CS 661 Computer Vision Final Project Final Report

Enhanced Object Tracking Using Kalman Filtering Techniques

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- Initial Project Goals

Our goal was to implement Object Tracking using Kalman Filtering Techniques. More specifically, we aimed to test our program on artificially generated data and further apply it on custom videos on simple shaped objects.

- Achievements

We successfully constructed a program where the Kalman Filtering Object Tracking works on artificially generated videos, as well as on custom videos. These videos include simulations of: 1. an irregularly shaped object moving in linear motion with constant acceleration with random noise in position 2. a ball tossed vertically and 3. two balls in projectile motions in a noisy background. Functions to generate these videos will be included in the source code submission. The results that show the performance of our program on artificially generated data are shown below:

Since the results demonstrate similar trends for all three videos, we will discuss the results on the video with two balls in projectile motions in a noisy background. Other results can be found in the appendix.

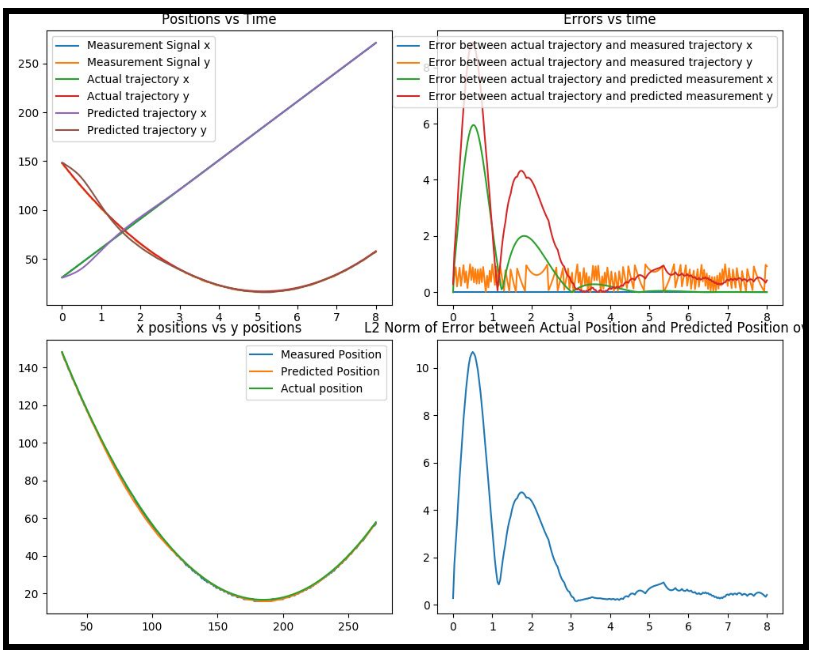

Figure 1&2: Overall Performance Analysis on artificially generated video(Two Balls in projectile motions in a noisy background) - 1. Upper Left 2. Upper Right 3. Lower Left 4. Lower Right

Plots 1 and 3 compare the x,y positions of measured position, actual position and the position corrected using Kalman Filter. Plot 2 displays errors between actual trajectory and measured trajectory in x and y and errors between actual trajectory and corrected measurement of x and

y. Plot 3 shows the L2 Norm of error between actual position and predicted position. As shown in all 4 plots, the error between the predicted and actual position is the largest at the beginning of the Kalman search. In plot 2, you can see that the error between actual positions and predicted positions is greater than that between actual positions and measured positions. However, as the Kalman search stabilizes the error between actual and corrected positions almost converges to 0 and becomes even smaller than the error between actual and measured positions.

For the artificially generated videos, the Kalman enhanced object tracking took about half the time as object tracking without the Kalman filter, with no loss of accuracy.

For the custom video, we moved (translation, scaling, rotation) a square object for object tracking. Our results for custom video are as follows:

