Recursive Filter Algorithm for Noise Reduction in SLR

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Abstract

This report presents the concept and implementation of a recursive filter for the identification of satellite returns in laser ranging in the presence of strong noise. This project was aiming for an increased data yield of automatically filtered satellite laser ranging measurements in order to maximize the number of correctly identified returns. Furthermore the amount of false readings have to be reduced and an automatic timebias-adjustment during ranging was required.

Introduction

Automatic data screening of timer readouts in SLR is widely used by many laser ranging facilities of the ILRS. All of them depend on some type of histogram evaluation of short time slices of measurements throughout the ranging process. The approach uses the fact that return signals from a satellite bunch up at a specific location in the range gate window, while noise readouts caused by background light or intrinsic detector noise are far more spread out throughout the range gate. For satellite passes with reasonable or good signal to noise ratio this method is fully adequate. However, in particular for daylight passes of the GPS and GIOVE satellites, this method is often extracting much fewer returns than actually were recorded by the ranging facility. On top of that a non negligible number of false readings is usually upsetting the normal point generation process, because erratic data points prevent the fitting procedure from converging. Figure 1 shows an example of such a weak satellite pass. One can clearly see time intervals where a reasonable or good signal to noise ratio exists for the measurement. However there are also times where only sparse data is recorded. In order to extract the valid returns out of all the recorded data points in near real-time the control software examines small portions of the pass of a few seconds length. The data is then converted to a histogram and if a suitable bin contains a sufficient number of echoes, these are extracted and stored away as satellite returns. This evaluation process is fast and strictly linear in time. In the presence of very sparse data the threshold criterion is never satisfied and valid data is lost. If on the other side the threshold value is lowered too far, then randomly lumped together background noise events will accidentally be taken as good data and the post-processing can be disrupted.

By using more than one criterion at a time and introducing reprocessing of past data as well as a locally linearized look ahead strategy, one can vastly improve the robustness of the filter procedure. At the same time the data yield improves substantially in particular for passes with a low signal to noise ratio.

Function of the new filter algorithm

The new filter applies two distinctly different methods. A histogram-analysis is used to detect possible satellite returns in a reasonably short time interval. The results then are used to predict the likelihood of valid returns into the future, where it also

successfully recovers valid data-points at a low data rate. Both methods cooperate to not only detect, but also rate identified returns during the ranging activity.
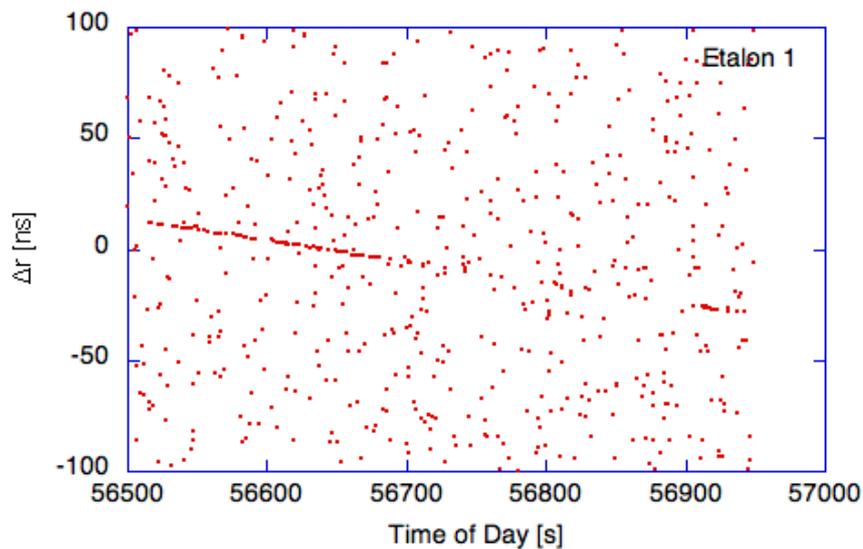
Figure 1: Example for a measurement window of an ETALON pass with sparse data in daylight.

