ASE 372N Laboratory Exercise Set #1:
In-field data collection with a handheld GPS receiver

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Reading

Misra & Enge, Ch. 1 & Appendix 4.A (Coordinate Conversion)

Setup

In this lab you'll learn how to operate a handheld GPS receiver and assess its accuracy from an end-user perspective. You'll work with receivers in the same way that most users do, by viewing them as a "black box" whose internal operation is mysterious. You'll witness the several stages associated with tracking the GPS signal and you'll see how satellite geometry affects navigation accuracy.

The most common GPS receivers are those found embedded in other devices such as smart phones. The receiver we'll use in this lab, the Trimble Juno, is an example of a GPS receiver embedded in a personal digital assistant (PDA).

Teams

You'll divide into teams of 2-3 to collect data. After the data are collected, each member will write an individual report with analysis and discussion of results. All team members will base their reports on the same data set. You are encouraged to work together on problems and compare results, but don't copy solutions or trade code.

GPS Receivers

Each team will check out a Trimble Juno SB handheld receiver from the TA for the duration of the first laboratory assignment. Owner manuals can be found on the course website. Before performing the first lab, you'll want to spend some time getting familiar with the receiver.

The handheld receivers are fairly rugged. Even so, please exercise all the caution that you normally would when working with a $500 piece of precision electronic equipment. While the receivers are in your possession, you are personally responsible for their care and safety. Please do not drop them or abuse them in any careless way. Do not take them out of town without asking the instructors permission.

The receivers operate on a rechargeable battery. You'll want to have the battery charged before you go out to collect data.

Data Extraction

The Juno receiver outputs positions in a format called NMEA 0183 over a communications port. An application called SirfTech has been installed on the Juno to log those positions to a file. Log observations to a new file for each measurement session. A MATLAB script on the course website will convert the NMEA 0183 messages into vectors of longitude, latitude, and height above the WGS-84 ellipsoid. You'll use Google Earth and MATLAB to visualize the coordinates.

Exercise Report and Grading

Each exercise report is graded for technical merit (60%) and professionalism (40%). Each exercise assignment contains a number of technical objectives. Read each assignment carefully to discern the objectives; in general, they will not be listed or tabulated for you but will be described in paragraphs. The technical score represents how well each objective is addressed in the report. Professionalism measures the craftsmanship of your report. Your report will be graded using the same standards applied to any professional report or paper. The Technical Writing Manual on the course website gives guidelines for report structure, grammar, and format.

Survey Sessions

Sessions 1 and 2: The effect of WAAS on GPS Accuracy

In our first two sessions we will explore the impact of the Wide Area Augmentation System (WAAS) signal on GPS navigation accuracy. Pick a site that has an unobstructed view to the south because the WAAS satellite is in a geosynchronous equatorial orbit. If you are unsure what site to use, from experience we know (1) 24th street in front of WRW is not suitable, (2) the middle of the bridge over Dean Keeton provides a sufficient view, and (3) the plaza north of the South Mall (south of the Tower) provides an excellent view.

Use the Juno SB receiver to log two GPS tracking sessions. The only difference between the sessions will be whether or not the receiver uses the WAAS satellite. Record the sessions back to back at the same point in space. Record observations as follows:

1. Close any program that uses GPS observations from COM or Bluetooth ports, such as SirfTech or Google Maps.
2. Open the Trimble GPS Controller program (Windows flag → GPS Controller).
3. If a dialog box appears warning that NMEA messages will be output when it is closed, simply close the dialog box. We'll use this feature later on to record observations. If this dialog box does not appear, then configure the GPS Controller to output NMEA messages to the default port, COM4 (Setup → GPS Settings → scroll down → set NMEA Output to On).
4. Switch to the Sat Info view and wait for the receiver to finish acquiring the GPS almanac (a complete list of approximate satellite orbits). You'll know you have a complete almanac when the current date shows up next to the Almanac field. This may take up to 25 minutes. At this time the receiver is successfully tracking a number of GPS satellites and knows what satellites should be visible under clear sky conditions.
5. Switch to the Skyplot view. If you see an airplane symbol in the skyplot then you're tracking a Wide-Area Augmentation System (WAAS) satellite; the airplane symbol marks the location of the WAAS satellite

in azimuth and elevation. If you don't see the airplane signal, make sure your receiver is configured to receive the WAAS satellite signal (Real-time → wrench symbol → set Choice 1 to Integrated SBAS → set Choice 2 to Use Uncorrected GPS). SBAS stands for Satellite Based Augmentation Systems—an umbrella term for the U.S. WAAS system, the European EGNOS system, etc. Once you see the airplane symbol in the skyplot and the airplane with antenna signal at the top of the screen you'll know that you're properly tracking the WAAS satellite. To toggle to a mode in which you're not tracking the WAAS satellite, set Choice 1 to Use Uncorrected GPS.

