MSc Human and Biological Robotics

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Human Neuro-Mechanical Control and Learning: Tutorial 5: Linear Quadratic Estimator (LQE)

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1 Part A

Figure 1 shows the signal tracking of the LQE based on a single position sensor with sensor noise σ. The true position is tracked accurately by the filtered signal for a sensor noise $\sigma = 1.5cm$. The noisy position signal deviates considerably more from the true signal as you increase the value of σ from 1.5 cm to 4.5 cm. As a result, the filtered signal when $\sigma = 4.5cm$ tracks the true signal with much less accurately. This tracking inaccuracy trends to occur at large gradients in the projectile (i.e. when the directional velocity of the butterfly changes quickly over time).

Figure 1 shows the results for the signal tracking as the initial covariance matrix P_0 changes. In these simulations, the sensor noise was set to $\sigma = 1.5cm$. As the initial covariance matrix is reduced, the convergence of the system takes longer. In other words, the higher the initial error covariance the faster the prediction converges to the true position.

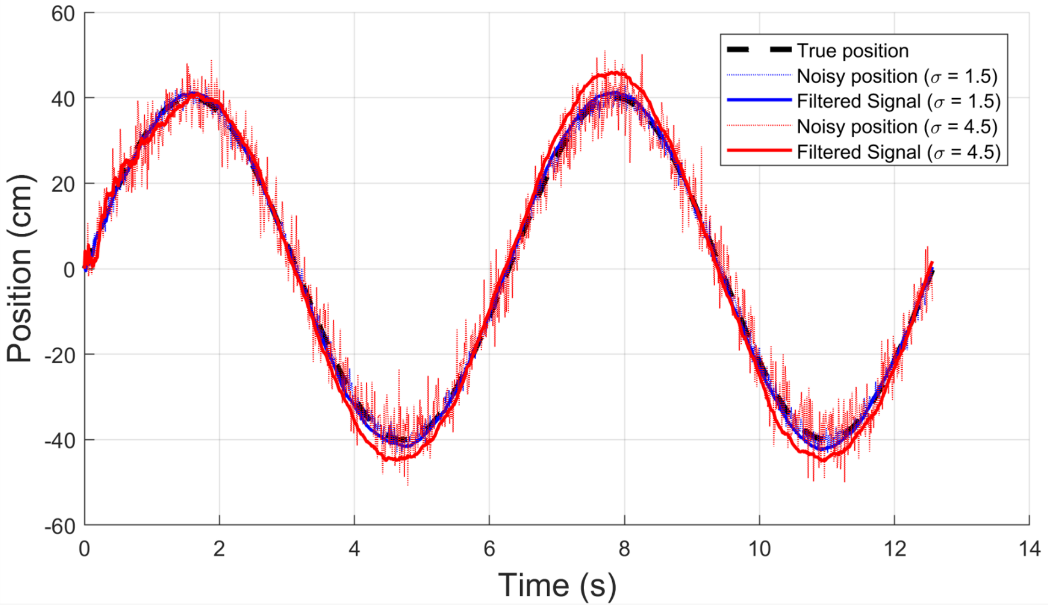

Figure 1: Signal tracking as the visual sensor noise, σ, is varied. As the sensor noise increases, σ is given in cm.