From a number of verified satellite returns within a number of time slices, the actually applied time bias value for the momentarily observed satellite pass can be improved. With time bias corrected range residuals the histogram of the analysis process sharpens substantially. As a consequence the width of the rangegate can then be reduced automatically, which in turn enhances the data yield of the ranging operation. The program module works in several layers. The inner loop of the filter procedure is based on time slices of 5 seconds of observations (fig. 2). The length of the time slice is adjusted to the 10 Hz repetition rate and the background noise level typical for the Wettzell Laser Ranging System (WLRS). Other systems will have different settings. If already available a time bias correction is applied to all the data points in that time segment. Then the data is passed on to a histogram analysis routine, which has a bin width of 5 ns. This arbitrarily chosen value too has shown to work well for the WLRS operation parameters.
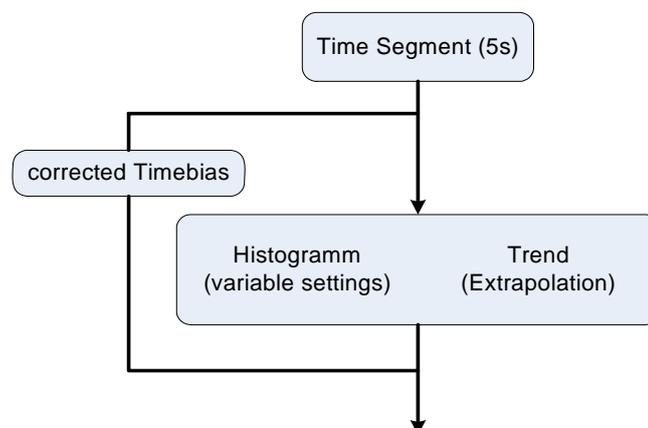
Figure 2: Flowchart of the inner loop of the data-screening program.

The threshold value for the histogram evaluation is currently set to 4 events per bin. In order to avoid ambiguities from unfavorable bin boundary settings (see fig. 3) in the histogram analysis, this evaluation is made twice with all the bins shifted to one side by half the bin-width.

When the threshold value of 4 events per bin is exceeded, all data points within that histogram bin are taken as possible returns. If the threshold value is exceeded by a factor of 2 the data within this bin is considered as reliably identified returns. Reliable returns are used twofold for the remainder of the satellite pass. They are used for an updated time bias computation, which feeds back to the next time slice and they are used in order to predict future locations within the range gate for the next few time slices. Figure 5 illustrates the prediction approach. Known trustworthy returns from the most recent past are linked with a straight line. The line is extended into the future and a corridor of ±2.5ns is set around this predicted line. Any single event that happens to fall within this corridor is considered a potential return and subjects it to further verification.
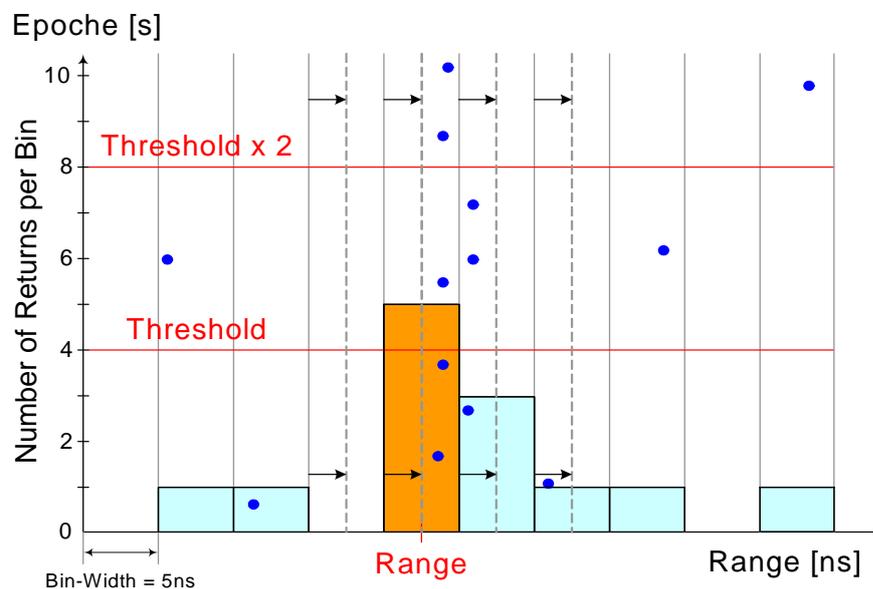
Figure 3: *A histogram of a 5 second long segment of a satellite pass of the WLRS. Unfavorable bin boundary settings are avoided by a re-evaluation with shifted bins.*

Therefore also extremely low return rates well short of the threshold value of 4 can be detected. The predicted linear corridor where future returns are expected expires after about 30 seconds when no further satellite echoes are recorded, because this simplified piecewise linearization of a satellite pass does not represent a valid approximation indefinitely.