6. Return to the Skyplot view and wait for the error metric at the top to settle (the number just above the satellite icon). For uncorrected GPS, this value will end up between 2 to 7 meters. For WAAS-corrected observations, the value will drop to roughly half at 1 to 3 meters. This settling period will take a few minutes. The Trimble Juno SB device uses an internal filter to make a best estimate of user position, and unfortunately that filter has a slow convergence.

7. Once the error metric converges to a fairly stable value, close the GPS Controller. (*Close it*; don't just minimize it.)

8. Open the SirfTech program (Windows flag → File Explorer → SirfTech.2009 → SirfTech).

9. If your opening screen does not contain updating values, then SirfTech needs to be configured to connect to the GPS receiver. Open up the COM screen (the screens are listed at the bottom of the SirfTech main screen). Use the buttons on this display to configure SirfTech to the correct settings, which should be COM 4 at either 4800 or 9600 baud. It's easiest to use the Find Port & Baud button instead of setting these values by hand. If the number to the right of the Messages NMEA field in the lower part of the Com screen is incrementing by two or more at a time, then the SirfTech program is ready to log data.

10. Go to the Com screen if you're not already there. Hit the Open button to the right of Log File to initiate data logging. You'll be prompted for a file name and destination folder. The None destination will put files in the My Documents folder. Log at least 10 minutes of data.

11. Hit the Close button to the right of Log File to terminate a data logging session.

12. Use File Explorer to locate your log file. Open it with Mobile Word and verify that it contains lines that start with $GPGGA. Close the file.

Extract your log files from the Juno SD over a WiFi (802.11-type) network. To link to the UT `utexas` wireless network, use the following setting on the Juno:

```
Connects to: The Internet
This is a hidden network: unchecked
Authentication: WPA2
Data Encryption: AES
The key is automatically provided: checked
EAP Type: PEAP
Domain: utexas.edu
```

Then, under the Network Adapters tab in WiFi settings:

```
My network card connects to: The Internet
```

Sessions 3 and 4: Surveying Two Known Sites

Surveyors use brass markers embedded into concrete at established sites to perform precise surveys. The brass markers serve as permanent references from which differential GPS and visual line-of-site measurements can be made. In this session, you are to use your handheld receiver to survey two brass markers near the WRW building. The two markers are located at:

1. The Mustang statue, at the intersection of 24th Street and San Jacinto Avenue. The marker is embedded in the sidewalk in front (west) of the statue. Etched on top is the number 83.
2. The front of the Engineering Teaching Center (ETC) building, where the Mechanical Engineering Department is located. This marker is labeled with the number 56.

One student should stand on each marker with the GPS receiver and record observations.

By now you should be familiar with the procedure to record position estimates from the Juno SB, so they will not be repeated here. Instead, here are a few guidelines. Before starting the recording session, open the GPS Controller and use it to confirm two conditions. First, ensure that SBAS tracking is turned on. Second, ensure that the noise metric on the Skyplot screen settles down to a roughly constant number. Then record at least 10 minutes of observations.

Return to the same spot at least 30 minutes later and record another set of observations. Have a different team member collect these observations.

Analysis Tasks

1. Write a MATLAB function to convert from latitude, longitude, and height relative to the WGS-84 ellipsoid into a position vector in the earth-centered earth fixed reference frame. Your function should adhere to the following interface:

```
function [pVec] = lla2ecef(lat,lon,alt)
% lla2ecef : Convert from latitude, longitude, and altitude (geodetic with
%            respect to the WGS-84 ellipsoid) to a position vector in the
%            Earth-centered, Earth-fixed (ECEF) reference frame.
%
%
% INPUTS
%
% lat ----- latitude in radians
%
% lon ----- longitude in radians
%
% alt ----- altitude (height) in meters above the ellipsoid
%
%
% OUTPUTS
%
% pVec ---- 3-by-1 position coordinate vector in the ECEF reference frame,
%           in meters.
```

```
%
%+------------------------------------------------------------------------------+
% References:
%
%
% Author:
%+==============================================================================+
```

Turn in a printout of your function.