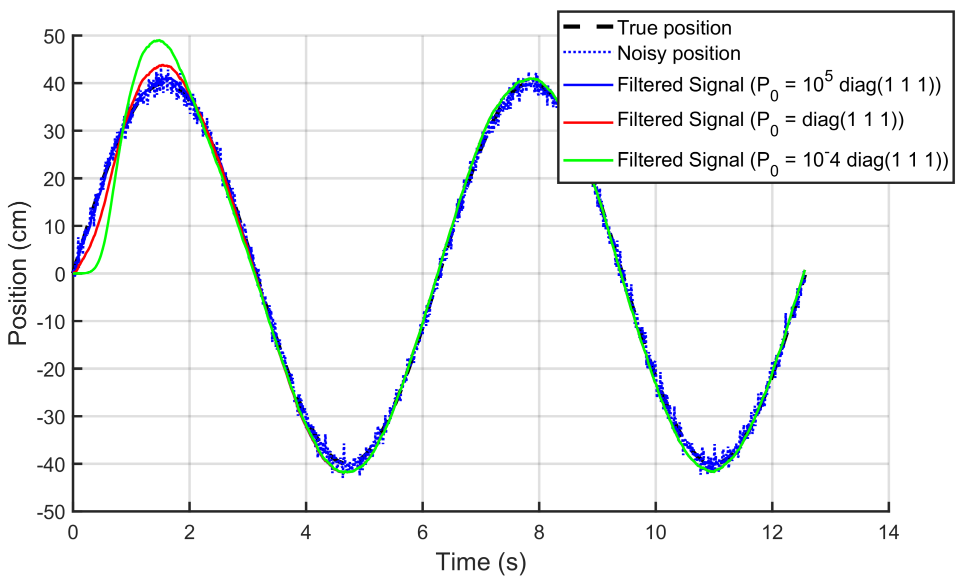

Figure 2: Signal tracking as the initial covariance matrix, P_0, is varied. In this instance, $\sigma = 1.5cm$

2 Part B

Figure 3 shows the signal tracking results when a position tracking proprioceptive sensor is added to the LQE. In this instance, the visual and proprioceptive sensors have a noise $\sigma_v = \sigma_p = 1.5cm$. The results of this added sensor into the system to the performance of the LQE indicate that in both instances the true signal is tracked accurately. By looking at the Mean Squared Error (MSE) between the the filtered signal and true position, the performance of the system with visual and proprioceptive position tracking can be compared more accurately to the system with vision precision tracking alone. The MSE for the vision sensor alone was 1.29 cm^2, while the MSE for vision and proprioception was found to be 0.63 cm^2. From this it can be concluded that adding the proprioceptive sensor increases the performance of the tracking system. These MSE readings were taken as an average over 5 trials as the noise in the system is random.

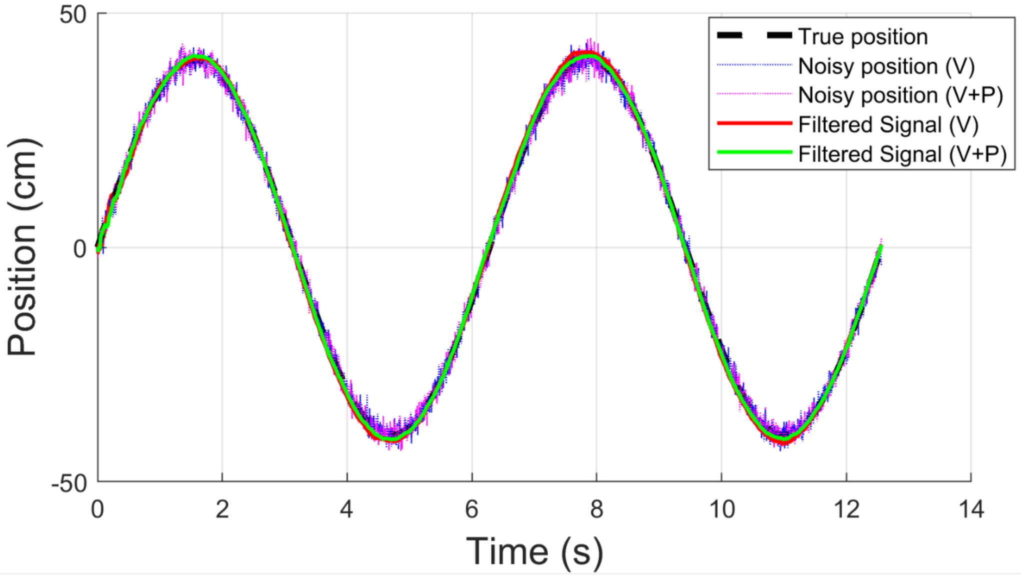

Figure 3: Signal tracking for vision alone and when coupled with proprioception ($\sigma_p = \sigma_v = 1.5cm$)

3 Part C

In this part, again the tracking system is implemented with visual and proprioceptive position tracking and compared to vision alone. However, here, the proprioceptive noise is increased to $\sigma_p = 4.5cm$, while the noise on the vision sensor remains at $sigma_v = 1.5cm$. The results are shown in figure 4. Again the performance is almost identical. By looking at the MSE of both cases gives us a better idea of the relative performance of the two implementations. The MSE of the visual tracker alone was found to be 1.36 cm^2 while it was shown to be 1.21 cm^2 for the visual and proprioceptive tracker. Again we see that adding the proprioceptive tracker increases the performance of the LQE, however, as there is increased noise compared with part b, the increase in performance is marginal. Again, the MSEs were calculated over 5 trials to find an average MSE.

