  a) Temperature (deg C): 14.33 (GPT model),
  b) Pressure (Mb): 947.14 (GPT model),
  c) Relative humidity (%): 50.00 (Default),
- tropospheric models:
  a) Hydrostatic delay: Davis (GPT),
  b) Wet delay: Hopfield (GPT) initial, but ZWD component is estimated,
  c) Mapping functions: GMF,
- instrumental biases DCB_{P1C1}, DCB_{P2C2}: applied,
- initial receiver coordinates: from RINEX file,
- pseudorange bias: 2 m,
- carrier-phase bias: 1.5 cm,
- cutoff elevation: 10^0,
- pseudorange: P1, P2 applied,
- carrier-phase: L1, L2 applied,
- interval of calculations: 1 s,
- linear combination: L3,
- number of parameters estimated: k=6.

3. EXPERIMENT AND RESULTS

The raw GPS observations from Topcon TPS HIPER receiver were used in the airborne experiment. The Topcon TPS HIPER was utilized as a rover station and installed in Cessna’s aircraft. Receiver registers and collects code (P1, P2, C1) and phase (L1, L2) observations from GPS and GLONASS satellites, with sample rate 1 second. In test, only GPS observations (P1, P2, L1, L2) were taken from RINEX 2.11 format for determination vehicle's position. Flight test was realized in September 2011 year, close to Mielec airport (see Fig. 2 and 3). Time of flight mission was equal to 3537 measurements epoch, but only 3523 was utilized in computations. The RINEX file, in primary 14 seconds of flight mission, have got none observations on 2^{nd} frequency and sometimes number of observations was less than k parameter (k=6).

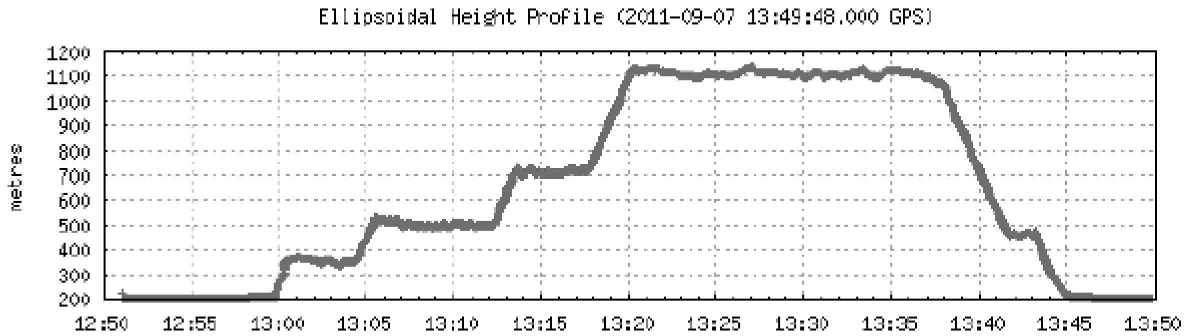

Fig. 2. Vertical trajectory of Cessna's aircraft [5]

Moreover, this problem is very important from flight safety point of view and should be monitored in another airborne tests. Figure 2 presents vertical trajectory for presented experiment. Vertical profile in Fig. 2 shows changing of ellipsoidal height in time function. Maximum and minimum value of vehicle's height is between about 200 m and 1200 m, respectively.

Figure 3 shows horizontal trajectory in WGS-84 ellipsoidal frame. Vertical and horizontal axes correspond to Latitude and Longitude coordinates and they are express in meter unit. Primary and finally point of horizontal trajectory was the same point in Mielec airport.

