

Unscented Kalman Filter Notes

Error Parameters

The project requires estimations to be made for the process noise, to set values for the standard deviation of longitudinal acceleration (`std_a_`) and yaw acceleration (`std_yawdd_`).

```
// Process noise standard deviation longitudinal acceleration in m/s^2
std_a_ = 0.8;      // was ridiculous value of 30...

// Process noise standard deviation yaw acceleration in rad/s^2
std_yawdd_ = 0.6;  // was ridiculous value of 30...
```

These values were derived as follows.

Longitudinal acceleration

For a bicycle, it is reasonable to assume that the maximum speed is approx. 20mph / 32km/h.

This is equivalent to a maximum speed of approx. 9m/s.

This maximum speed can be achieved in c. 5-6sec from a standing start, giving a maximum acceleration (a_{\max}) of approx. 1.6m/s².

Using the rule of thumb (from lectures of taking half the maximum acceleration as the standard deviation), this gives `std_a_` = 0.8m/s².

This value was used as the estimate for the filter parameters.

Yaw acceleration

For a bicycle, consider how a rider may make a sharp turn left (in the UK/driving on the right) or right (in the US/driving on the right) – i.e. without having to consider crossing oncoming traffic. This would be roughly a 5 second manoeuvre to make a ¼ of a full turn. The rider will need to go from zero yaw rate to maximum yaw rate and back to zero (straighten up).

Assuming that the rider reaches maximum yaw rate mid-turn (at 2.5sec), we can estimate that the rider could continue at that yaw rate and complete a full turn in 10sec (very rough estimate of bicycle dynamics). That would be a maximum yaw rate of $2 * \pi / 10 = 0.6\text{rad/s}$.

This is equivalent to accelerating from zero yaw to max yaw in 2.5sec. This likely isn't a smooth acceleration, so if we assume 1sec to go from zero to 0.6rad/s, this give an acceleration of 0.6rad/s².

This gives an initial estimate for our value of `std_yawdd_` = 0.6rad/s².

Filter Consistency

Filter consistency can be estimated from the NIS calculated values.

The plot below shows Lidar NIS values from the test data, plotted against the Chi-Sq.050 value for 2 degrees of freedom (5.991).

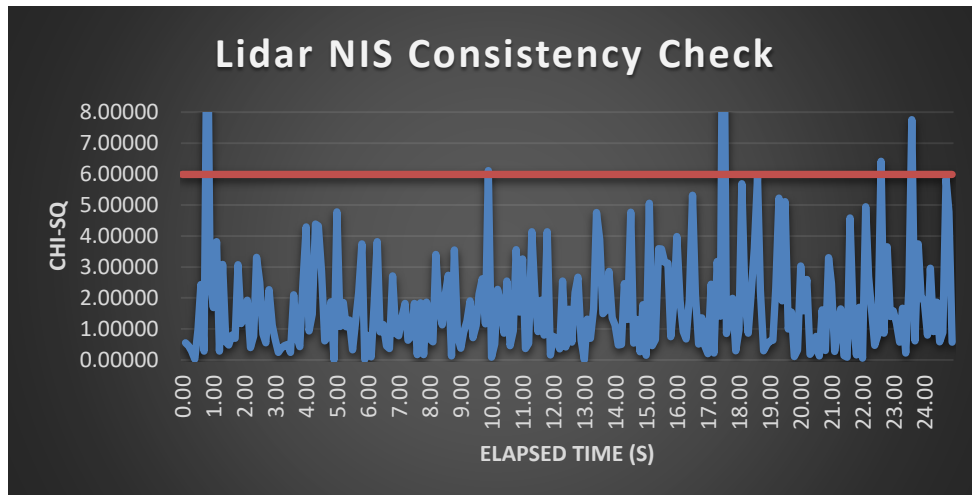


Figure 1: Plot of Lidar NIS against 5% Chi-Sq value of 5.991 for 2 degrees of freedom

The plot shows occasional breaches of the 5% reference line, with the majority of predictions within the expected range, as would be expected for a consistent filter.

