Adaptive Human Motion Prediction using Multiple Model Approaches by Joppich, Rausch, and Kuhlen

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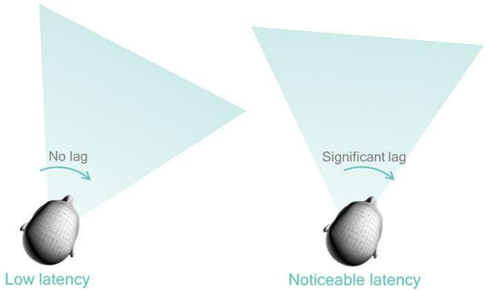
The Main Issue

- **Latency:** The delay between user input and the reaction of the system.
- Prediction can reduce the impact of latency once hardware can no longer be improved.



[1] https://www.qualcomm.com/sites/ember/files/styles/optimize/public/blog/managed-images/image-1_0.jpg?itok=uSAdJPeK

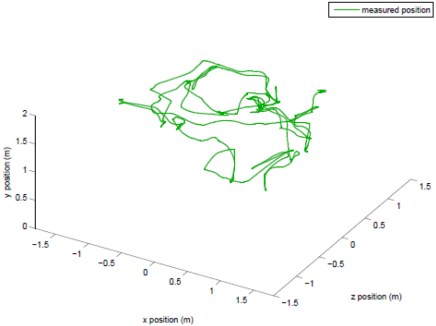
Sources of Delay

- Refresh Rate
  - Fixed value
  - Usually set to 60 frames per second/ 16.7 ms of delay
- Frame Buffers
  - Double buffering
  - One buffer is displayed while the next frame is generated on a different buffer
    - ★ purpose is to avoid displaying an unfinished frame

Modeling Human Motion

- **Two types:**
  - general model that attempts to predict any movement
  - optimized model for a specific motion
    - walking forward
    - kneeling
    - turning
- **Methods of modeling**
  - Double Exponential Smoothing (DES)
  - Kalman Filters

Modeling Human Motion cont.



Double Exponential Smoothing

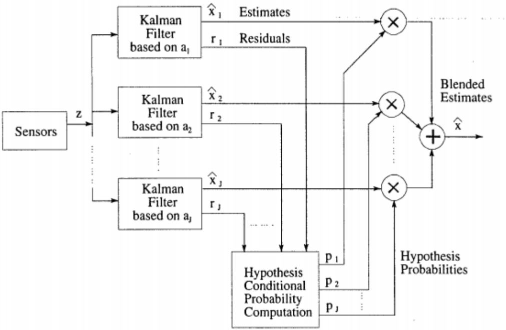
- Provides similarly accurate predictions compared to Kalman Filters at 135 times the speed
- Reduction in computational complexity comes from the transitional factor in the each equation i.e.,
  - Kalman Filters multiply the current state by a transition matrix A to get the next state
  - DES multiplies the current state by constant α to get the next state
- DES represented by two equations, one to estimate the state and one to update the trend
  - $S_t = \alpha x_t + (1 - \alpha)(S_{t-1} b_{t-1}), 0 \leq \alpha \leq 1$
  - $b_t = \gamma(S_t - S_{t-1}) + (1 - \gamma) b_{t-1}, 0 \leq \gamma \leq 1$

Only Linear

- Human motion is defined as general motion i.e., a combination of linear and angular motion
- Linear motion is motion along a line
  - Straight
  - Curved
- Angular motion is rotation around a central line or point
- **Orientation is not considered, therefore angular motion can be excluded**

Multiple Models Adaptive Estimator (MMAE)

- Model for traditional MMAE algorithm



- The prediction is a weighted sum of all KF-models represented by
  - $\hat{x}(t_{k+N}|t_k) = \Sigma_{Filter_i}\ \omega_i(t_k) * \hat{x}_i(t_{k+N}|t_k)$

MMAE cont.

- Multiple Kalman Filter-based models are created representing different types of motion, such as:
  - linear motion
  - parabolic motion
  - constant position
  - constant velocity change
- Each model's error is compared to the recorded trend of the system for a certain number of past frames
- Models that have high error or medium error over an interval of frames are removed from consideration while those that accurately predict the trend are added
- New models are considered every certain number of frames
  - Each filter is initialized to some number of frames in the past
  - The data is used to generate a history for the new filter
  - If the error is low enough in comparison to the current trend, the new filter is added to the weighted sum

Dual Models Adaptive Estimator (DMAE)

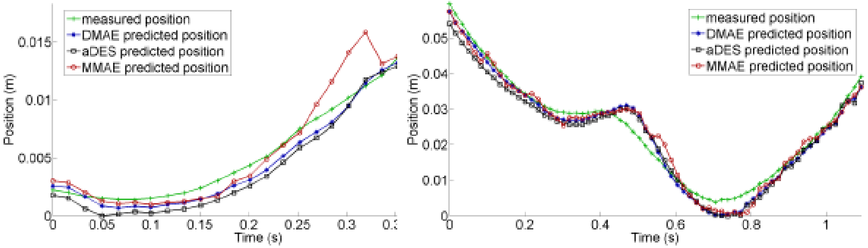
- Most human movement is either linear with short periods of acceleration or slow during motions like turning
- Only uses two models: Fast and slow linear motion
- Trades the ability to predict smaller details for better overall prediction of linear movement
- Better computation time because it only uses two filters

Evaluation

- **Two main measures of quality:**
  - Mean Absolute Error (MAE): a measure of the difference between two continuous variables
  - Jitter (as a comparison): the level of fluctuation on the prediction line

	MAE [mm]	median [mm]	0.9-quantile [mm]	jitter
no prediction	14.515	12.735	30.464	1.0
aDES	2.999	2.453	5.917	2.814
MMAE	2.806	2.338	5.255	1.909
DMAE	2.539	2.126	4.822	1.496

Conclusions



- MMAE: reacts too quickly to minor changes in velocity and assumes a curve
- DMAE: produces better results over all but loses accuracy around curves in the trend
- **Better prediction by DMAE is worth the loss of detail**

Future Works

- Expand to include focus on movement in the y-axis
  - e.g., modeling head bobbing
- Predict user orientation as well as position
- determine the effects of jitter vs positional error

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Questions?