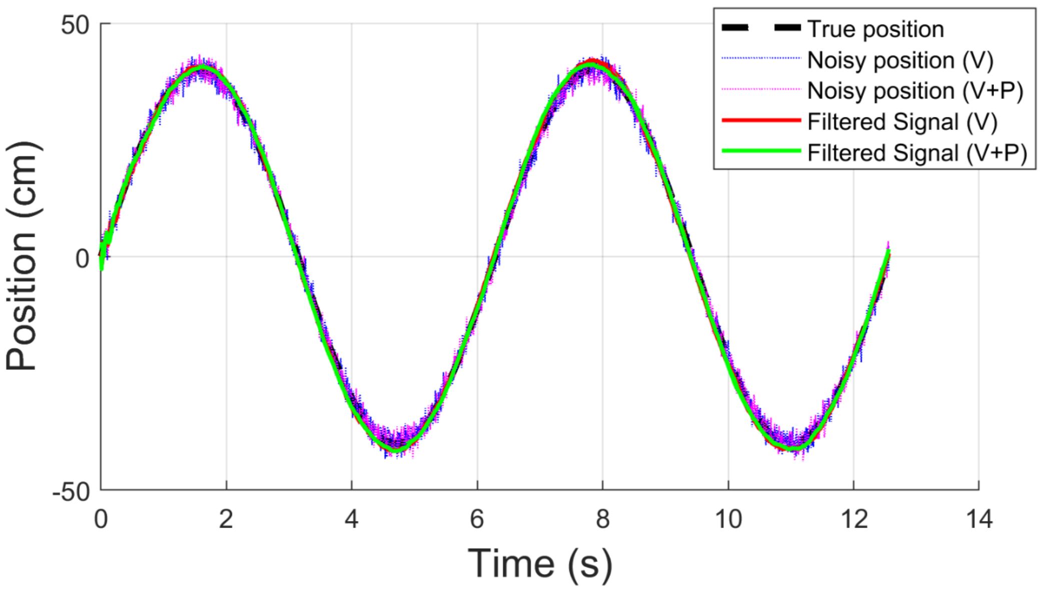

Figure 4: Signal tracking for vision alone and when coupled with proprioception ($\sigma_p = 4.5cm$, $\sigma_v = 1.5cm$)

4 Part D

Figure 5 shows the signal tracking when there is a delay in the visual sensory information of 0.1s. Figure 6 displays the same data for the time period 0 to 2s. The red dotted line denotes the delayed sensory signal and the blue solid line shows the filtered signal as a result of the state prediction data shown in magenta dotted. As is indicated in Figure 6, the predicted state only commences after 0.1s as this is the time delay of the visual sensory data. This state prediction allows the filtered signal tracking to track the true position with reasonable accuracy in spite of the delayed noisy position data.