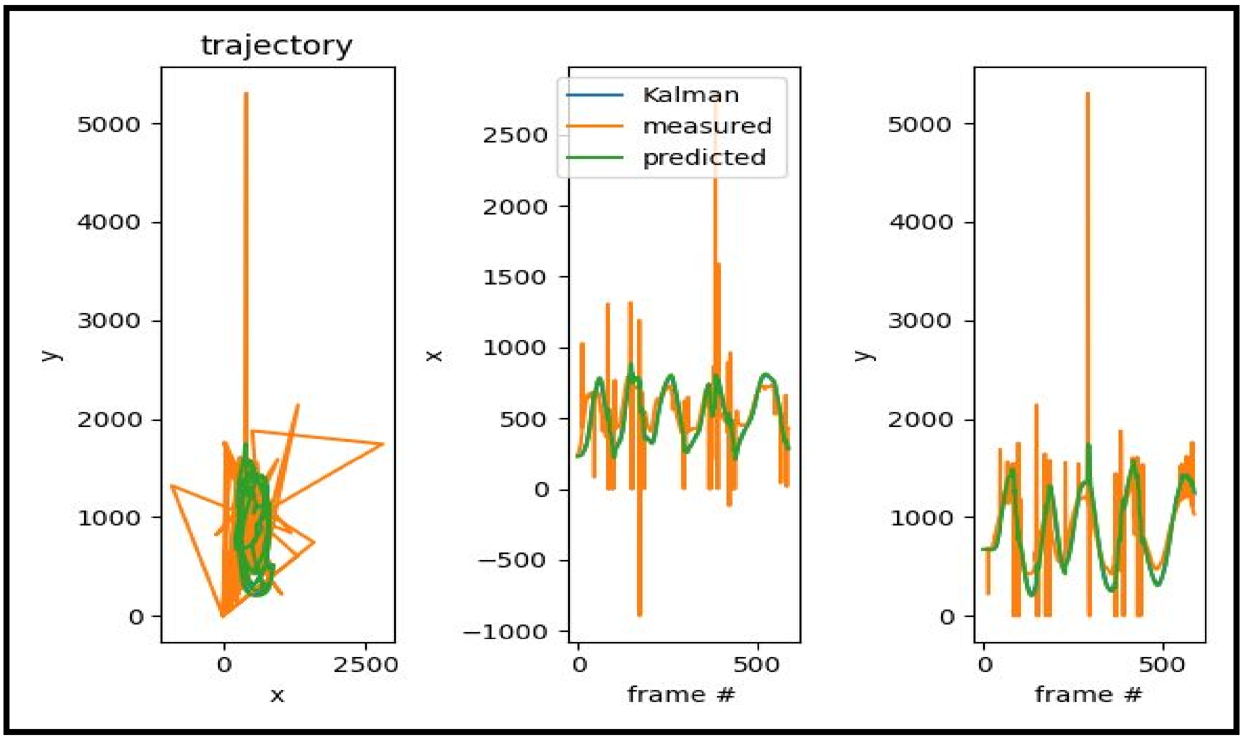

Figure 3,4 & 5 (Left to Right): Overall Performance Analysis on custom video(moving a square object)

Figure 3 shows the predicted, measured and corrected (x, y) positions of the object. Figure 4 and 5 show the predictions, measurements and corrections of x and y positions separately over frame numbers. As you can see, the predictions follow the general trend of the measured positions but do not respond to rapid changes quickly. Also note that the corrected measurement (blue) is not visible since it is covered by the predicted measurement.

We have included the video demonstrations in the code submission in gradescope to help the readers understand the results visually.

● Implemented Computer Vision Methods

Object Detection:

For object detection, we used two methods individually; one for simulated videos, the other for custom videos. On the simulated videos, we utilized a simple template matching algorithm, as we are tracking 2-D translating objects without changes in the object's image. This provided high accuracy for our simulated data, however, would not extend to real videos. In order to accommodate custom videos, we used SIFT feature detection and feature matching to track objects. This allowed for out-of-plane transformations and rotations. We would then use RANSAC and fit an affine transform to matched features. Finally, we mapped the template image's center through affine transform to determine the object's position in the video's frame.

Kalman Filter Techniques:

A linear Kalman filter was used, and a second order approximation was used to solve for a future position in terms of the current position, velocity, and acceleration. The prediction step of the Kalman filter was used to estimate the position of the tracked object in the next frame. Once the object in the next frame is found, the Kalman filter takes the predicted and actual positions and statistically combines them to form a better estimate of the position. These refined positions are then used in future predictions, leading to improved predictions over time.

● Limitations and Future Work

A limitation of template matching for object detection was its inability to extend to real images. With changes in luminosity and image lighting, template matching was not ideal. Using SIFT feature matching reconciled this limitation, however it did not always converge to a stable solution. Often, it yielded very noisy measurements and limited our Kalman Filter's accuracy. A possible future work to mitigate this issue is to develop and implement a framework that would robustly measure the accuracy of the SIFT feature matching measurement on a per-frame-basis and incorporate that into the Kalman Filter's measurement model.

● What We Learned

When we implemented the Kalman filter on custom videos using SIFT feature matching, we realized that the detection is very sensitive to the background noise. Fine tuning was very significant in improving the performance of object tracking.

● Advice to Next Year's CV Students and Instructors

Especially when meeting for projects in person is very difficult, it is important to meet often through zoom meetings. This way, there is no ambiguity of assignment responsibilities allowing for ease of parallel development. It would also be beneficial to start the project as early as possible since one might run into unforeseen errors problems in your project.

