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Probabilistic Robotics
Autumn 2015
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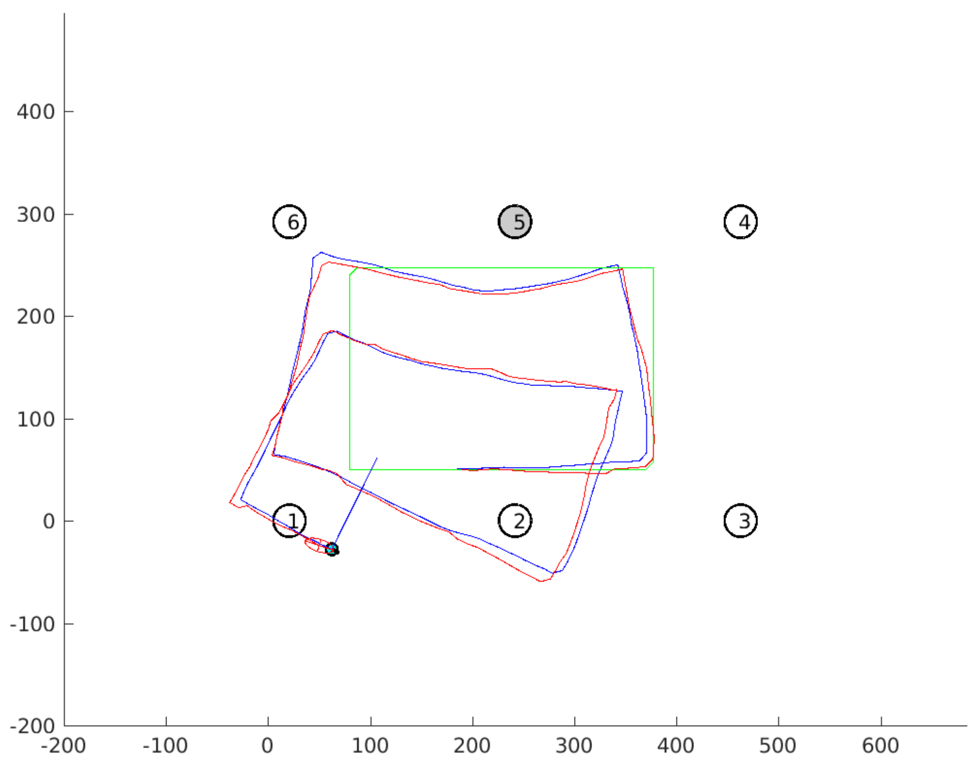
Project 2: EKF and Particle Filter Localization
Analysis

