

Reduction of Jitter within Optical Tracking Data through an In-depth Survey of Smoothing Techniques

Schinnel Small, Kofi Nyarko and Craig Scott
Morgan State University

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ABSTRACT

Signal Jitter is an impediment that continues to affect many technologies. Its presence in optical tracking devices is manifested in tracking data and affects the device's accuracy and latency. Previous studies have investigated several smoothing techniques to reduce jitter, while accounting for engine vibration as an external source. This paper will delve further into the research by exploring the characteristic behavior of the optical tracking data, so that a more intuitive selection of a smoother can be made. This process will not only justify the suitability of a smoothing technique for SVS, but also lead to increased tracking efficiency.

INTRODUCTION

Aircraft mishaps and fatalities remain a constant issue for general aviation pilots. The majority of these setbacks can be attributed to low visibility. In low visibility situations, such as night time or unpleasant weather, a pilot's perception of his or her environment, or situational awareness (SA), is drastically decreased. Synthetic Vision Systems (SVS) addresses this issue by offering 'enhanced' vision to the pilots. The enhanced vision is achieved by displaying three-dimensional representations of the outside environment, in spite of exterior conditions [1].

The successful implementation of an SVS is dependent on an accurate and reliable control mechanism. In this application, control is often provided by an optical tracking device. An assessment of the feasibility of a commercial-off-the-shelf (COTS) optical tracking device with SVS revealed that signal jitter was not only present, but also affected all six degrees of freedom (yaw, pitch roll, x, y, and z) for the device. These findings not only spurred the essential study of the extent of signal jitter effects but also the most appropriate means of reducing them [2]. Initial tasks involved the determination of signal jitter sources (both external and internal), as well as the utilization of common smoothing algorithms to reduce it. In some cases, effects from the attempted methods were visible and contributed to changes in latency and accuracy[3]. Although smoothing was achieved by each of the

attempted methods, a suitable trade off between jitter reduction and accuracy was not sufficiently attained.

This paper focuses on the determination of a suitable smoothing algorithm via the characterization of the tracking data obtained for this application. There has been reputable research that suggests the behavior of data sets and the desired criteria of the researcher are significant factors that can determine the selection of a smoothing algorithm [4]. By identifying the data's behavioral patterns, it is likely that a smoothing technique can be selected that reduces jitter effects and caters to the data's characteristics. This, in turn, can lead to improved performance for COTS optical tracking devices applied to SVS.

DATA AND SMOOTHER ANALYSIS

DATA CHARACTERIZATION. A key component in data analysis is the revelation of patterns within data. This process is necessary because data patterns allow meaningful observations and conclusions to be drawn about the variables that are under scrutiny. Smoothing is the suitable way to uncover data patterns as it removes the noisy components of data, and increases the visibility of any data pattern that may exist. If a pattern exists, it may be compared to traditional mathematical models, so that the data may be thoroughly classified and further understood [4].

There are three main classes of optical tracking data to consider within this study. The first class of data is obtained in near-stationary situations, where minute object movements may be observed. The second class consists of tracking data obtained while the object makes slow or gradual movements. The third data class is obtained when the tracking object makes sharp but intentional movements. A fourth class, which comprises data obtained with a stationary object, may also be considered. However, since the object is not moving, then it is expected that if the sampling frequency is large, the data obtained will adhere to linear properties, and so any smoother selected for smoothing should be sufficient for this type of data.

