Using RINEXPVT

by R. Benjamin Harris

Applied Research Laboratories,
The University of Texas at Austin

Email: pben@arlut.utexas.edu

February 24, 2005

1 Overview

The `rinexpvt` application is a GPSTk [1] based application that generates user positions from pseudoranges recorded in the RINEX [2] format. One user position, or PVT, is generated per epoch of observation. No smoothing is applied to the pseudoranges, nor are the solutions filtered. A number of error models are applied to the pseudoranges before the generating the position calcuation, such as atmospheric delay. The user can select an elevation mask for satellites. Also only healthy satellites, as defined by the ephemeris, are used in the solution. The user can control which pseudoranges are used, and some of the corrections applied to them.

2 Synopsis

The user executes `rinexpvt` from the command line. The processing performed by the `rinexpvt` is specified through command line arguments. The full set of arguments is defined below. This list can be duplicated by running `rinexpvt -h` on the command line.

```
shell] ../rinexpvt -h
```

```
Usage: rinexpvt [OPTION] ...
GPSTk PVT Generator

This application generates user positions based on RINEX
observations.

NOTE: Although the -n and -p arguments appear as optional below,
one of the two must be used. An ephemeris source must be specified.

Required arguments:
  -o, --obs-file=ARG       RINEX Obs File.

Optional arguments:
  -d, --debug              Increase debug level
  -v, --verbose            Increase verbosity
  -h, --help               Print help usage
  -n, --nav-file=ARG       RINEX Nav File. Required for single frequency
                           ionosphere correction.
  -p, --pe-file=ARG        SP3 Precise Ephemeris File. Repeat this for each
                           input file.
  -m, --met-file=ARG       RINEX Met File.
  -t, --time-format=ARG    Alternate time format string.
  -e, --enu=ARG            Use the following as origin to solve for
                           East/North/Up coordinates, formatted as a string:
                           "X Y Z"
  -l, --elevation-mask=ARG Elevation mask (degrees)
  -s, --single-frequency   Use only C1 (SPS)
```

```
-d, --dual-frequency     Use only P1 and P2 (PPS)
-i, --ionosphere         Do NOT correct for ionosphere delay.
```

3 Detailed Description

3.1 Observation Model

The user position is related to the pseudorange observation through the following formula [3, 4].

$$\rho = \sqrt{(x_u - x_s)^2 + (y_u - y_s)^2 + (z_u - z_s)^2} + c\delta t + t + i + \nu + m + \epsilon \tag{1}$$

where
ρ is the pseudorange measurement
x, y, and z represent Cartesian coordinates
u is the user position at time of reception
s is the satellite position at the time of transmission
$c\delta t$ is the clock offset between the user and spacecraft clocks
t is the delay due to the troposphere
i is delay due to the ionosphere
ν is relativistic delay
m is multipath delay
ϵ is thermal measurement noise

For each satellite in view at a given epoch, one independent relation can be formed. When the satellite position is known as a function of time, and atmospheric delays have been estimated, then unknown terms are user position, at x_s, y_s, and z_s, and the clock offset, $c\delta t$. If more than four such observations are available for a given epoch, then gradient search methods are be used in combination with least squares to solve for the user position [3, 4, 5].

3.2 Satellite Position Models

Satellite positions are computed as a function of time by one of two methods. The first method applies modified Keplerian parameters found in the broadcast ephemeris, as defined by the ICD-GPS-200 [3, 4, 6]. The second method is by Lagrange interpolation of precise ephemerides [3].

3.3 Delay Models

Many of the delays found in Eq. 1 are modeled within `rinexpvt`. The delay due to special relativity can be computed directly from satellite position and velocity. The troposphere delay can be estimated using meteorological observations. Finally, the ionosphere delay can be computed using additional range observation or using a reference model.