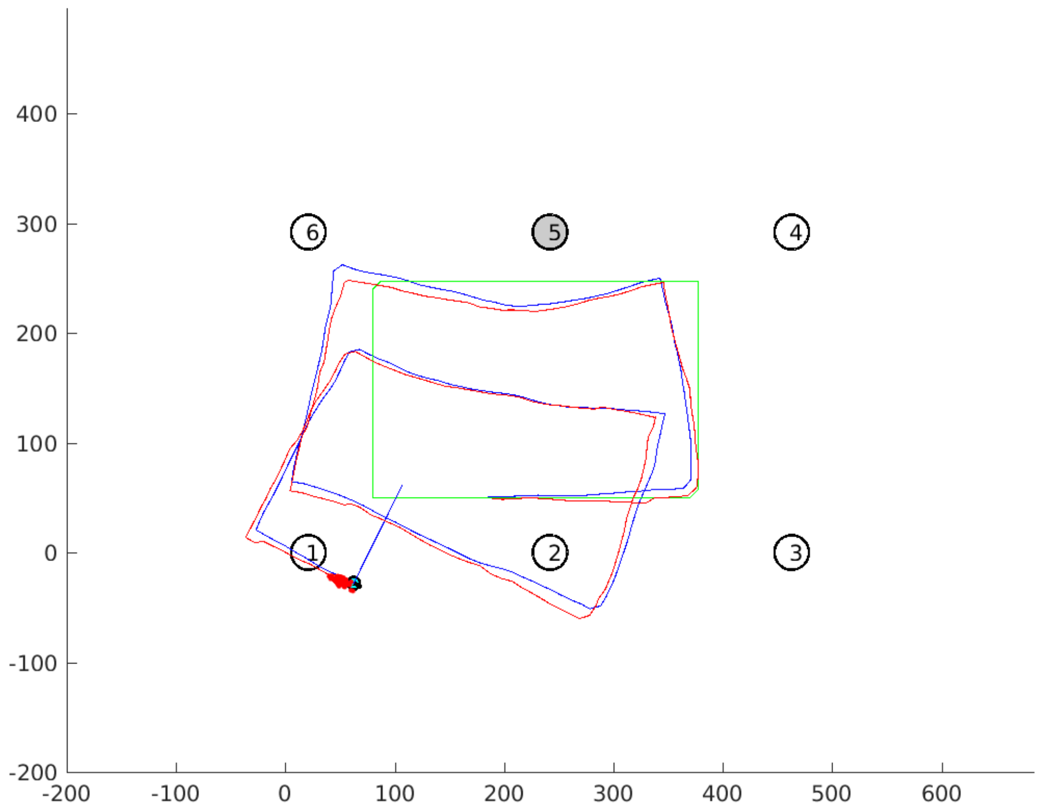
This paper investigates the effectiveness and performance of my implementations of the Extended Kalman Filter and the Particle Filter.

In the below pots, the noise-free path is shown in **green**, the real robot path is shown in **blue**, and the filter's estimated path is shown in **red.** These plots were generated over 200 time time steps, with the same starting position, noise, and control. In addition, in the Kalman filter plot, the final timestep's covariance is shown as a red circle. In the Particle Filter plot, the final timestep's samples are shown as red dots clustered around the final position of the robot.

Kalman Filter Paths



Particle Filter Paths

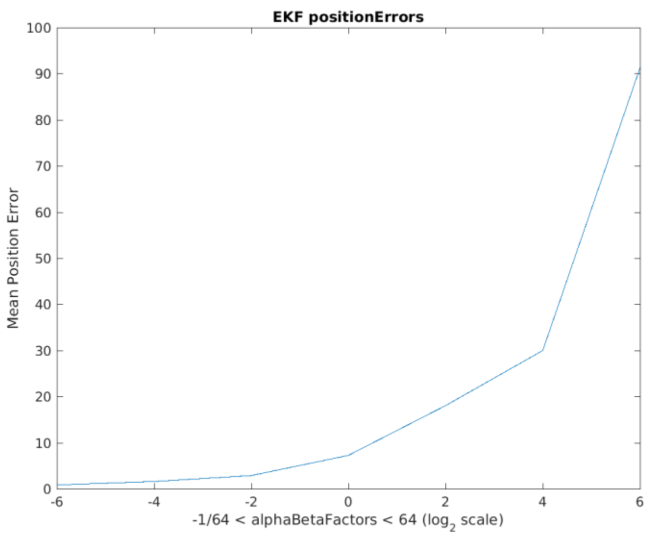


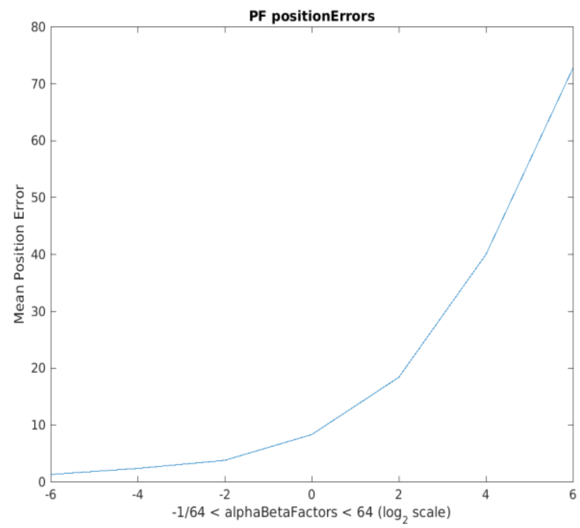
These plots alone don't tell us too much about the differences between these two plots. Upon close inspection we may be able to guess that the Particle Filter exhibits slightly more error around corners than the Kalman Filter.