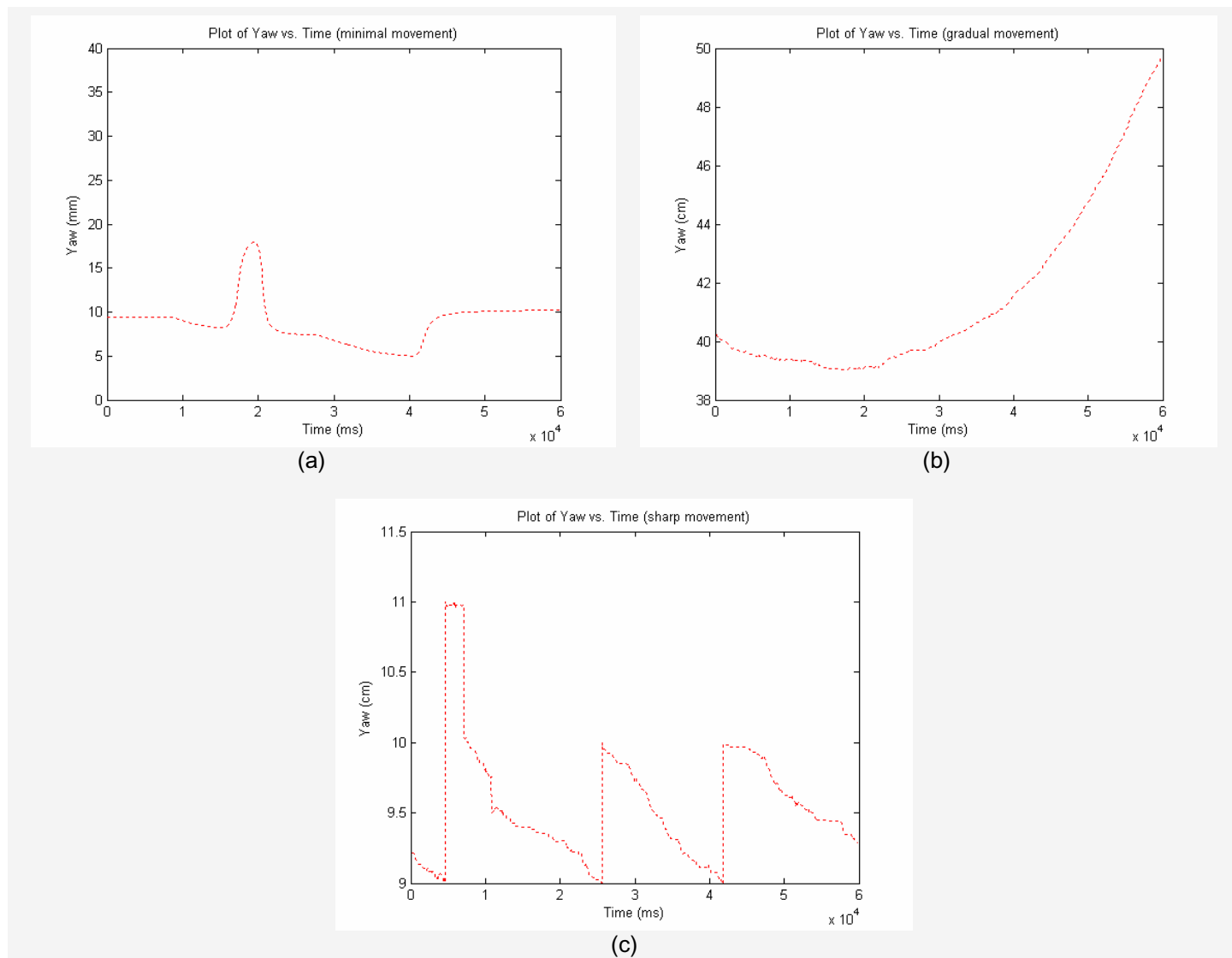


Fig. 1. Three classes of optical tracking data. a) Minimal Movement. b) Gradual Movement. c) Sharp Movement.

All of the optical tracking data was obtained using the Natural Point TrackIR optical tracking device, which was selected as a potential commercial-off-the-shelf (COTS) optical tracking device which may be used for SVS [2]. An example of the three major classes of data is shown in figure 1. Only one of the six parameters is shown.

SMOOTHING ALGORITHM CONSIDERATIONS. The choice of an applicable smoothing algorithm is largely dependent on the extent of smoothness that is required. The extent can be classified by the number of selected data values to be smoothed, or window, as well as the width of that window, or span. In this aspect, smoothers may be light, moderate or heavy. Light smoothers typically have narrow windows, and show little correlation when consecutive smoothing takes place. In contrast, heavy smoothers have broader windows and more correlation among consecutive smoothing attempts, due to the high extent to which smoothing spans overlap [4]. Consequently, a light smoother shows the least smoothing effect, but can be

suitable in preserving data trends with relatively small error. A heavy smoother can demonstrate the most prominent effect, but its repeated use can drastically alter the original data pattern. Moderate smoothers are generally capable of providing apparent smoothing effect while preserving data integrity, although the degree of moderation can be altered via the span.

The smoothing extent is typically revealed by the algorithm's performance based on pre-set assessment standards. In the past, the selection of initial smoothers for optical trackers was based on their current integrations with readily available graphical tools, and smoothing analysis was conducted by assessing the trade-off between accuracy (adherence to optical tracking data values) and latency (introduction of lag or delay). Although this condition is still desirable for its convenience, the accuracy and latency values that were obtained suggests that other smoothing techniques should be explored to ensure that the most optimal selection can be ultimately made for optical tracking data.