The net effect due to special relativistic delay is frequently modeled within receivers using the following equation [4, 6]

$$\delta t' = 2\frac{\vec{r} \bullet \vec{v}}{c^2} \tag{2}$$

where $\vec{r}$ is the Earth centered, Earth fixed (ECEF) position vector, $\vec{v}$ is the ECEF velocity vector and c is the speed of light.

If observations from more than one frequency are available for an epoch, then the ionosphere delay i is estimated using the following linear relationship [5].

$$i \approx \frac{f_2^2}{f_2^2 - f_1^2}(P_1 - P_2) \tag{3}$$

where P_1 is the pseudorange measurement on L1 and P_2 is the pseudorange measurement on L2. If dual frequency measurements are not available, then ionosphere delay is estimated using the Klobuchar model [2].

The troposphere delay is estimated using meteorological observations. The modified Hopfield model is used within **rinexpvt** to model this form of error.[7] If no actual weather measurements are provided, then a default weather condition is assumed: 20 degrees ceslius, 1000 millibars and 50 percent humidity.

4 Examples and Usage Notes

This section contains a number of practical examples in the use of **rinexpvt**. In each subsection there is a brief description of the desired processing, as well as a snapshot of a shell session as a demonstration. All of the example files used are distributed with the application.

4.1 Generating Positions in WGS 84 Coordinates

By default, **rinexpvt** generates the user position in the Cartesian, WGS reference frame. The user needs only supply observations and a source of ephemerides. If a RINEX meteorological file is provided, then troposphere delays are modeled. Otherwise the troposphere delay is modeled using a standard temperature of 20 celsius, . The following example demonstrates the most basic processing provided by **rinexpvt**.

```
shell] rinexpvt -o usno0200.05o -n brdc0200.05n -m usno0200.05m
```

```
2005 1 20 00 00 0.000000 1112192.67926 -4842951.98205 3985348.06329
2005 1 20 00 00 30.000000 1112188.65938 -4842953.48346 3985351.48398
2005 1 20 00 01 0.000000 1112189.48576 -4842957.45711 3985356.92698
2005 1 20 00 01 30.000000 1112191.15384 -4842957.53284 3985355.11895
2005 1 20 00 02 0.000000 1112191.1508 -4842955.89459 3985352.76549
2005 1 20 00 02 30.000000 1112190.99828 -4842954.61737 3985352.3681
2005 1 20 00 03 0.000000 1112189.92412 -4842954.29518 3985348.72842
2005 1 20 00 03 30.000000 1112189.16937 -4842954.31307 3985351.92146
2005 1 20 00 04 0.000000 1112191.62124 -4842955.6613 3985354.82972
2005 1 20 00 04 30.000000 1112188.66733 -4842953.49038 3985348.04322
```

4.2 Generating Positions in East/North/Up Coordinates

The user may wish to transform the results of the position calculation to local, or topocentric, reference frame. The new coordinates, still Cartesian, refer to the cardinal directions: East, North and Up. The positions calculated by **rinexpvt** can be tranformed to a topocentric origin using the **-e** option. The argument to this option is a single string, with three numerical entries for the origin of the topocentric system. Often, within RINEX observation files, the header entry "APPROX POS XYZ" is a recent surveyed origin of the receiver and forms a useful origin for a topocentric system. In the following example the topocentric transformation is applied to the results from the previous subsection.

```
shell]grep "APPROX " usno0200.05o
```

```
  1112189.9031 -4842955.0319  3985352.2376                  APPROX POSITION
XYZ
```

```
shell]rinexpvt -o usno0200.05o -n brdc0200.05n -m usno0200.05m -e "1112189.9031 -
    4842955.0319  3985352.2376"
```

```
2005 1 20 00 00 0.000000 -2.64323278089 1.39273684601 -4.44579107837
2005 1 20 00 00 30.000000 0.675237880363 -0.413842977087 -1.86595014292
2005 1 20 00 01 0.000000 0.74075583724 -1.74562915823 4.70500528956
2005 1 20 00 01 30.000000 -0.514261859844 -0.427112579929 3.92260789052
2005 1 20 00 02 0.000000 -0.798000760765 0.225433490228 1.2040383517
```

```
2005 1 20 00 02 30.000000 -0.905046895282 -0.156961158353 -0.0422947010004
2005 1 20 00 03 0.000000 -0.144614169541 1.78733342562 -2.7520269223
2005 1 20 00 03 30.000000 0.432346745093 -0.229710319547 -0.872438081029
2005 1 20 00 04 0.000000 -1.19640547889 -1.09032516564 2.40032451942
2005 1 20 00 04 30.000000 0.670398976551 1.68417470062 -4.01206558988
```

