An Analysis of Smoothing Algorithms and their effect on Signal Jitter in Optical Tracking Data

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Synopsis

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- Acknowledgements

Introduction

- The Synthetic Vision System (SVS) initiative is designed to curb the issue of low visibility
- Solution: SVS displays which render the environment regardless of external circumstances
- Current Research: Integration Commercial-Off-The-Shelf (COTS) optical tracking devices with SVS-enabled displays
- Findings revealed the necessity for a thorough study of signal jitter and its effects on optical tracking

Background

Optical tracking

- utilizes cameras and reflective material to track objects of interest
- Can be configured in two ways
  - Outside In
  - Inside Out
- No physical constraints / hindrances
- No interference from metallic objects
- No concerns about
  - Excessive reflections
  - Sound absorption

Background

Signal Jitter

- short term variations of a signal from its nominal positions
- "short term" represents the rapid occurrence of the distortion within the signal
- two main types
  - Deterministic Jitter – reproducible variations within a given system a.k.a. "bounded" jitter
  - Random Jitter - fluctuations caused by non signal or noise sources a.k.a. "unbounded" jitter

Objective

The goals of this project are:

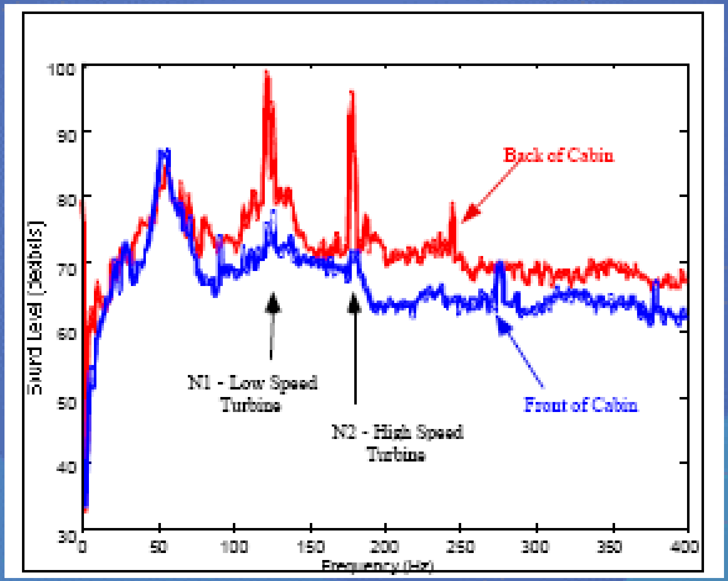
- to examine the effect and determine the significance of jitter induced by engine vibration

- to assess the effects of smoothing techniques on optical tracking data

Procedure

Simulation of Engine Vibration Jitter

- Source of Simulation



- Frequencies and Sound Pressure levels extracted from graph

Procedure

Determine vibration displacement

- Relation between pressure amplitude, p, and displacement, ε_0, is given by

$$p = \rho_0 \omega v_s \varepsilon_0$$

where: ρ0 – density of air

v_s – speed of sound in air

ω – angular frequency

- Hence

$$\varepsilon_0 = \frac{p}{\rho_0 \omega v_s}$$

Procedure

Determine vibration displacement

- Since sound pressure level, L_p is provided in decibels it must be converted using

$$L_p = 20\log\frac{p}{p_0}$$

where p_0 - threshold of hearing
p – pressure amplitude

- Hence

$$p = p_0\left[10^{\frac{Lp}{20}}\right] \quad \rightarrow \quad \varepsilon_0 = \frac{p_0\left[10^{\frac{L_p}{20}}\right]}{\rho_0 \omega v_s}$$

- Must be computed for all sampled frequencies

Procedure

Adding Vibration Displacement

- For every ε_0 calculated, the range of jitter, $j_{\varepsilon 0}$ was denoted

$$-\frac{\varepsilon_0}{2} \leq j_{\varepsilon_0} \leq \frac{\varepsilon_0}{2}$$

- A Modified Random Number Generator was created for numbers within the specified ranges
- Special generating conditions were applied for frequencies below 50 Hz
- Low frequencies corresponded to rates that were slower than the optical tracker frame capture rates