Mean Position Errors as a function as All Noise Varies

a/bFactors	1/64	1/16	1/4	1	4	16	64
EKF	0.8382	1.5776	2.8616	7.2436	18.0389	29.9772	91.2609
PF	1.2497	2.3170	3.7392	8.2722	18.3438	39.9221	72.6936

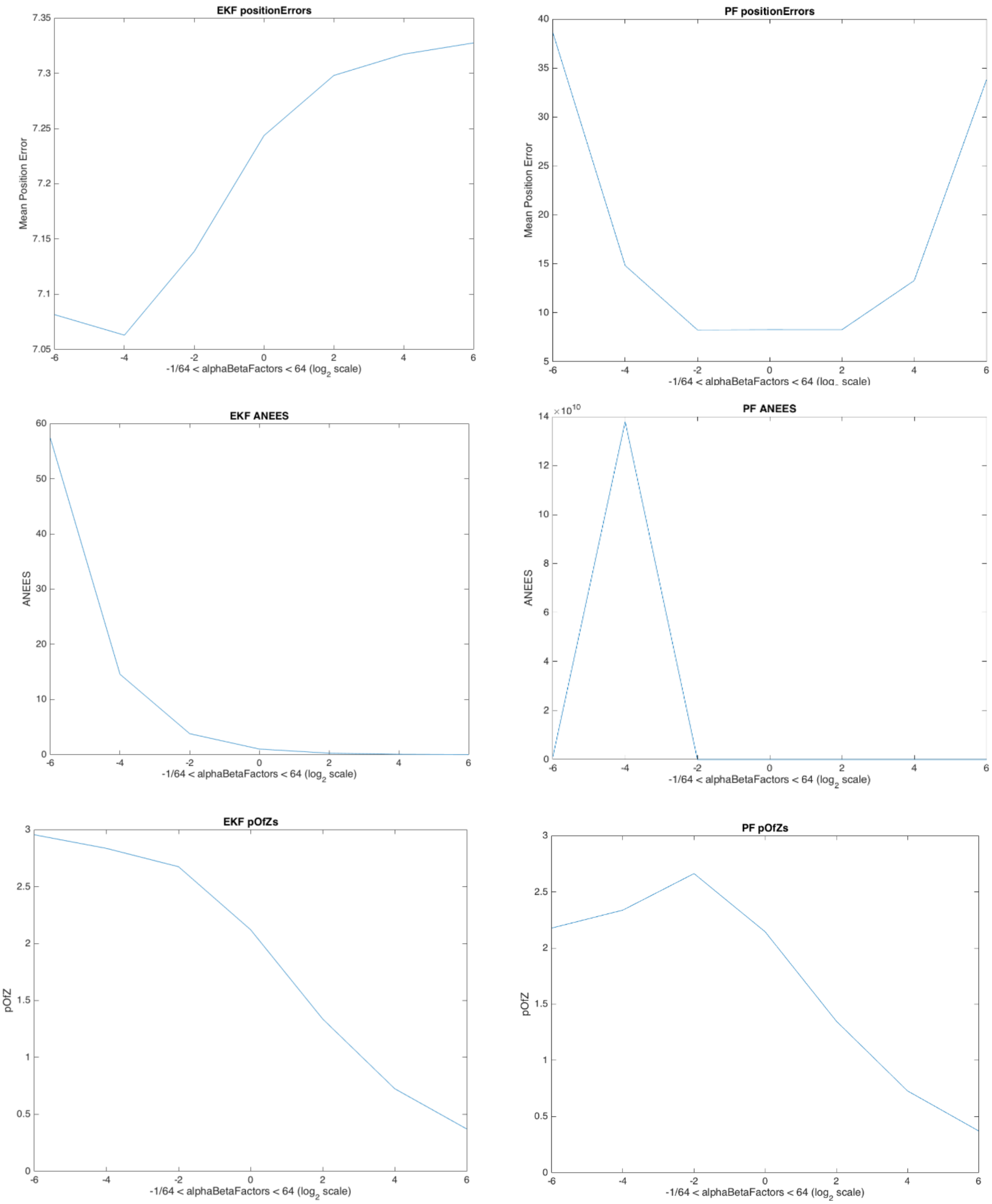
Table 1 – Mean Position Error of EKF and PF w.r.t. alpha and beta factors