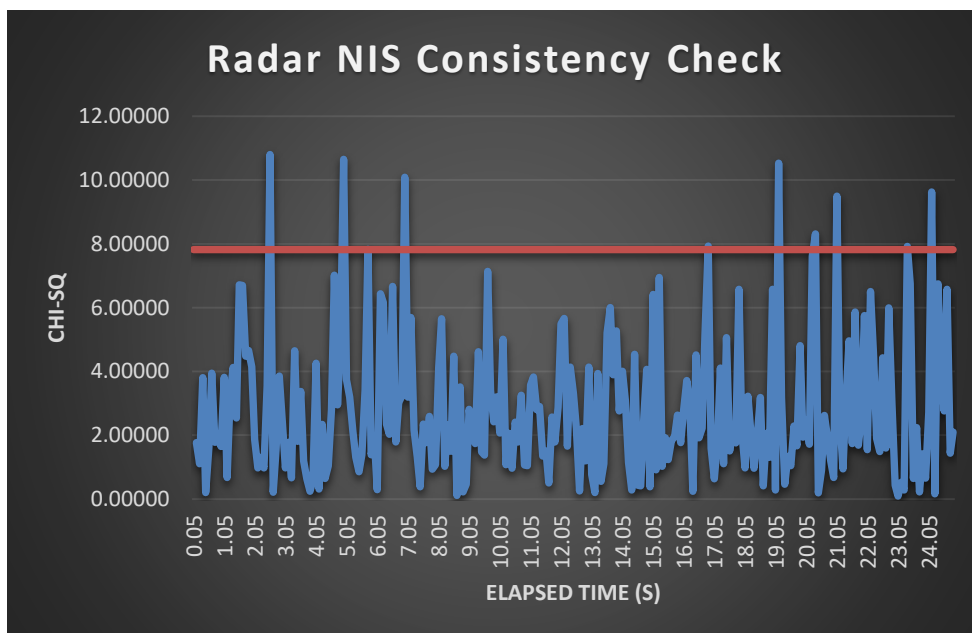


Figure 2: Plot of Radar NIS against 5% Chi-Sq value of 7.815 for 3 degrees of freedom

Again, the plot shows occasional breaches of the 5% reference line, with the majority of predictions within the expected range, as would be expected for a consistent filter.

Comparison with Extended Kalman Filter

The EKF project returned RMSE values on sample data as shown in the following table.

Value	RMSE sample data #1	RMSE sample data #1	RMSE “synthetic” data
Px	0.065	0.185	0.140
Py	0.061	0.190	0.666
Vx	0.533	0.477	0.604
Vy	0.544	0.804	1.624

(Note: the “sample data” files are those provided for the EKF project, whilst the “synthetic” data is the file provided for the UKF project.)

The UKF project returned the following RMSE values:

Value	RMSE sample data #1	RMSE sample data #1	RMSE “synthetic” data
Px	0.075	0.184	0.068
Py	0.077	0.214	0.083
Vx	0.587	0.433	0.280
Vy	0.577	0.610	0.216

From the table above, it appears that the EKF and UKF projects perform to a similar level on the first two sets of sample data (in fact, the EKF is slightly better but always by less than 0.05). This very similar performance should be expected on data drawn from an object in linear motion, as the EKF is a good predictor of linear motion.

Note however that the UKF is generally better in predicting velocity (similar on data set 1, better on set 2 and much better on the synthetic data set). This is because the UKF uses the CTRV model, which is inherently more precise than the constant-velocity motion model used in the EKF.

Across all 4 variables, there is a marked difference in performance on the non-linear data provided for the UKF project – especially in the y direction, where the UKF is an order of magnitude improvement over the EKF results.

Comparison of Single Sensor Results

The UKF project returned the following RMSE values, all on the “synthetic” data set, with varying combinations of sensors

Value	Lidar Only	Radar Only	Lidar + Radar
Px	0.102	0.164	0.068
Py	0.097	0.178	0.083
Vx	0.605	0.301	0.280
Vy	0.249	0.317	0.216

It is clear that the combination of sensors provides a significantly more accurate set of predictions than either sensor type alone.

(A further project to compare the accuracy of this type of sensor combination with a Tesla-style video-only object detection system would be highly interesting.)