Procedure

Adding Vibration Displacement

- Optical tacking parameter must be (converted from screen units (su) to meters)

- 1 su = 1.79 * 10^{-5} m

- Total displacement, D_T is then given by

$$D_T = (1.79 * 10^{-5})k_{opt} + j_{\varepsilon_0}$$

where k_{opt} – Optical Tracking Parameter in su

Procedure

Application of Smoothing Algorithms

- Three algorithms were used in this study
  - Loess Smoothing
  - Moving Average Filter
  - Savitzky-Golay Filtering
- Criterion for selection
  - Relation to classical methods of smoothing
  - Current Integration into software

Procedure

Application of Smoothing Algorithms

- Loess Smoothing
  - uses locally weighted linear regression to fit data in the form of a second order (quadratic) polynomial
  - The regression weights are computed using the tricube function

$$w_i = \left(1 - \left|\frac{x - x_i}{d(x)}\right|^3\right)^3$$

Where:

w_i - regression weight

x - predictor value,

x_i - nearest neighbors

d(x) - distance from x to the furthest predictor value in span

  - Pros: Flexibility; Cons: Computationally Intensive

Procedure

Application of Smoothing Algorithms

- Moving Average
  - computes the average of neighboring points
  - equivalent to a low pass filter whose smoothing response is defined by the difference equation

$$y_s(i) = \frac{1}{2N+1}\left(y(i+N) + y(i+N-1) + \ldots + y(i-N)\right)$$

  - $y_s(i)$ is the smoothed value for every ith point, and N is the number of points on either side of $y_s(i)$

