

Automatically and Consistently Detecting and Extracting SLR Measurements for Every Satellite Pass

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Abstract

After each observed satellite pass, SLR return measurements must be identified and extracted from the surrounding noise points. This task is made more difficult with weaker return signals, intermittent data flows and greater background noise levels due to sky brightness. At the SGF, Herstmonceux, an operator manually selects regions of a range residual plot that contain visibly recognisable returns. This selected dataset is flattened by time and radial corrections to the reference orbit, filtered for high return rate levels and clipped so that normal points can be calculated. This task takes observer time and is only performed when the observing schedule allows.

A process for reliably and automatically extracting SLR returns is under development and testing at the SGF. Range returns are first recorded by track detection in real-time and these are used for an initial orbit correction solution using the orbitNP.py software, developed at the SGF. Applying these orbital corrections to the whole dataset produces flattened SLR residuals. Selecting areas around SLR returns is achieved by considering the relative densities of surrounding residual points. A new return rate calculation method uses the interval between successive track points and the data is filtered for high and low return rates.

A continuously running, multi-processing Python program organises the necessary calibration, track, prediction, status and meteorological files for each satellite pass in preparation for automatic data reduction.

1. Introduction

There are many SLR stations in the ILRS network that operate with some degree of automation. This includes automatic scheduling, automatic pointing, track detection, cloud detection or automatic in-sky safety interruption. Some stations can even be left unattended to track a pre-determined schedule of satellites in periods of clear sky.

A SLR observation begins as the telescope tracks along a satellite's predicted path. The laser fires short pulses and the detector is armed for returning signals. Acquiring returns requires clear skies and often some telescope alignment or correction to the orbit prediction. Once a pass is complete, the data is stored and the SLR system can switch to the next available target.

Later on, the recorded dataset must undergo post-processing to separate the laser range returns from the background noise. This is either fully or partly a manual process, requiring observer time and availability. For each recorded pass, the observer visually inspects plotted range residuals and selects the areas containing SLR track.

If automated systems were allowed to take the final step of generating and submitting data files then the reduction process would need to be very reliable. The separation of

signal from noise is made more difficult with weaker return signals, intermittent data flows and greater background noise levels due to sky brightness.

At the SGF, Herstmonceux, a process for automatically and reliably extracting SLR returns with the end goal of then submitting ILRS normal points is under development. This uses data recorded by the secondary Riga A033-ET event timer which is installed at the SGF in parallel. The SGF is a kHz SLR station.

To automate the process and to prepare for the reduction of a pass file, the required files and information, such as system calibration, meteorological data and track files, are organised by a continuously running, multi-processing central task manager, which was developed in Python.

2. Real-Time Track Detection

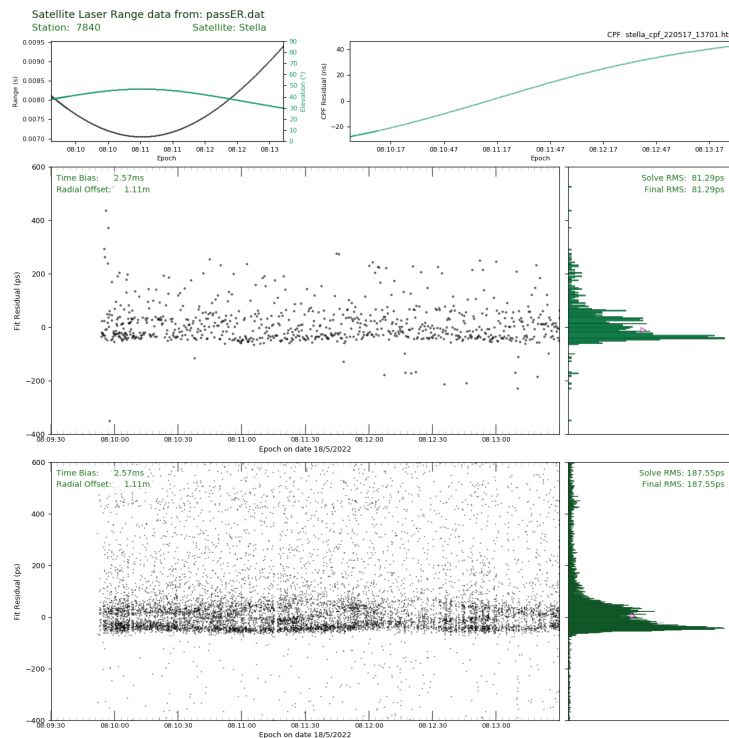
At the SGF, Herstmonceux, the SLR measurements are displayed for the observer in real-time as residuals to the orbit prediction. This includes a continually refreshing residual window and a short-term histogram. The observer can adjust the telescope pointing and make time and range bias corrections in order to align the tracking telescope with the target and to start receiving laser returns. Satellite track can be seen as repeating points at the same residual level and as a spike in the histogram.