These data confirm our initial hypothesis from the visual inspection -- the Particle Filter does exhibit a larger magnitude position error at a wide range of noise factors. However, for the most part they follow a similar trend, as the noise increases, the error in the filter's predictions increases accordingly.

Mean Position Error, ANEES, and pOfZ as Filter Noise Varies



bFactors	1/64	1/16	1/4	1	4	16	64
EKF	7.0815	7.0629	7.1387	7.2436	7.2981	7.3173	7.3275
PF	38.6001	14.8217	8.2484	8.2722	8.2681	13.2862	33.8008

Table 2 – Mean Position Errors of EKF and PF w.r.t Beta Factors Only

bFactors	1/64	1/16	1/4	1	4	16	64
EKF	57.3591	14.5635	3.7971	1.0131	0.2663	0.0682	0.0172
PF (1.0e11 *)	0.0122	1.3792	0.0000	0.0000	0.0000	0.0000	0.0000

Table 3 – ANEES of EKF and PF w.r.t Beta Factors Only

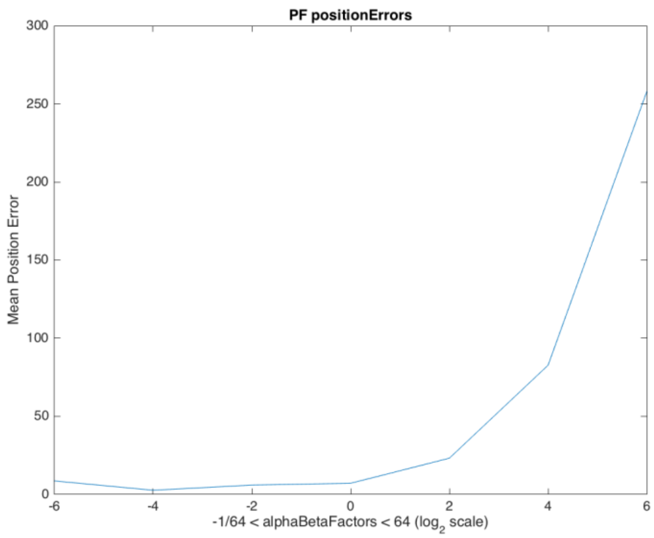
bFactors	1/64	1/16	1/4	1	4	16	64
EKF	2.9550	2.8355	2.6745	2.1214	1.3378	0.7253	0.3715
PF	2.1780	14.8217	2.6629	2.1447	1.3497	0.7289	0.3724