2. Write a MATLAB function to convert from a position vector in the earth-centered earth fixed reference frame to latitude, longitude, and height relative to the WGS-84 ellipsoid. You'll use this function in a later lab. Your function should adhere to the following interface:

```
function [lat,lon,alt] = ecef2lla(pVec)
% ecef2lla : Convert from a position vector in the Earth-centered, Earth-fixed
%            (ECEF) reference frame to latitude, longitude, and altitude
%            (geodetic with respect to the WGS-84 ellipsoid).
%
%
% INPUTS
%
% pVec ---- 3-by-1 position coordinate vector in the ECEF reference frame,
%           in meters.
%
% OUTPUTS
%
% lat ----- latitude in radians
%
% lon ----- longitude in radians
%
% alt ----- altitude (height) in meters above the ellipsoid
%
%+------------------------------------------------------------------------------+
% References:
%
%
% Author:
%+==============================================================================+
```

Turn in a printout of your function.

3. Write a MATLAB function that generates the rotation matrix used to convert from ECEF coordinates to local east, north, up (ENU) coordinates. See Misra and Enge, 4.A.2. Your function should adhere to the following interface:

```
function [R] = ecef2enu(lat,lon)
% ecef2enu : Generate the rotation matrix used to express a vector written in
%            ECEF coordinates as a vector written in local east, north, up
%            (ENU) coordinates at the position defined by geodetic latitude
%            and longitude.
%
```

```
% INPUTS
%
% lat ----- geodetic latitude in radians
%
% lon ----- longitude in radians
%
%
% OUTPUTS
%
% R ------- 3-by-3 rotation matrix that maps a vector v_ecef expressed in the
%           ECEF reference frame to a vector v_enu expressed in the local
%           east, north, up (vertical) reference frame as follows: v_enu =
%           R*v_ecef.
%
%+------------------------------------------------------------------------------+
% References:
%
%
% Author:
%+==============================================================================+
```

4. Use the NMEA data you collected to perform the following analysis for each survey session:
   (a) Run the data file through the provided MATLAB script to obtain a time, latitude, longitude and height for each sample during the session (likely these are recorded at a one second rate). Using these samples, calculate the mean latitude, longitude, and height.
   (b) Calculate the average number of satellites tracked. Again, use the supplied MATLAB script to obtain the number of satellites tracked at each epoch of tracking.
   (c) Describe the general characteristics of the data at each marker.
   (d) Using the average latitude, longitude, and height values at each site and your MATLAB function, compute the ECEF position vector.
5. Estimate the distance between the two markers, in meters.
6. For each of the two sets of data you collected at the Mustang statue, perform the following data processing:
   (a) Create a single scatter plot of the delta-latitude (vertical axis) versus delta-longitude (horizontal axis) measurements for both data sets by subtracting the average latitude and longitude values. Make sure the axes are to the same scale, i.e., the xy-grid should be square. Identify on the plot which measurements go with which data set by choosing different symbols on the scatter plot for each data set.
   (b) Create another scatter plot in delta-east and delta-north by the following procedure:
      i. Calculate the mean ECEF position vector.
      ii. Subtract the mean ECEF position vector from each one of the ECEF position vectors in the set to generate a set of ECEF difference vectors.
      iii. Calculate the rotation matrix corresponding to the Mustang statue's latitude and longitude with your `ecef2enu` function.
      iv. Multiply each ECEF difference vector by the rotation matrix (e.g., R*dp, where R is the 3-by-3 rotation matrix and dp is the 3-by-1 difference vector) to express the difference vector in ENU coordinates.
      v. Plot only the east and north coordinates from the ENU difference vectors.

vi. Set the axes to the same scale.

vii. Identify on the plot which of the two data sets is represented.

(c) Calculate SEP (Misra and Enge, 6.1.4) in meters and compare it to the receiver's reported position error metric.

7. Analyze the Mustang statue data:

   (a) Offer explanations for any outliers or groupings of data in these plots.

   (b) Compute the height residuals compared to the mean for this station and compute the standard deviation of these height residuals. How does this compare with the CEP (Misra and Enge, p. 215) of the horizontal positions? Explain why one might be greater than the other.

   (c) Based on your data sets, what is the precision of the Trimble receiver (precision is experimental repeatability, or spread around the mean)? Is this the same as the accuracy of the receiver? Explain. Give a brief discussion of how you determined the precision. How precise is your precision estimate?

8. Extra Credit (5 points): Plot one of the Mustang statue data sets in Google Earth. Do this by formatting the latitude, longitude, and altitude data as shown in the example KML file `rocket.kml` found on the course website. Simply draw your modified `*.kml` file into Google Earth using Open under the Google Earth File menu. Hand in a screenshot of Google Earth with your data plotted. How accurately do you think Google Earth renders its photographs?