4.3 Generating Positions using Precise Ephemerides

Precise ephemerides may be substituted for broadcast ephemerides. The precise ephemerides must be in the SP-3 file format. In order to process a given period of RINEX observations, precise ephemerides must be utilized for times before and after that period in order to eliminate interpolation effects. For this reason the `-p` option to specify a precise ephemeris can be repeated. The following example demonstrates the use of precise ephemerides.

```
shell]rinexpvt -o usno0200.05o -m usno0200.05m -e "1112189.9031 -4842955.0319
      3985352.2376" -p nga13063.apc -p nga13064.apc -p nga13065.apc
```

```
2005 1 20 00 00 0.000000 -2.08992486501 1.51632100425 -5.38603364386
2005 1 20 00 00 30.000000 1.22849620836 -0.281974793322 -2.78857829356
2005 1 20 00 01 0.000000 1.29400421219 -1.60589389988 3.7997452854
2005 1 20 00 01 30.000000 0.03901809145 -0.279940424961 3.0344477269
2005 1 20 00 02 0.000000 -0.141549865351 0.430550617004 0.613916181074
2005 1 20 00 02 30.000000 -0.247842106971 0.0554617639326 -0.61408409222
2005 1 20 00 03 0.000000 0.513345520633 2.00662083505 -3.30594517769
2005 1 20 00 03 30.000000 1.18397434384 0.173306575113 -1.80221181762
2005 1 20 00 04 0.000000 -0.445369991941 -0.681710302654 1.48775750121
2005 1 20 00 04 30.000000 1.26854804266 1.86268110989 -4.31594225054
```

4.4 Emulating Standard Positioning Service (SPS) Performance

By default, `rinexpvt` will attempt to form the best possible position for each epoch of observation. If dual frequency observations are applied, they are used. If for a single epoch, only C/A observations are available, then it is used. In order to perform solutions using only C/A, the `-s` switch is available. The following is a demonstration of this switch.

```
shell] rinexpvt -o usno0200.05o -n brdc0200.05n -m usno0200.05m -s
```

```
2005 1 20 00 00 0.000000 1112192.36858 -4842952.68698 3985350.17084
2005 1 20 00 00 30.000000 1112190.34546 -4842953.75694 3985351.57171
2005 1 20 00 01 0.000000 1112191.29632 -4842954.16477 3985353.65599
2005 1 20 00 01 30.000000 1112191.97305 -4842954.21052 3985353.96079
2005 1 20 00 02 0.000000 1112191.47444 -4842954.60185 3985351.44099
2005 1 20 00 02 30.000000 1112191.67217 -4842953.79149 3985352.74304
2005 1 20 00 03 0.000000 1112192.35285 -4842953.76184 3985351.25908
2005 1 20 00 03 30.000000 1112189.43589 -4842951.88681 3985348.73888
2005 1 20 00 04 0.000000 1112190.55705 -4842953.10278 3985349.95615
2005 1 20 00 04 30.000000 1112188.71119 -4842952.128 3985348.15393
```

