**ENGO-629 LAB 1 REPORT**

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* **Data Description and Lab objective**

Data file (satpos\_meas.txt) contains GPS pseudorange (distance between GPS satellite and receiver) observations at a data rate of 1 Hz from a Trimble R8 receiver set up on a moving land vehicle. The following 3D plot shows the trajectory of the vehicle in the ECEF frame.

A picture containing chart

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Figure : Vehicle Trajectory in ECEF frame (axes in meters)

Following are the Lab Objectives -

* Implement Least Square and Kalman filter methods with application to GPS positioning of a moving land vehicle.
* To gain insight into the difference between the Least Square and Kalman Filter methods
* **Methods Implemented**

1. **Least-Squares** –

**ALGORITHM**

I have implemented two types of Least-Squares.

* LS, where Weight Matrix is taken as identity matrix
* WLS, where Measurement/Pseudorange standard deviation is determined using the following formula and therefore weight is assigned =

Threshold of 1 millimeter ( is chosen for which if the value of goes below this threshold, the regression will be discontinued, and final estimates will be obtained.

Initial state vector approximation is taken zero vector.

1. **Extended Kalman Filter** –

**ALGORITHM**

Diagram

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Parameter Settings –

* Matrix coefficients are taken identity matrix.
* For Initial State Vector (), XYZ is initialized WLS generated position, estimated using first epoch data. All the other state variables are assigned zero values.
* A-Priori estimate error covariance matrix () for state XYZ is therefore assigned - value. Other state variables are assigned infinite(large) variance.
* Posterior Estimate Error () is updated using Joseph Form to ensure Positive Definiteness
* The process noise(Q) for Rx Clock offset and Clock drift is the following matrix: spectral density is based on Typical Allan Variance Coefficients for TCXO (low quality).

*Reference - Introduction to Random Signals and Applied Kalman Filtering by Robert Grover Brown and Patrick Y. C. Hwang.*

* I have implemented two different EKF models –
  + Constant Position Model - Modeling the dynamics of the receiver’s position and clock offset errors as a random walk process.
    - Spectral density is assigned in ENU frame
  + Constant Velocity Model - Modeling the dynamics of the receiver’s velocity and clock drift errors as a random walk process.
    - Spectral density is assigned in ENU frame
* After assigning spectral density in ENU frame they are then transformed to ECEF frame –

The reason behind assigning spectral density matrix in ENU frame is that we know with certainty that in local tangent plane, the vertical motion of the moving vehicle is very limited or negligible, and this helps to better model the process noise matrix(Q).

* Measurement Noise matrix(R) is assigned value based on the following formula
* **Results and Graphs**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| RMSE(m)/Method | Least Squares | Weighted Least Squares | EKF – position random walk | EKF – velocity random walk |
| Easting | 0.8755 | 0.8087 | 0.7902 | 0.7389 |
| Northing | 1.7544 | 1.7968 | 1.8230 | 1.7233 |
| Up | 1.5586 | 1.5875 | 1.5374 | 1.4934 |
| 3d Error | 2.5047 | 2.5304 | 2.5122 | 2.3972 |
| 2d Error | 1.9607 | 1.9704 | 1.9869 | 1.8751 |

**Table 1: RMSE error measures (in m) for each of the implemented algorithms.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 95th Percentile (m)/Method | Least Squares | Weighted Least Squares | EKF – position random walk | EKF – velocity random walk |
| Easting | 1.7163 | 1.5535 | 1.4980 | 1.4282 |
| Northing | 3.4091 | 3.4770 | 3.3810 | 3.1224 |
| Up | 3.0715 | 2.9961 | 2.4036 | 2.3453 |
| 3d Error | 4.5622 | 4.4929 | 3.9939 | 3.8727 |
| 2d Error | 3.5635 | 3.5899 | 3.4215 | 3.2270 |

**Table 2: 95th percentile error measures (in m) for each of the implemented algorithms.**

The following graphs show the comparison of all four implemented estimation algorithms.

Chart, scatter chart, bubble chart

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Figure : Horizontal Error (in m)

Chart, histogram

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Figure : 3D RMSE error

Chart

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Figure : RMSE error in East component (in m)

Chart, line chart

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Figure : RMSE error in North component (in m)

Chart, line chart

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Figure : RMSE error in Vertical/Up component (in m)

***Please Note: Individual graphs for each estimation method is present ‘results’ folder***

* **Analysis and Conclusion**
* EKF method based on receiver position and clock offset as a random walk or constant velocity model EKF is the best performing estimation algorithm out of all the four algorithms implemented and tested and followed by EKF based on constant position model. And eventually, the least accurate method is least squares.
* The accuracy performance of both LS and WLS is almost equivalent for the given data. Theoretically, WLS is a superior estimation method to LS.
* 95th percentile accuracy metric exhibits the superiority of both the EKF models compared to the Least square’s method, which wasn’t that explicit with the RMSE metric.
* The reason becomes apparent on observing the graphs. EKF model undoubtedly produces a less noisy or smoother error curve, meaning a more precise position solution. But there are instances/during the data processing when EKF models produce outliers. This can be attributed to faulty prediction during filtering, possible scenario can be receiver vehicle taking sharp turns.
* Large errors are given more weightage in the RMSE metric, leading to nearly equivalent RMSE metric among all four implemented methods.
* Among the three directions in the local tangent plane, error in the East direction is the least followed by vertical or up direction, and lastly, error in the North direction is the most.
* In the next lab, I will implement adaptive KF and robust estimation methods and compare the results.

***NOTE:*** *The source code for this Java based project can also be found on the github – (link:* [*naman4u13/ENGO629 (github.com)*](https://github.com/naman4u13/ENGO629)*). User only needs to modify the output file path, before compiling the code to output the solution. Graphs and Output file concerning estimation accuracy and errors can be found in ‘ENGO629 -> result’ folder in the home directory. Code is present inside ‘ENGO629 -> lab’ folder.*