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TD state estimation by Kalman filtering

Consider a vehicle moving in a straight line with variable acceleration and speed. Its dynamic state X to observe is characterized by the position "x" and speed "v".
It is assumed that the vehicle path is linear.

It has a GNSS receiver. We use the raw pseudo-ranges of 3 GPS satellites the positions of which (x_i, y_i) are known (they are located at a typical altitude of 20200 km). For simplicity, we assume that the 3 satellites are in the same plane and the path of the car belongs to this plan.
In addition, it is assumed that the road is perfectly horizontal, in which case, for the car, $y = 0$.

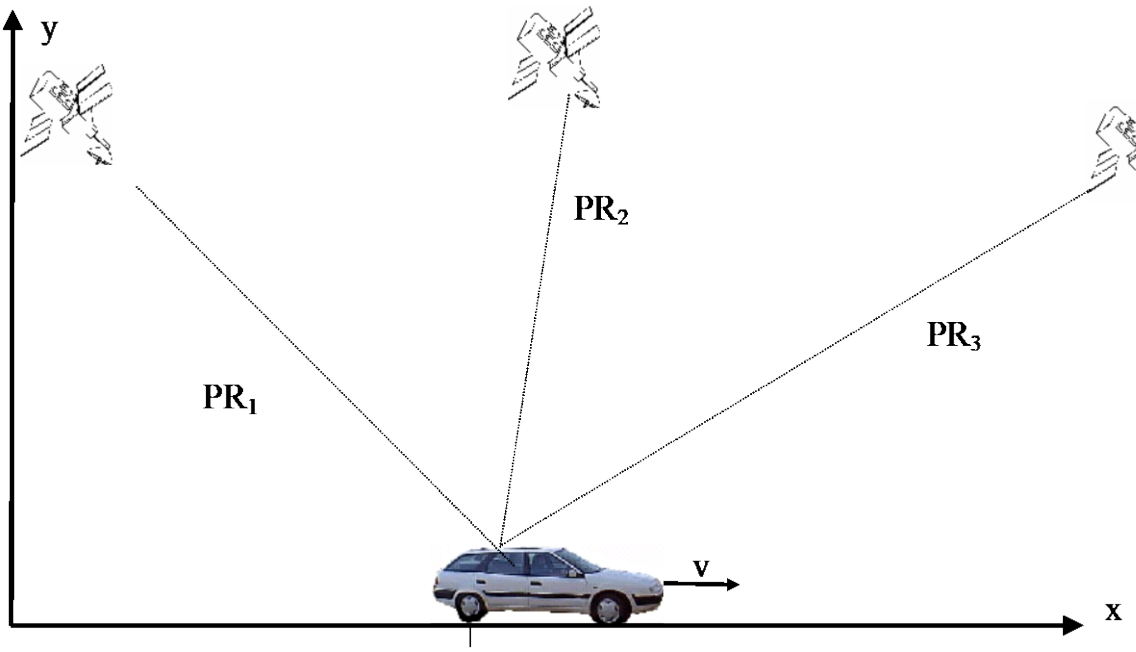

Figure 1. A car driving on a straight road.

1 System modeling

What is the discrete recurrence equation linking $\{x_{k+1}, x_k, v_k\}$ assuming that the speed is piecewise constant?
Assuming further that the speed varies randomly between two sampling instants, give a stochastic discrete state space of the system.
What are the pseudo-range equations taking into account the clock offset of the receiver w.r.t. the GPS time?
Write a discrete state representation of the system assuming that the speed and the receiver clock offset are constant (even if there are varying with respect to time).

2 Observation of the state

Give the equations of the Kalman filter to observe X.
What is the expression of the covariance matrix of the noise model?
What state and what initial covariance matrix of the observation error do you take?

3 Simulation

In the Matlab simulation kit, get inspired from the model file to test the filter performance with the data file "data.mat" corresponding to a mobile and unknown variable speed for two minutes.
Tune the different covariance matrices.

With the given Matlab simulation kit, test filter performance with the data file "data.mat".

```
Te            sampling period
t             time
c             the speed of light in vacuum
dt            true offset between the receiver clock and GPS time (to
              calculate errors)
strada.x      real position (to calculate errors)
strada.v      real speed (to calculate errors))
gps.s1.x      abscissa of satellite 1
gps.s1.y      ordinate of satellite 1
gps.s1.PR     Measured pseudo-Range on satellite 1
gps.s1.sPR    Standard deviation of the pseudo-distance measurement
on satellite 1
```

4 Fusion of GNSS and tachometer

The vehicle measures the speed using an odometer (tachometer). The GNSS receiver and the odometer are sampled simultaneously and periodically with the period Te=1 s.
Repeat the same questions using now the measurement of the speed in the filter.

```
tachy.v       speed measured by the tachometer
tachy.sv      standard deviation of speed measurement
```

Compare with previous observations. Is the estimation process improved?

5 Sequential data fusion

We suppose that the noises on the pseudoranges are not correlated.
Modify the implementation of you Kalman filter to make it update the state sequentially with one pseudorange at a time.
Try your filter with two satellites. What can you see?
Does-it works with one satellite only?

6 Handling outliers measurements

Pseudoranges are sensitive too multipath which can generates “outliers”. Use the Mahalanobis test to reject bad GPS pseudoranges which are not coherent with the predicted measurements.
Use the file “simulated_data_with_outliers.mat” in which only “satellite n°1” is affected by multipath.