In addition, track is automatically detected in real-time by the observing software using the short-term histogram. When the peak amplitude reaches above a set threshold, the track is detected and residuals are recorded. At the end of the pass, a polynomial is fitted to flatten these returns for easy reduction. In addition, for the new reduction process, track ranges are recorded. These ranges are then used in an orbit adjustment solution to produce flat residuals.

3. Range Residuals from Orbit Corrections

The epoch-range data recorded during a SLR pass can be used as an input to the orbitNP.py program (Wilkinson, 2018). It requires additional information such as the target name, the modified julian day and an ILRS CPF prediction. It solves for time bias and radial bias corrections to the reference orbit to produce flattened range residuals, which can be output to a file. OrbitNP.py is written in Python and is available

Figure 1(a) The flattened residuals from the real-time epoch-range data recorded during a Stella satellite pass. 1(b) The residuals obtained for the raw dataset by applying the same orbit corrections.



to download on the ILRS website (<https://ilrs.gsfc.nasa.gov/technology/software/index.html>).

The orbit corrections determined by orbitNp.py using the real-time epoch-range dataset can be applied to the entire raw dataset to give flat track residuals around the zero mark. This also requires the pass calibration and meteorological records. Figure 1(a) shows the orbitNP.py output residuals from ranges recorded in real-time during a Stella pass. Figure 1(b) shows the entire dataset flattened using the same orbit corrections.

4. Track Selection

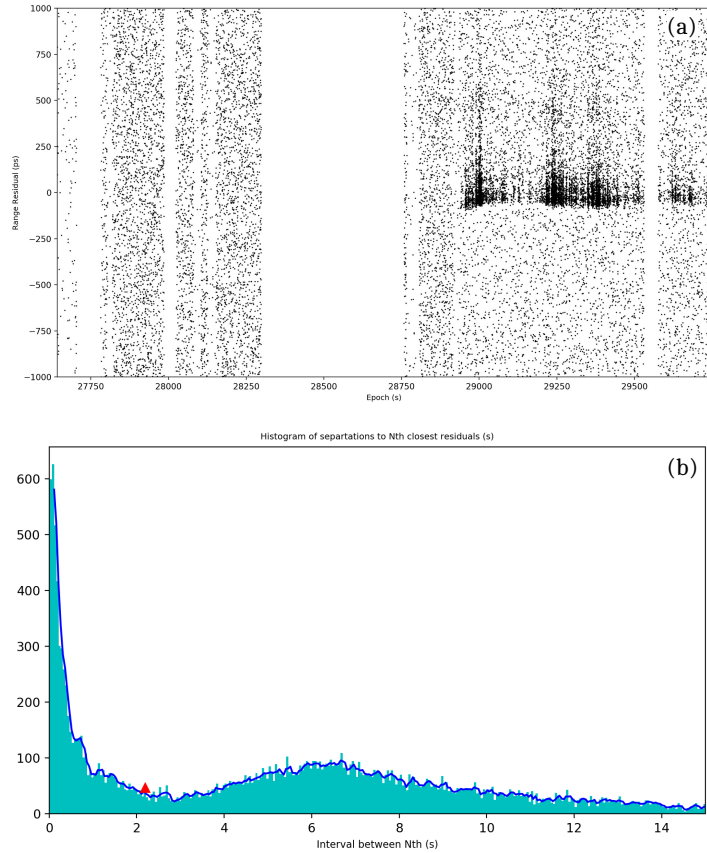
It is possible to automatically produce flattened SLR residuals for every pass by detecting track in real-time, using the recorded ranges in orbitNP.py to provide orbit corrections and applying these to the whole dataset.