4.5 Emulating Precise Positioning Service (PPS) Performance

Similar to the option described in the previous subsection, there is an option to limit the solutions of `rinexpvt` to those strictly derived from dual frequency observations. The following session demonstrates this switch.

```
shell] rinexpvt -o usno0200.05o -n brdc0200.05n -m usno0200.05m -d
```

```
2005 1 20 00 00 0.000000 1112192.67926 -4842951.98205 3985348.06329
2005 1 20 00 00 30.000000 1112188.65938 -4842953.48346 3985351.48398
2005 1 20 00 01 0.000000 1112189.48576 -4842957.45711 3985356.92698
2005 1 20 00 01 30.000000 1112191.15384 -4842957.53284 3985355.11895
2005 1 20 00 02 0.000000 1112191.1508 -4842955.89459 3985352.76549
2005 1 20 00 02 30.000000 1112190.99828 -4842954.61737 3985352.3681
2005 1 20 00 03 0.000000 1112189.92412 -4842954.29518 3985348.72842
2005 1 20 00 03 30.000000 1112189.16937 -4842954.31307 3985351.92146
2005 1 20 00 04 0.000000 1112191.62124 -4842955.6613 3985354.82972
2005 1 20 00 04 30.000000 1112188.66733 -4842953.49038 3985348.04322
```

4.6 Customizing the Epoch Format

The GPSTk library supports conversion among a number of time formats. This conversion ability is provided to the end user of **rinexpvt** in the form of the **-t** command line switch and its argument, a string describing the time format. The GPSTk documentation to DayTime's printf method contains a full list of specifiers that can be used within the time format string. The following table summarizes some of these options.

%Y	Four digit year
%y	Year modulo 100
%m	Month number
%b	Month name
%d	Day of month
%S	Second of minute
%F	Full GPS week
%Z	Z count
%g	Seconds of week
%j	Day of year
%s	Seconds of day
%Q	Modified Julian Date

Table. Time Format Specifiers

In the following example we see how to apply the format specifiers in the form of a string.

```
shell]rinexpvt -o usno0200.05o -n brdc0200.05n -m usno0200.05m -t "%F %g"
```

```
1306 345600.000000 1112192.67926 -4842951.98205 3985348.06329
1306 345630.000000 1112188.65938 -4842953.48346 3985351.48398
1306 345660.000000 1112189.48576 -4842957.45711 3985356.92698
1306 345690.000000 1112191.15384 -4842957.53284 3985355.11895
1306 345720.000000 1112191.1508 -4842955.89459 3985352.76549
1306 345750.000000 1112190.99828 -4842954.61737 3985352.3681
1306 345780.000000 1112189.92412 -4842954.29518 3985348.72842
1306 345810.000000 1112189.16937 -4842954.31307 3985351.92146
1306 345840.000000 1112191.62124 -4842955.6613 3985354.82972
1306 345870.000000 1112188.66733 -4842953.49038 3985348.04322
```

5 References

1. The GPS Toolkit, GPSTk. Website: http://www.gpstk.org/.

2. RINEX: The Receiver Independent Exchange Format Version 2.10. Available on the web at http://www.ngs.noaa.gov/CORS/Rinex2.html.

3. Hofmann-Wellenhoff, B., Lichtenegger, H., and Collins, J. Global Positioning Theory: Theory and Practice, fifth ed. Springer-Verlag. 2004.

4. Parkinson, Bradford W. and Spilker, James J., editors. Global Positioning Theory: Theory and Applications, Volume I. AIAA Press, 1996.

5. Borre, Kai and Strang, Gilbert. Linear Algebra, Geodesy and GPS. Wellesley-Cambridge Press, 1997.

6. The GPS Interface Control Document (ICD-GPS-200), which can be found at http://www.navcen.uscg.gov/ftp/policy/icd200/ICD200Cw1234.pdf.

7. Goad, C. C. and Goodman, L. "A modified tropospheric refraction correction model." Proceeding of the Annual American Geophysical Union Fall Meeting, San Francisco, 1974.