Another important aspect of this new approach is a retrospective analysis, which identifies satellite returns that have been overlooked in the near real-time evaluation. A very sparse return rate may cause such lost returns as well as a number of false alarms. The retrospective analysis step revisits the last whole minute of observation. From the time slice analysis a number of returns are found. Some of them will be unambiguously identified as valid returns, while a certain number of returns are only classified as possible candidates. Again a linear regression through all unambiguously identified data points along with a corridor of ±2.5ns selects the part of the range gate where returns are most likely. Three cases may be found:

- All candidates (orange points in fig. 5) within these limits are now recognized as valid returns.

- All candidates outside this corridor are deleted from the list of possible returns.

- All not identified (white) data points inside the corridor are added to the list as possible candidates.
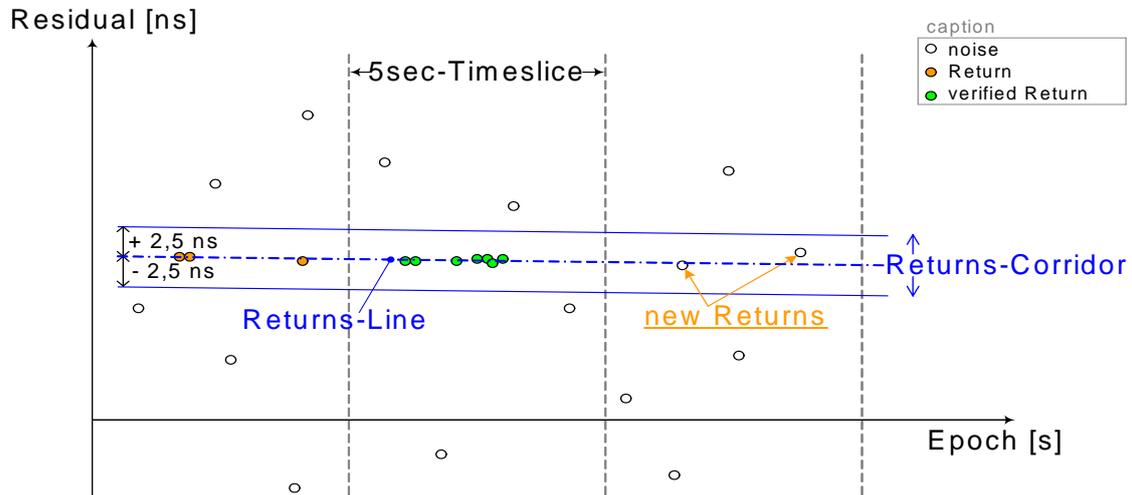
Figure 4: *Reliably identified returns within a time slice of data are extrapolated into the future in order to find otherwise lost data points when the return rate is sparse.*

The linear approach for this screening procedure is justified because only very small segments of a complete pass are analyzed at a time. It has the advantage that this processing is fast and that it does not diverge quickly as polynomials tend to do in the presence of an inhomogeneous data distribution.
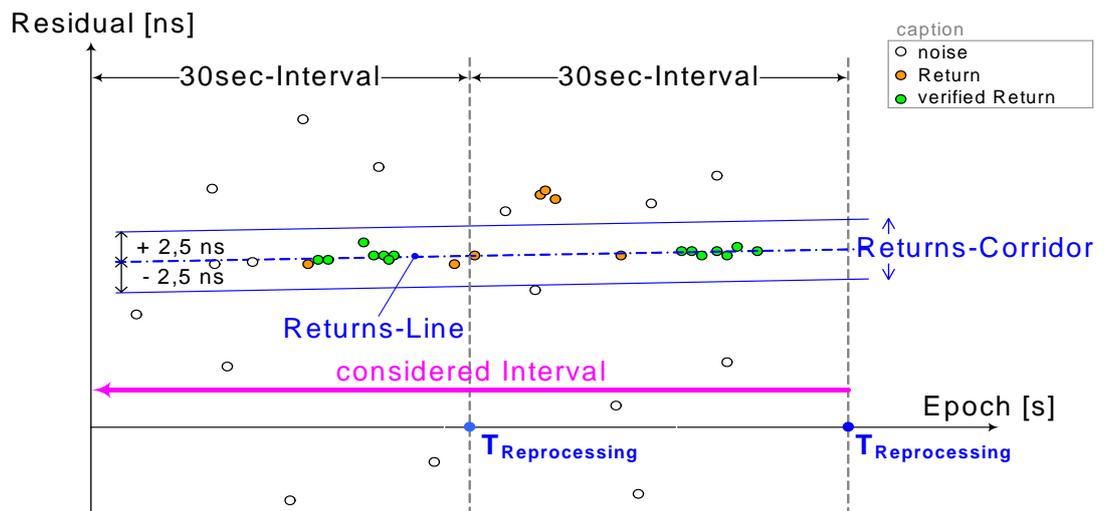
Figure 5: *Reprocessing of the last 60 seconds of data. Reliably identified returns are used to define a return corridor. Potential returns outside this corridor are deleted from the list, while potential returns inside the corridor are turned into verified returns.*

