GPS Signal Processing Tool Box

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Abstract

This document describes a library of MatLab utilities for GPS scintillation diagnostics that evolved from the International Reference Ionosphere Workshop, November 6-10, 2017, at the Central University, Taiwan.

1 Introduction

High-end GPS diagnostic receiver manufacturers provide data acquisition software that extract multi-frequency reports of signal intensity, $I(k\Delta t_I)$, signal phase $\phi\,(k\Delta t)$, and pseudo range $\rho\,(k\Delta t_\rho)$. The samples rates vary: typically $\Delta t_I = 1/50$, $\Delta t = 1/100$, and $\Delta t_\rho = 1$. Processing these data for ionospheric diagnostics requires a library of supporting utilities. The GPS_ToolBox_Library is a collection MatLab utilities for GPS diagnostic processing. This document describes a GPS_ToolBox collection of MatLab utilities. The book *Linear Algebra, Geodesy, and GPS*, by Gilbert Strang and Kai Borre lists a website `http//www.14.auc.clk/borre/matlab` where a collection of very useful MatLab utilities can be downloaded. The GPS_Toolbox_Library uses and supplements the Strang-Borre MatLab utilities.

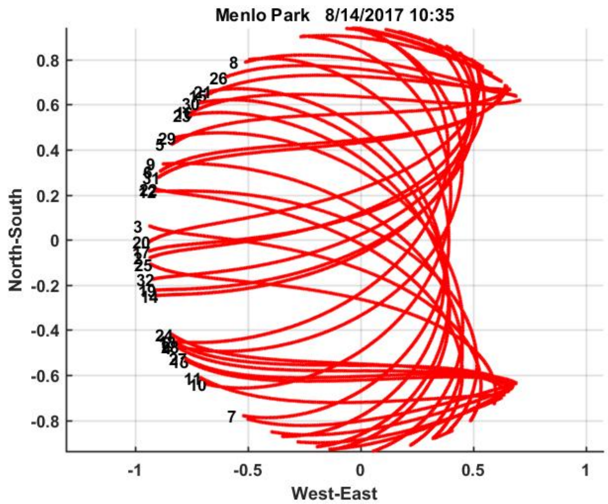
1.1 GPS Orbit Calculations

GPS orbit calculations are supported by published daily 2-hour 21-element ephemerides. The library contains utilities for extracting the ephemerides and calculating GPS satellite positions and velocity. As an illustration, the script `FindSatellites` uses extractRINEXeph(year,day_of_year,[]) to download the orbital elements for all the GPS satellites. The 21-element ephemeris rcords are used to calculate the earth-centered-fixed (ECF) coordinates. The calculations are referenced to GPS time. The utility

`[GPSTime,GPSweek]=UT2GPStime([year,month,day,hh,mm,ss])`

is used to convert UT to GPSTime. Note that GPS leap seconds are provided in a table that must be kept current. The utility

[sat_ecf,sat_vel]=satposvel(GPSTime,eph(:,neph))



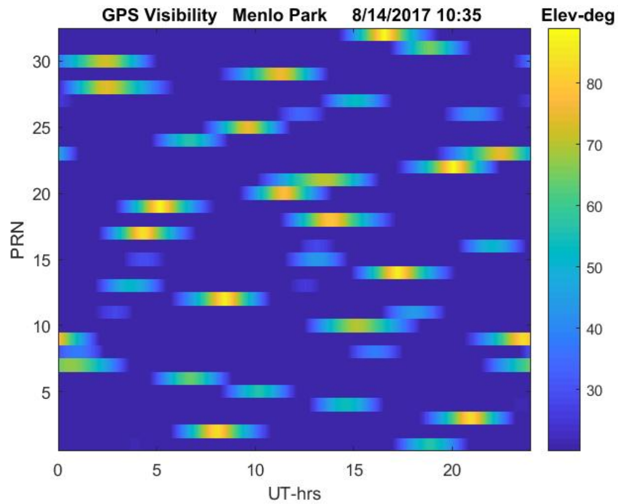
calculates the satellite position and velocity. A library of GPS coordinate transformation utilities are used to manipulate the ECF cordinates to calculate, for example, satellite range, range rate, and directions versus time. Figures 1 and 2 show sample visitility plots and time.