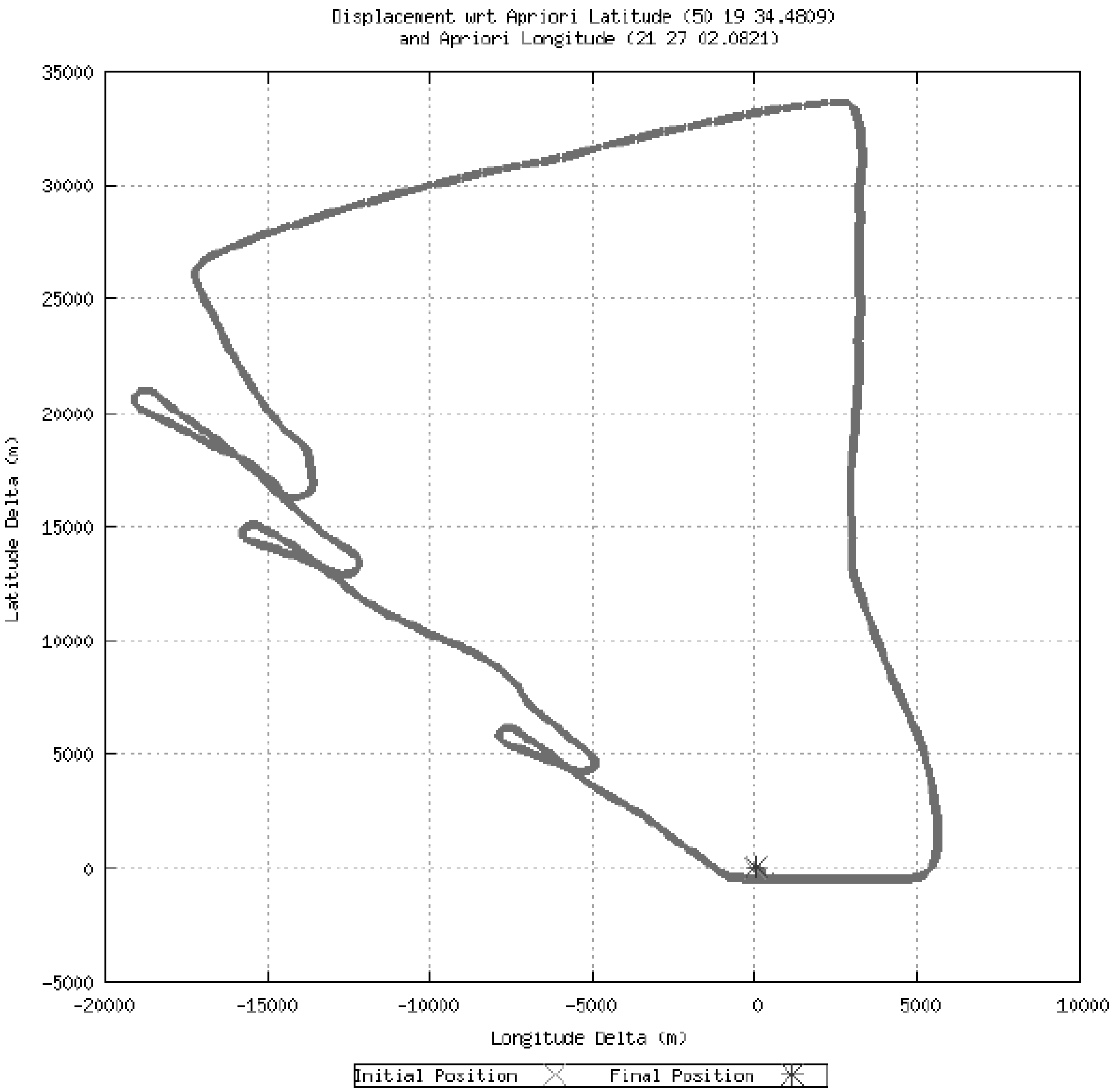

Fig. 3. Horizontal trajectory of Cessna's aircraft [5]

Figure 4 presents positioning accuracy on the background of trajectory differences for each coordinate. Magnitude of mean errors for latitude coordinate is between 2.9 cm and 6.1 m, for longitude coordinate between 2.5 cm and 2.7 m, for ellipsoidal height between 6.1 cm and 4 m, respectively. Average error for Latitude component is about 3.5 cm with standard deviation about 10 cm, for longitude component 2.9 cm with standard deviation about 4.5 cm, and for ellipsoidal height coordinate 6.6 cm with standard deviation 6.6 cm (the same value), respectively. Very important is accuracy of vehicle position during approach to landing phase. Mean errors for horizontal coordinates are about 3 cm and for vertical coordinate less than 7 cm, respectively.