Areas of the resulting residual plot that contain SLR return must subsequently be selected. In the example shown in Figure 2(a), there are clearly areas on the right of the residual plot that contain SLR returns, and there are areas on the left that do not.

SLR track is visible in residual plots due to the higher point densities in both the residual (y-axis) and epoch (x-axis) directions. To exploit this computationally, first only the data around the zero residual point is selected. For each point a narrow range residual window (± 200 ps) is considered and then the Nth closest point in epoch is found. By choosing the Nth value, for example the 20th, it is ensured that there are 19 closer points and so if the 20th is still short in epoch separation, it is likely that the point is part of a cluster. The Nth time interval will be very short for satellite track and longer for random noise. Plotting these values as a histogram, as shown in figure 2(b), separates the two different data groups. The track points have the shortest values on the left of the plot and the empty noise areas are to the right.

A cut-off point on the histogram needs to be defined, below which the points are determined as satellite track returns. Two methods to define this point have been designed and tested. The first uses the histogram and finds the rate of change of the bins as the interval increases. It looks for a peak in values and then determines the end of the peak and sets this as the cut off value, as plotted in red. The second method, now in use, uses the RMS of the residuals for the shortest intervals. It then incrementally

Figure 2(a) The flattened residuals from the full data set of an example LAGEOS pass. 2(b) A histogram showing the separate data groups generated from the Nth closest points, with the cut-off point in red.

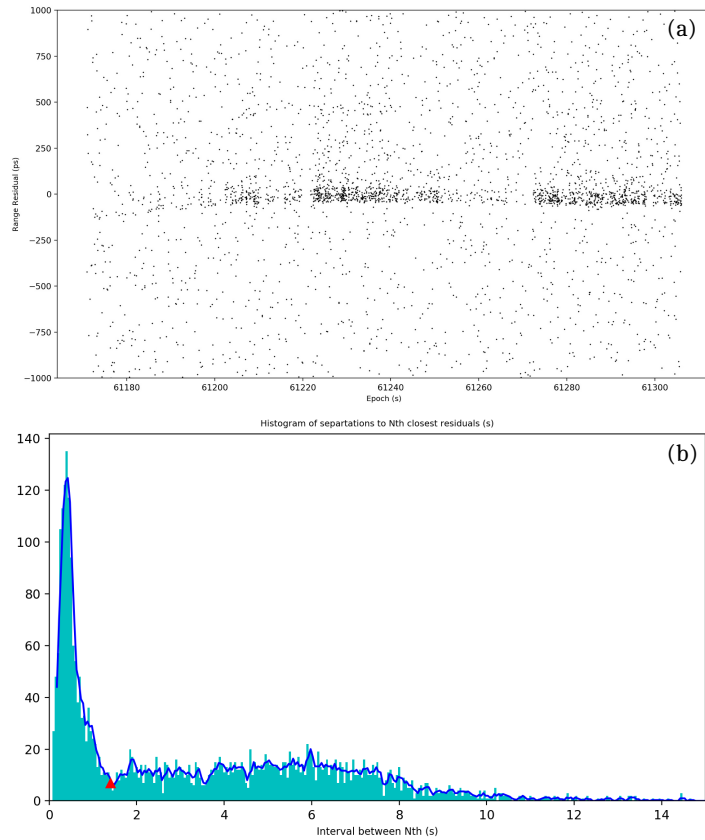


adds more of the shortest interval points and recalculates the RMS to look for a significant change in the RMS, the cut off point, where SLR track becomes background noise.