1.2 Propagation Geometry Computations

1.3 Propagation Geometry

Calculation that only involve the GPS satellite and receiver locations were introduced in the previous subsection. Propagation of the GPS signal from the transmitter to a receiver are influenced by the interveining ionosphere and atmosphere. It is convenient to use a coordinate system with the origin specified as the ionosphere penetration or pierce point. The pierce point is specified by an altitude. The origin of the coordinate system is the intercept of the ray from the satellite to the source at the specified penetration point height. Propagation is influence by the direction of the magnetic field, whcih requires a model calculation. The penetration point coordinate system is oriented with the y axis eastward, the z axis southward, and the x axis downward. To velocity of the penetration point determines that time rate of change of structure intercepted by the propagation path. The structure itself may be drifting.

The utility `satGEOM_struct=GenerateGPSGeometry` will generate all the geometric variables used for interpreting propagation effect. It uses a MatLab implementation of the IGRI magnetic field model. Supporting conversion utilities for GPS time are included.



2 GNSS Signal Processing

2.1 Background

Signal processing is guided by the following ideal relations that connect the basic delay, phase, and intensity to the ionosphere in the absence of noise, interference, and multipath:

$$c\widehat{\tau}_k = r_k + cK \cdot TEC_k / f_c^2 + \lambda\varphi_k / (2\pi) \tag{1}$$

$$\lambda\widehat{\phi}_k / (2\pi) = r_k - cK \cdot TEC_k / f_c^2 - \lambda\varphi_k / (2\pi) \pm M\lambda \tag{2}$$

$$\widehat{I}_k = CN0 \left| h_k \right|^2 \tag{3}$$

where r_k is propagation range distance, f_c is the carrier frequency, and c is the velocity of light. The term TEC_k is the total electron content, usually reported in units of 10^{16} electrons per square meter per meter of path length, and $cK = 40.33$. Scintillation imposes a complex stochastic modulation

$$h_k = |h_k| \exp\{i\varphi_k\}. \tag{4}$$

The conversion from TEC to phase in radians is $\phi = -2\pi K \cdot TEC / f_c$. The integer M is the phase ambiguity in cycles. Defining phase in meters removes the 2π factors. Delay reported in range units is called pseudo range.

2.2 Basic Signal Processing Operations

Intensity scintillation, as defined by (3), is modulated by variations that include path loss and antenna gain variations. Signal intensity is usually reported in post-detection (i. e. at the output of the correlator) signal to noise ratio units, denoted $CN0$. A detrending operation is performed to remove the average background variation. Butterworth filters are often used to high-pass filter or denoise the intensity. The `GPS_ToolBox_Libraries` include a simple wavelet-based denoising filter, which we believe is better suited to the task. The detrended intensity is defined as

$$I_k^d = \widehat{I}_k / \overline{I}_k \simeq |h_k|^2 ,$$

where $\overline{I}_k$ is the estimate of the mean background variation. Note that $\langle I_k^d \rangle \simeq 1$ up to the detrend interval.

Because phase, as defined by (2), is dominated by the range variation detrending is more problematic. There is no definitive temporal frequency separations between the true range, TEC, and, scintillation contributions. The best that can be done is to generate a coarse estimate of the range contribution and remove it. Ephemeris predictions can be used, but for the purpose at hand a high-order polynomial can be used to avoid orbit-geometry computations. The `GPS_ToolBox_Libraries` contains a utility that will generate phase residuals with frequency content comparable to the detrended intensity.

After detrending a segment length is chosen for statistical analysis. The segment length should be smaller than the detrend interval, but not so small that large-scale frequency content is compromized. Effectively, the detrend interval sets the upper bound. Smaller intervals might be used to capture scintillation events. The software library contains utilities for computing $S4$ and higher-order moments, probability distributions, cumulative probability distributions, and power spectra.

The directories `GPS_Processing_Examples` and `GPS_ScintillationModel_Demo` contain demonstration examples, respectively, of the data processing operations and and a GPS scintillation model that will reproduce representative multi-frequency scintillation realizations. To execute the demonstration code transfer the active MatLab directory to either `GPS_Processing_Examples` or `GPS_ScintillationModel_Demo`. Each directory contains the identical utility `SetPath4GPS`, which will put the library utilities on the MatLab path. The setup utility need only be initiated once in either directory. To demonstrate the signal processing operations run the script `GPS_DiagnosticProcessorDemo`. The script will select a user directed input from a moderately disturbed pass (Peru) or a highly disturbed pass (Hong Kong). The user can cycle through the processing and display options. The utilities are intended to be examples for specific signal processing operations.

The script `GeneratePhaseScreenModelRealization` will carry out the phase-screen model operations described in the paper, *A Compact Multi-frequency GNSS Scintillation Model*. Defaulting the parameter intputs will use representative values.