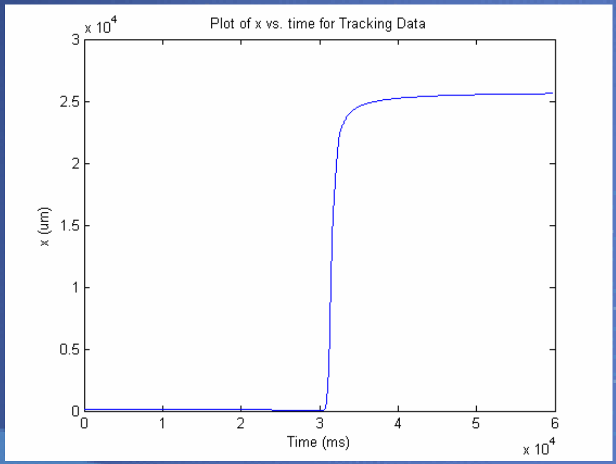
Procedure

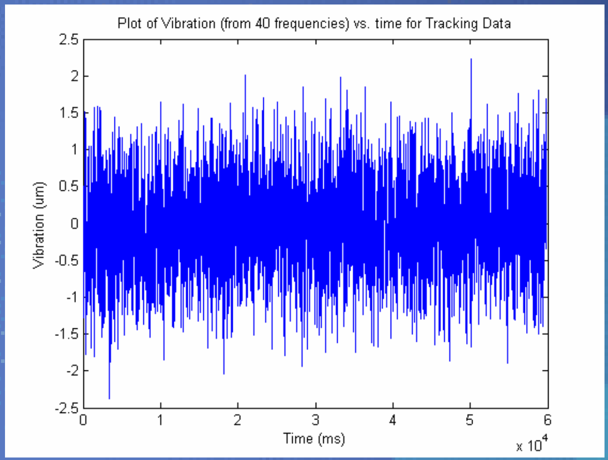
Application of Smoothing Algorithms

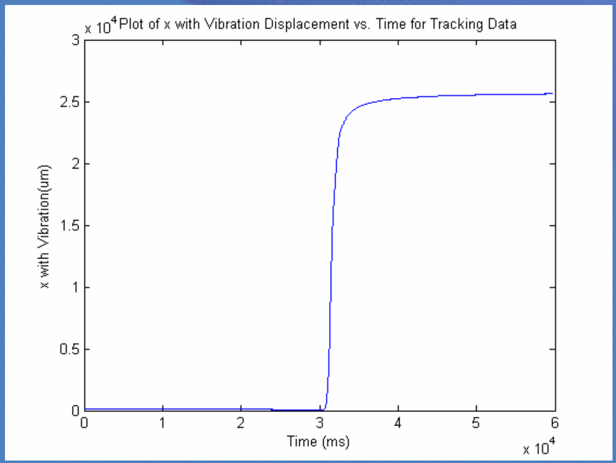
- Savitzky-Golay Filtering
  - aka least-squares filter or Digital Smoothing Polynomial (DISPO) filter
  - generalized form of the moving average filter
  - filter coefficients derived using an un-weighted linear least squares fit using a polynomial of a user-identified degree
  - Pros: Effective at preserving features of a graph
  - Cons: Does not reject noise as well as moving average