Selecting around the track points, which are defined as those points with intervals to the Nth point below the cut off value, allows for the areas containing no track to be discarded.

Figure 3 shows a second example pass where the track and noise profiles are separated in the histogram and the cut-off point in red on 3(b) determines which points are SLR returns.

Figure 3(a) The flattened residuals from the full data set of an example LARES pass. 3(b) A histogram showing the separate data groups generated from the Nth closest points, with the cut-off point in red.



5. Return Rate Filtering

The SGF calculates return rate by binning data and dividing the SLR returns points over the number of shots minus the points below the track. Alternatively, at the 20th International Workshop on Laser Ranging in Potsdam, José Rodríguez presented a filter method based on Poisson statistics (Rodríguez, 2016), which considered the time intervals between consecutive points.

A new method, developed at the SGF, Herstmonceux, for calculating return rates is described here. For each return, the average time interval between consecutive points, for M returns before and after is calculated, in the following examples M is set to 8. Inverting this average value gives the number of points arriving per second and then return rate when it is divided by the number of shots. The number of shots is adjusted for any lost points recorded below the track. This method has the advantage that every point is given a return rate value. The example shown in Figure 4(a) shows flattened range residual points and 4(b) shows the corresponding return rate histogram. The red points show return rate as calculated by the 2 second bin method and the light blue values show the new inverted interval method. The new method is much more variable on short time scales. To help illustrate this, figures 4(c) and 4(d) show the residuals and return rates for the zoomed section of the pass indicated in yellow in 4(b).

Return rates are filtered out if they go above the set threshold of 20%. For this example pass, the average residual value for the data filtered at high return rate minus the average residual for the remainder of the data is -5.390ns. This suggests that the filtered data is biased and not observed at single photon levels (Appleby, 1999).

It is also possible to filter for low levels of return rate, which removes poor signals and periods of no observations. A smoothed return rate profile is preferable to allow

the data to be more continuous. Considering the background noise level is useful for setting the lower threshold, which can be calculated by inverting the average residual difference from a point above the track. From this a return rate threshold can be set. Figure 5(a) shows return rates as calculated by the new interval method. A smooth profile is plotted in pink and the background noise threshold is plotting black. When the smoothed return rate profile drops below the threshold the data can be removed, as can be seen in figure 5(b).