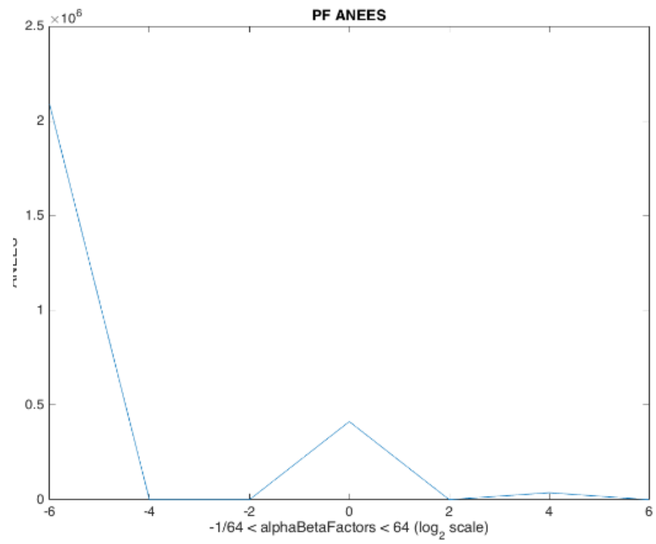
Table 4 – pOfZs of EKF and PF w.r.t Beta Factors Only

The above plots and graphs show some interesting trends. The position error of the EKF barely varies as the filter noise increases, whereas the Particle Filter's error increases exponentially as the noise increases. Perhaps this is due to the fact that the beta noise is incorporated into the weight calculation for each particle – as the noise increases, this has a profound effect on the weight of each particle, massively skewing results. We also notice that for both filters, as the filter noise increases, the mean pOfZ decreases accordingly. This is expected, as we can reason that the increased noise decreases the likelihood of any prediction being correct.

Mean Position Error and ANEES for Particle Filter as Noise and NumParticles Vary

NumParticles = 20:





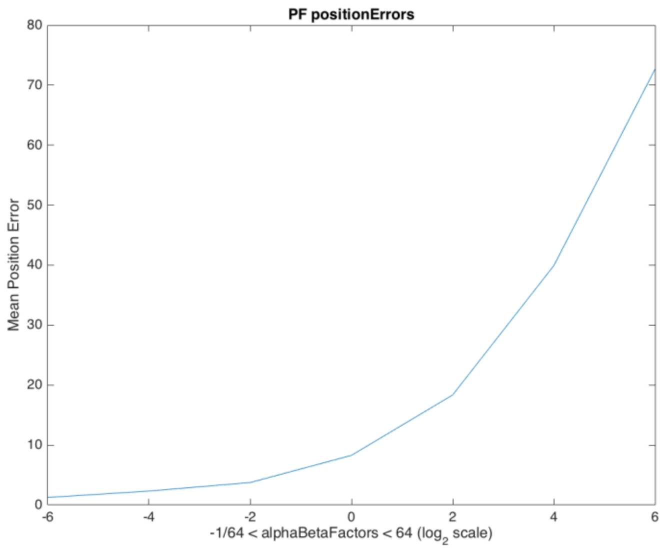
bFactors	1/64	1/16	1/4	1	4	16	64
PF	8.6314	2.6788	5.9820	7.1373	23.1865	82.7150	257.9861

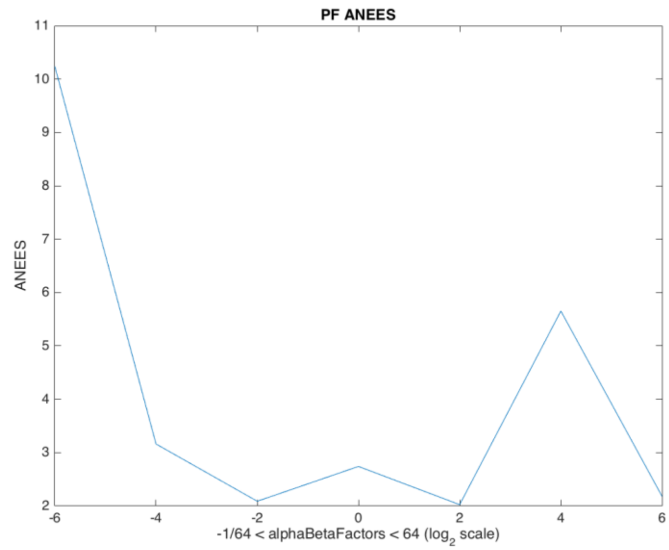
Table 5 – Mean Position Errors of PF (20) w.r.t a/b factors

bFactors	1/64	1/16	1/4	1	4	16	64
PF (1.0e6 *)	2.0889	0.0000	0.0001	0.4128	0.0008	0.0371	0.0004