The accuracy / latency trade-off mimics the first criteria utilized by a reputable smoothing comparison survey. In that survey, the criteria for evaluating the smoothers included the smoothers' effectiveness of noise reduction, while maintaining data patterns (referred to as "variance vs. bias"), and their treatment of outliers, spikes and steps ("resistance") [4]. These stipulations will be adopted in this paper as a means of assessing appropriate smoothers for SVS.

To determine the desired smoothing effect, it is necessary to look not only at the datasets, but also the environment in which the dataset would be obtained. Initial observation of the optical tracking data in figure 1 reveals that there is no presence of outliers or erratic data patterns that can be directly attributed to significant sources of error. Without considering the environment one may suggest that a light smoother would be sufficient. However, the illustrated datasets show the optical tracking expectations in a relatively stable environment. This behavior may not reflect the performance of the optical tracker in the cockpit, especially when device is exposed to engine vibration [3]. In such a situation, a light smoother may not be as effective. It is therefore very important to select a smoother that would accommodate those circumstances should they occur. As heavy smoothers possess the aforementioned risk of deconstructing the data pattern, it may be beneficial to apply a moderate smoother to this application.

The method of smoothing is also an important factor to consider. The methods may be broadly classified as smoothing by fitting, and smoothing by altering actual data values [5]. Smoothing by fitting consists of techniques which mold the data into the form of an established mathematical function, often by relying on the method of least squares. Examples of these methods include polynomial fitting and spline fitting. These methods are especially advantageous in cases where data predictions are necessary. However, fitting relies on the assumption that the user can mathematically describe their dataset. Further complications may arise if the user expresses the basic form of their data as a high order polynomial. Fitting is typically restricted to low order polynomials, since polynomials of a higher order are not very numerically stable [4, 5]. It is restrictive to use a fitting technique for the optical tracking data, as there is no assurance that the data will always assume the form of standard (particularly low order) mathematical functions.

The second method includes a familiar class of smoother, known as the moving averages or digital filters [4]. The moving average is a very common smoothing technique that is relatively effective and easy to implement. Previous studies have shown that the moving average filter provided the best balance between latency and accuracy with regard to optical tracking data [3]. However the moving average is quite susceptible to outliers, which can potentially ruin the integrity of the smooth. In addition to this, data that is smoothed by the

moving averages can exhibit edge effects due to the lesser smoothing extent of end points compared to the majority of the data [5]. These disadvantages pose serious risks in an optical tracking application since outliers or edge effects can potentially occur if the optical tracker temporarily loses its line of sight, or is placed in standby mode. Another common member of this class is the low pass filter. Typically, the low pass filter is suitable for removing noisy components, as noise is primarily comprised of high frequency components. However the low pass filter is less effective in cases where high frequency components are legitimate parts of the data, such as discontinuities (see figure 1c). In such a case the low pass filter would spread the effect across neighboring data points, which also reduces the effectiveness of the smooth [6].

The moving average and low pass filter represent the family of linear smoothers. A linear smoother is characterized as having the property of superposition such that

$$S(x + y)_i = S(x)_i + S(y)_i \quad (1)$$

where $S(x)_i$ and $S(y)_i$ are the i th terms within a smooth function S and $S(x + y)_i$ is the i th term of the sequence $x_i + y_i$ within the smooth. However, a key disadvantage of linear smoothers is that these smoothers are not resistant, i.e. these smoothers cannot effectively preserve all the trends within a data set [4, 6]. The lack of resistance is evident in the cases where the moving average and low pass filter perform poorly in the presences of outliers and edges. To avoid this disadvantage, an alternative class of nonlinear smoothers that utilize smoothing via the second method is now explored. This group of nonlinear smoothers consists of median filters or running medians. The median filters possess the property of location equivariance, such that

$$S(y + a)_i = S(y)_i + a \quad (2)$$

where a is constant. In addition to gaining more resistance, the median filters are faster to compute than moving averages, and are just as easily implemented in computing software [4]. Since the median filters have been established as effective in smoothing and noise reduction to various applications in signal processing and imaging [6-8], and SVS encompasses aspects from both these fields, they can be potentially useful in optical tracking applications for SVS.

A final aspect to consider is the use of compound smoothing. A compound smoother is created by applying repeated implementations of basic smoothing techniques. Compound smoothers, especially within the class of running medians, are common [4]. In addition to this, there is established research that suggests that compound smoothing that consists of running medians and linear smoothing can have desirable effects in many