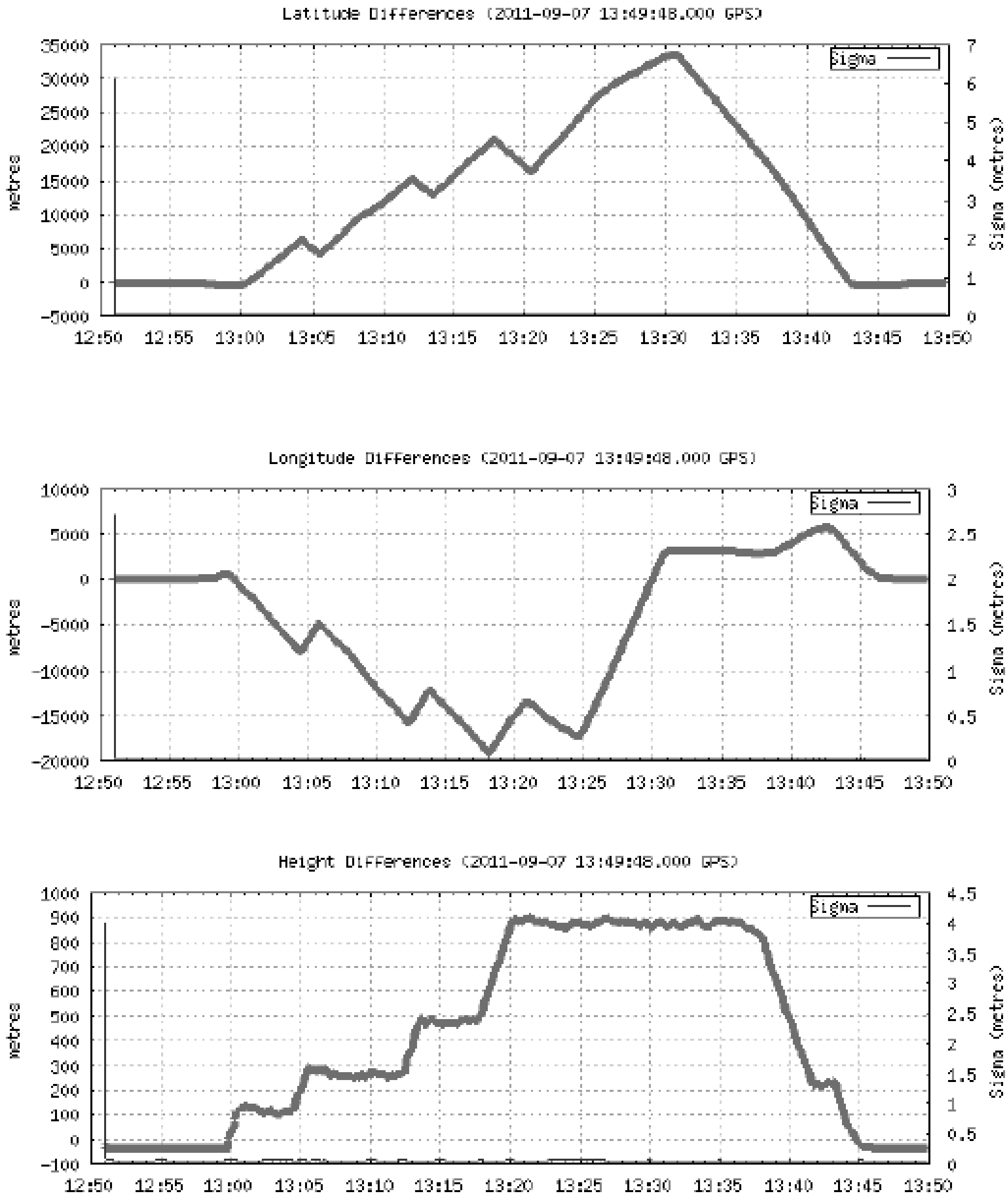

Fig. 4. Accuracy of aircraft's position for each measurements epoch [5]

4. CONCLUSIONS

In this paper, airborne experiment was presented using GPS technology. Aircraft's position was estimated in CSRS-PPP software based on PPP method. Algorithm of CSRS-PPP application was presented and PPP method was characterized. Flight mission was realized close to Mielec airport and Topcon receiver was utilized for collection raw GPS observations. Preliminary results of positioning accuracy show that mean errors for horizontal coordinates are about 3 cm and for vertical coordinate less than 7 cm, respectively. These values can be concluded that CSRS-PPP software can be applied in kinematic positioning.

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