Table 6 – ANEES of EKF and PF (20) w.r.t a/b factors

NumParticles = 100:





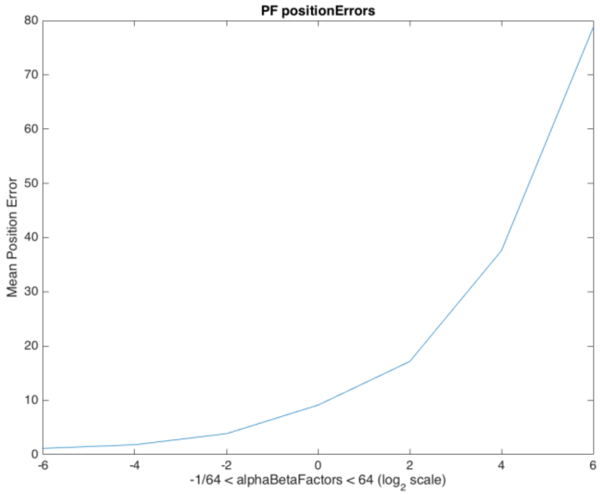
bFactors	1/64	1/16	1/4	1	4	16	64
PF	1.2497	2.3170	3.7392	8.2722	18.3438	39.9221	72.6936

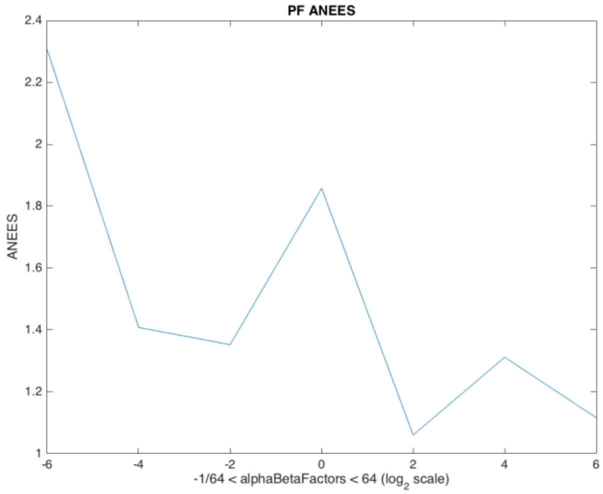
Table 5 – Mean Position Errors of PF (100) w.r.t a/b factors

bFactors	1/64	1/16	1/4	1	4	16	64
PF (1.0e11 *)	10.2365	3.1602	2.0873	2.7398	2.0237	5.6536	2.1792

Table 6 – ANEES of EKF and PF (100) w.r.t a/b factors

NumParticles = 300:





bFactors	1/64	1/16	1/4	1	4	16	64
PF	1.1424	1.8138	3.8484	9.1256	17.1696	37.5964	78.7136

Table 5 – Mean Position Errors of PF (300) w.r.t a/b factors

bFactors	1/64	1/16	1/4	1	4	16	64
PF (1.0e6 *)	2.3064	1.4080	1.3524	1.8576	1.0600	1.3116	1.1162

Table 6 – ANEES of EKF and PF (300) w.r.t a/b factors

Comparing the plots and data as the number of particles used for the particle filter increases, we see an interesting but understandable trend – as the number of particles increases, the overall error of the filter decreases to a point. We see that at the largest tested noise factor, 64, the mean error falls from over 200 at only 20 particles to 72 at 100 particles. However, this trend doesn't hold out: increasing from 100 to 300 particles actually sees a slight increase in the error, implying that adding an indefinite number of particles doesn't necessarily make the system more accurate.