● References

1. *Optimized Object Tracking Technique Using Kalman Filter*
   https://www.researchgate.net/publication/305742100_Optimized_object_tracking_technique_using_Kalman_filter
2. *Tracking Multiple Moving Objects Using Unscented Kalman Filtering Techniques*
   https://arxiv.org/ftp/arxiv/papers/1802/1802.01235.pdf
3. *Video object tracking using adaptive Kalman filter*
   https://www.sciencedirect.com/science/article/pii/S1047320306000113

Appendix

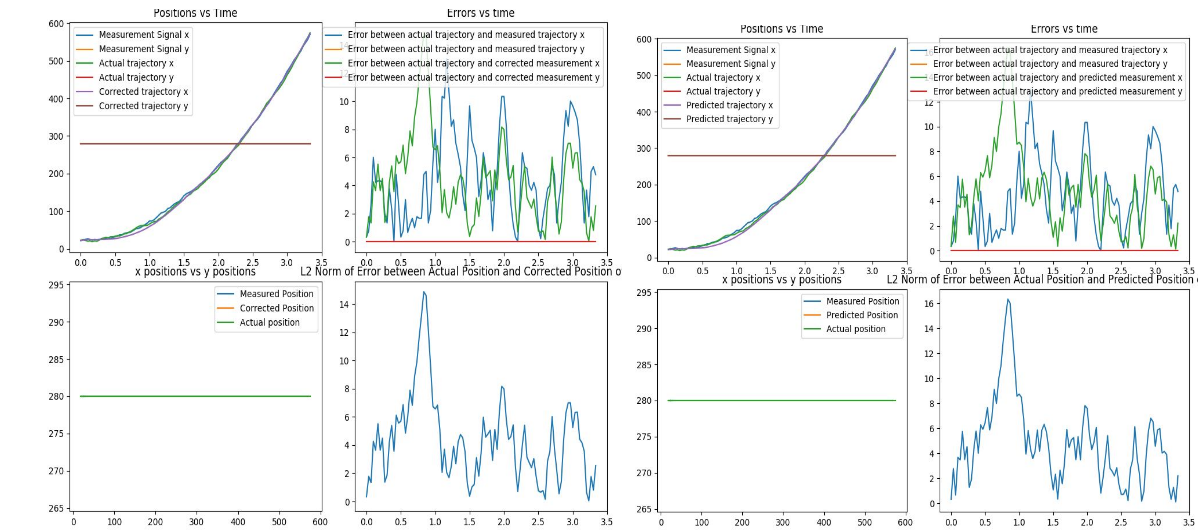

Figure 1&2: Kalman Performance Analysis(Left) and Overall Algorithm Analysis(Right) on artificially generated video(irregularly shaped object moving in linear motion with constant acceleration with random noise in position)

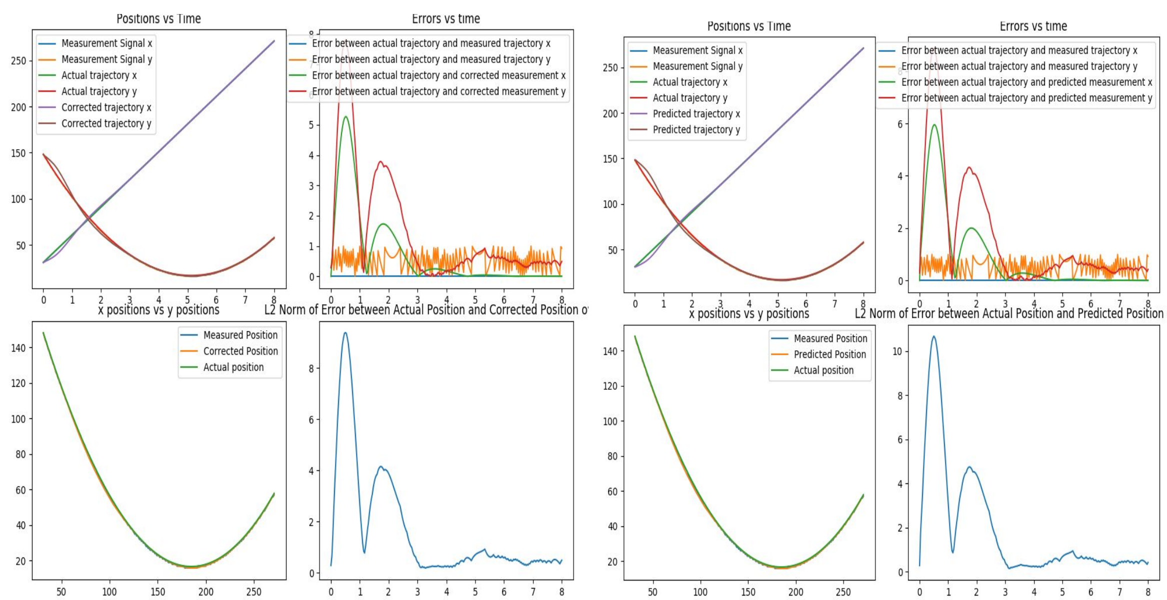

Figure 3&4: Kalman Performance Analysis(Left) and Overall Algorithm Analysis(Right) on artificially generated video(A ball tossed vertically)