Application Results

When this new data screening approach was integrated into the routine operation software of the WLRS, care was taken that rapid data processing was maintained throughout the ranging operation. We never encountered a situation where the ranging data came in faster than the various processing steps took to evaluate the data. We would expect that this would also apply for higher repetition rate systems, however with an appropriately adapted parameter setting.
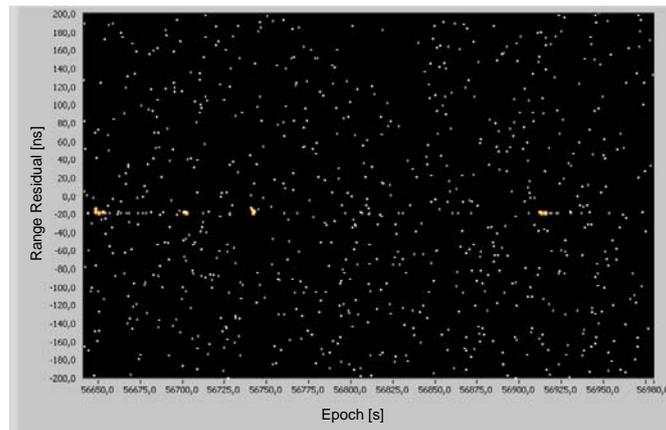
Figure 6: *A Section of an Etalon daylight pass with sparse data*
with returns identified with the previous screening program.
Clearly many valid data points were lost in the past.

Because of the repeated scanning of recent tracking data some adjustments to the data storage strategy had to be newly introduced. Essentially a larger data buffer is required as a temporal additional storage. As one might expect there is little to no advantage of this recursive screening filter over the simple histogram analysis when there are many satellite returns and almost no noise events. However for a weak signal to noise ratio approaching 1, rather dramatic improvements have been obtained. Figure 6 shows such an Etalon pass. Unfortunate boundary locations of the time slices often cause histograms to remain below the threshold limit. As a consequence a lot of data is lost. In this example only 12 returns were recovered out of the portion of data shown in the diagram.
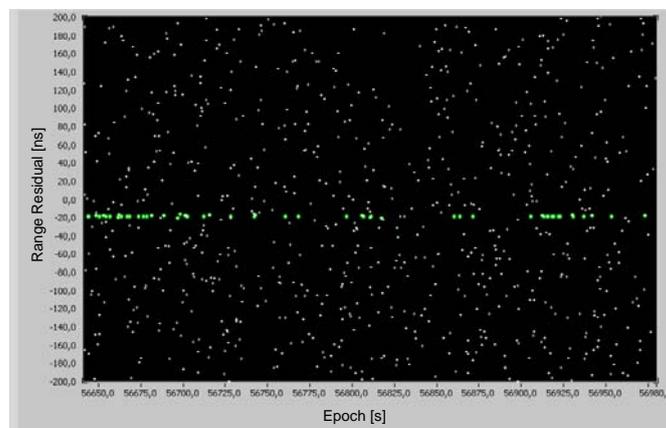
Figure 7: *The same section of the Etalon pass processed*
with the new screening programme.

In contrast to fig. 6 the same dataset was re-analyzed with the new screening procedure extracting 50 returns instead of 12. The results are shown in fig. 7. Again this may still not catch all available returns. On the other hand it does not generate false readings either which is also an important aspect for this filter process. The WLRS ranging software was updated to this new filter scheme in December 2006. As far as we can see it improved the efficiency of the WLRS and reduced the number of passes that need manual user intervention for the normal point generation process noticeably.

References

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