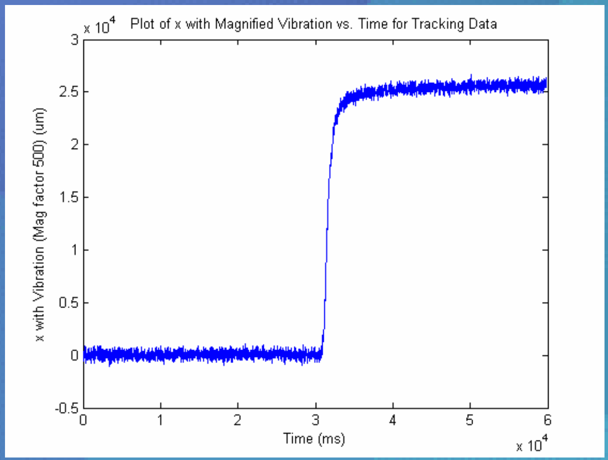
Results

Engine Vibration Simulation



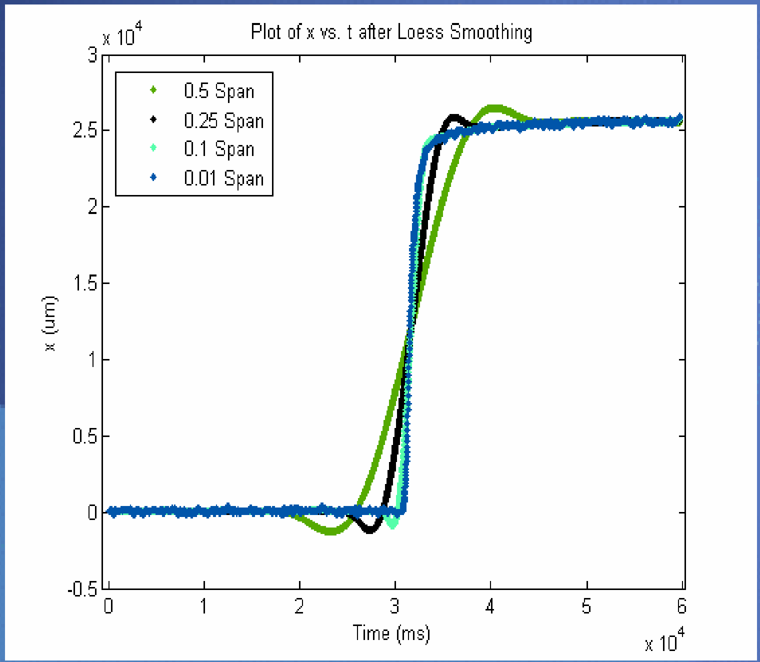




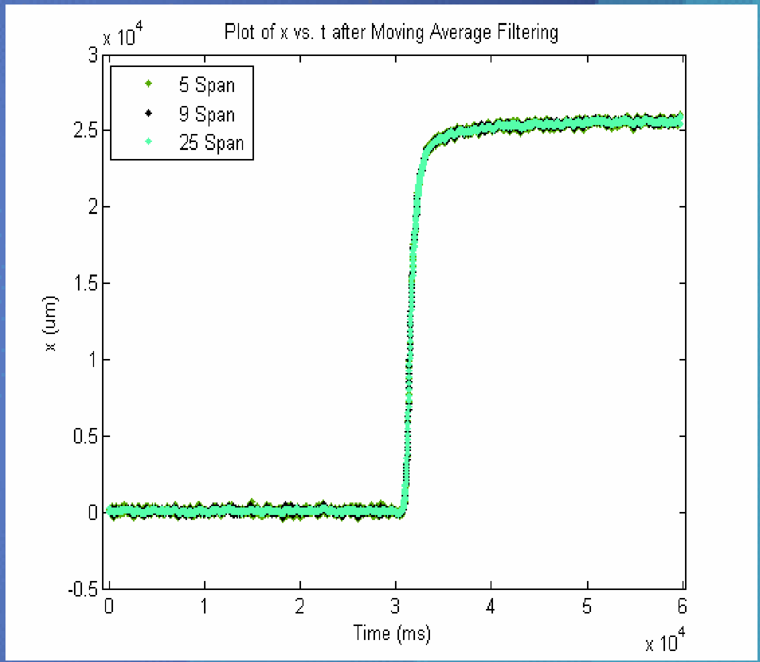


Results

Loess:

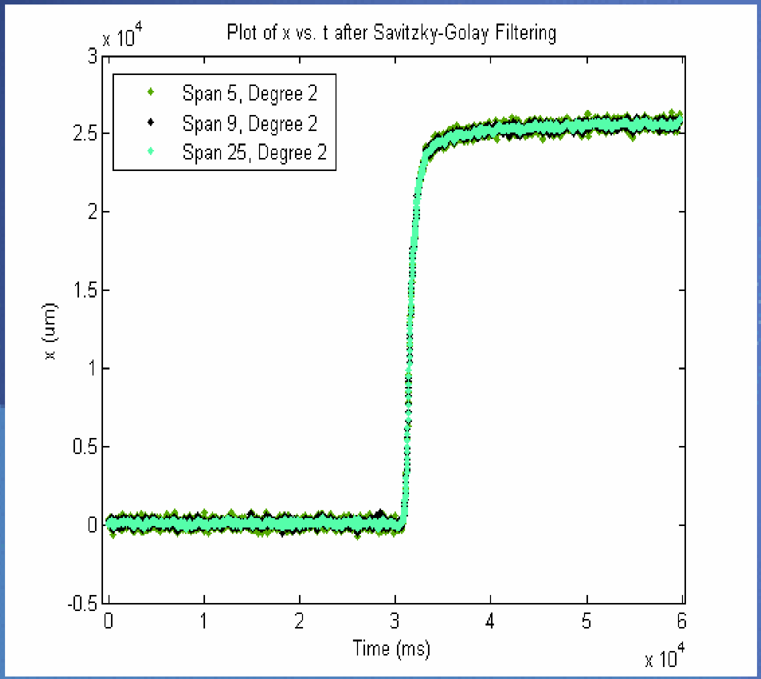


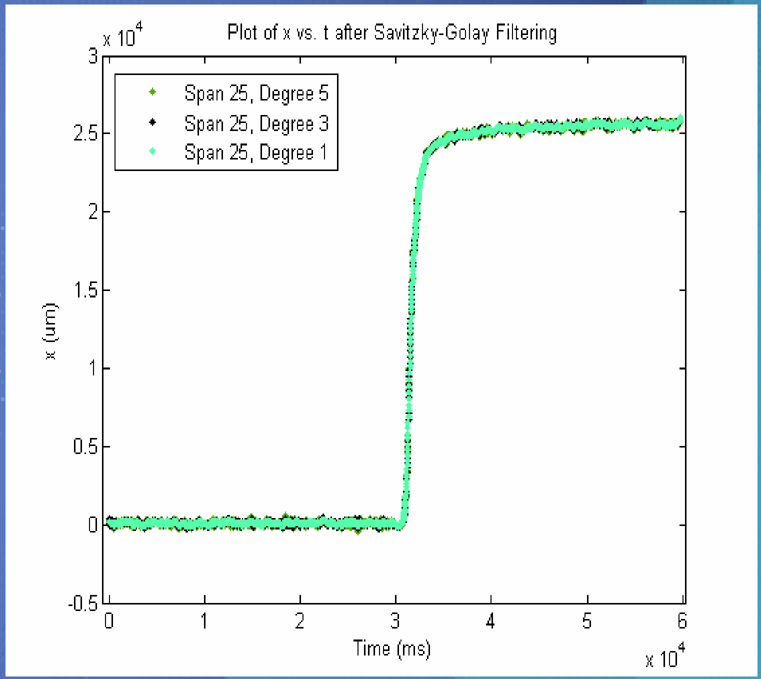
Moving Average:



Results

Savitzky-Golay:





Results

Accuracy Comparison:

Signal	Range of Difference	Range Size
Loess (0.5 Span)	-9568.7043 < x < 7766.78	17335.4843
Loess (0.25 Span)	-7432.6435 < x < 5850.12	13282.7635
Loess (0.1 Span)	-3662.48 < x < 2747.717	6410.197
Loess (0.01 Span)	-352.73 < x < 295.77	648.50635
Moving Average (5 Span)	-559.725 < x < 1100.70563	1100.70563
Moving Average (9 Span)	-398.48145 < x < 828.57131	828.57131
Moving Average (25 Span)	-718.255 < x < 1167.707	1167.707
Savitzky-Golay (5 Span, 2 Degree)	-801.17 < x < 845.28341	1646.45341
Savitzky-Golay (9 Span, 2 Degree)	-697.37878 < x < 665.8706	1363.24938
Savitzky-Golay (25 Span, 2 Degree)	-365.63427 < x < 324.57716	690.21143
Savitzky-Golay (25 Span, 1 Degree)	-723.255 < x < 453.452	1176.707
Savitzky-Golay (25 Span, 3 Degree)	-365.93427 < x < 324.84716	690.78143
Savitzky-Golay (25 Span, 5 Degree)	-471.73 < x < 490.46325	962.19365

Results

Latency Comparison:

Signal	Time Before Jump (ms)	Time After Jump (ms)	Jump Time (ms)
Original	30768	37335	6567
Loess (0.5 Span)	25913	37634	11721
Loess (0.25 Span)	28686	34978	6292
Loess (0.1 Span)	30230	37684	7454
Loess (0.01 Span)	30794	36737	5943
Moving Average (5 Span)	30877	37601	6724
Moving Average (9 Span)	30877	36356	5479
Moving Average (25 Span)	30844	37999	7155
Savitzky-Golay (5 Span, 2 Degree)	30910	34148	3238
Savitzky-Golay (9 Span, 2 Degree)	30894	33948	3054
Savitzky-Golay (25 Span, 2 Degree)	30910	33716	2806
Savitzky-Golay (25 Span, 1 Degree)	30877	33699	2822
Savitzky-Golay (25 Span, 3 Degree)	30910	33716	2806
Savitzky-Golay (25 Span, 5 Degree)	30910	33733	2823

Conclusion

- Jitter due to engine vibration remains imperceptible when included in optical tracking data

- There is a trade off between smoothing abilities and latency / accuracy values, particularly for regression techniques

- At this point, the moving average would be selected based on its balance performance among the tested techniques

Future Work

- Conduct more thorough assessment of the methods using more parameter variations
- Examine the cause of ringing effect that affected the loess algorithm
- Examine alternative smoothing proposals

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