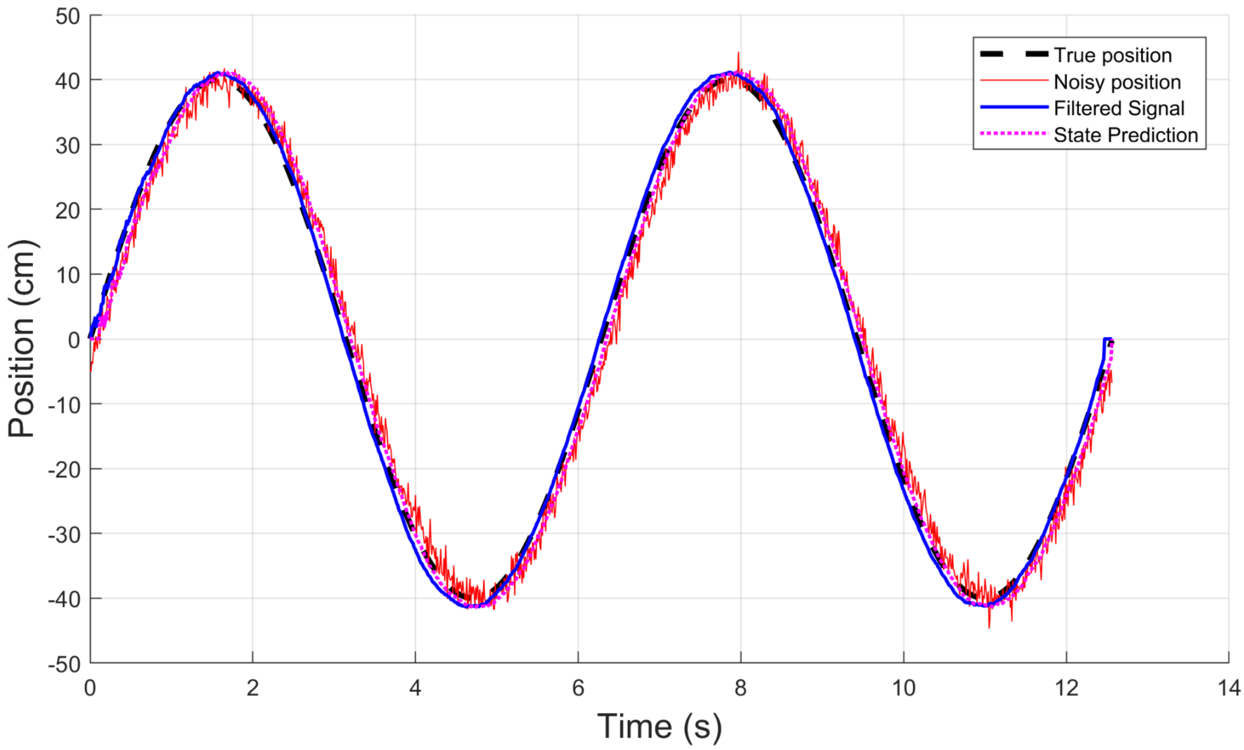

Figure 5: Signal tracking using visual sensory information with a signal noise $\sigma = 1.5cm$ and a sensory delay of 0.1 s.

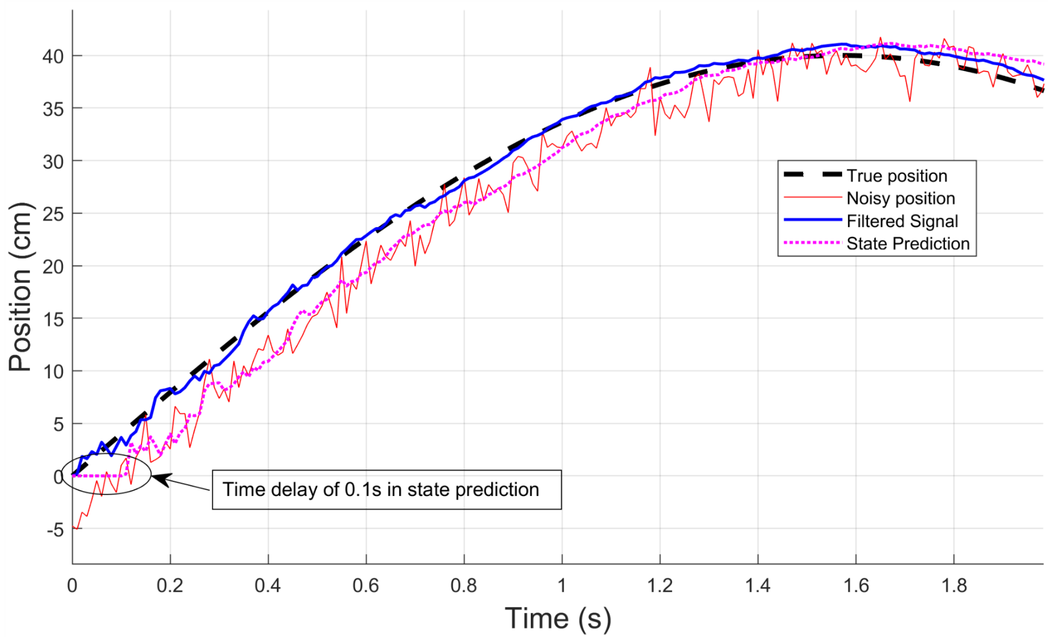

Figure 6: Zoomed in view of the first 2s of the simulation shown in full in Figure 5.