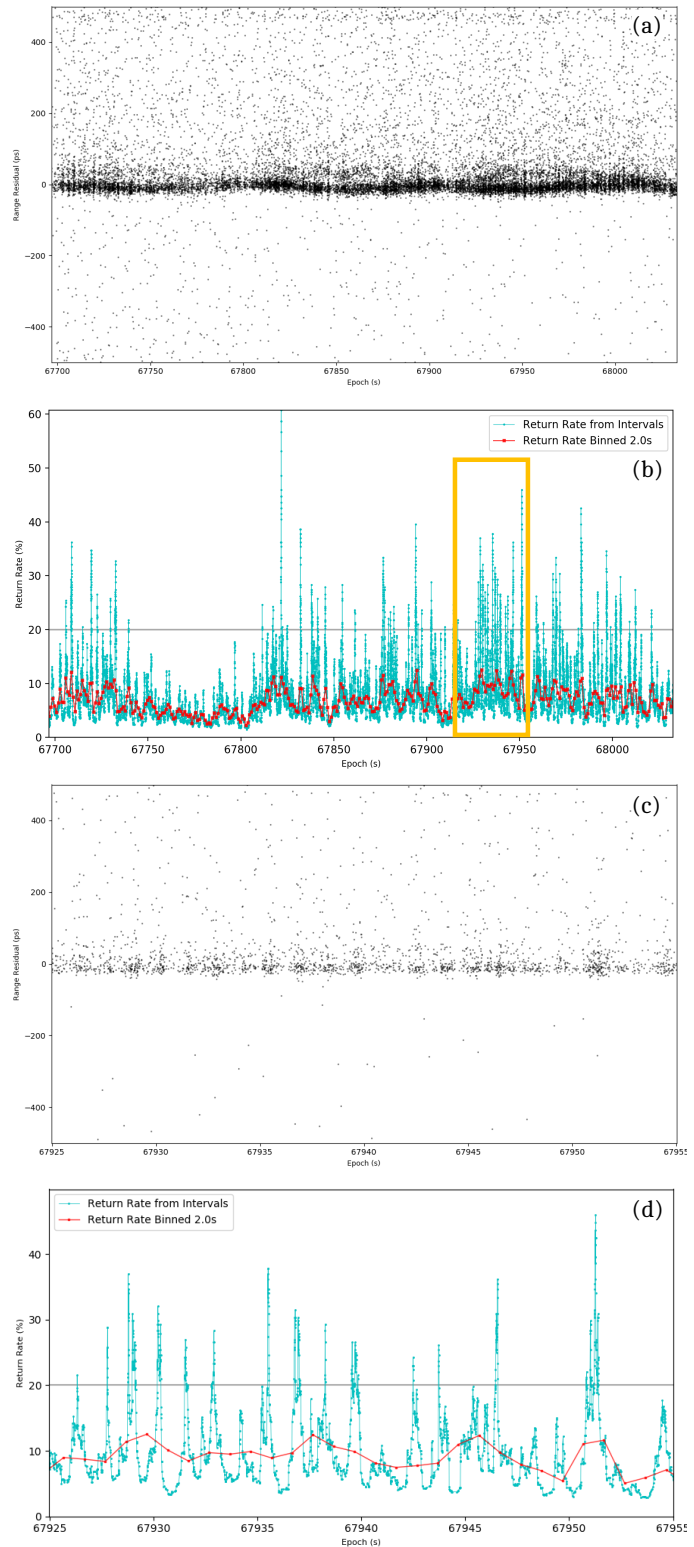
A final filter is applied to remove short data bits between the data that was filtered for return rate.

6. Multi-Processing Task Manager

To operate in an automated way, a background process is needed to react to new data sets and prepare the necessary information for the reduction process to take place. This is achieved using a multi-processing Python program. Routines are repeatedly run to check if new files exist or to complete a particular task. This program run continuously and prints to the screen as it executes its tasks.

Each pass requires a meteorological data file and these are assembled at the start and after the pass is completed. Similarly, a file containing the corresponding calibration files is needed. In addition, the task manager reacts to new calibration measurements and performs the reduction. The CPF predictions are kept updated and the track and status file generated during the pass are made available. Once the reduction completes the

Figure 4(a) The flattened residuals from the full data set of an example HY2C pass. 4(b) Return rates as calculated by the 2 second bin methods (red) and the new interval method (blue). 4(c) and (d) are a zoomed part of the same plots, as indicated in yellow in 4(b).



files are archived and the next pass can be processed.

7. Conclusions

The automatic reduction of SLR passes is desirable for stations that have begun the process of automated operations. This is achievable for the majority and possibly for all SLR passes.

Orbit correction is a stable way to produce flattened residuals. And this can be automated using real-time epoch-range data and applying the solved orbit corrections to the whole dataset.

High return rate filtering should be carried out on short time scales for high repetition rate SLR systems to remove the spikes caused by atmospheric variability.

8. Future Work

The automatic process will be used to reduce every satellite observation pass as recorded using the A033-ET timer by the SLR station at the SGF, Herstmonceux. These will be closely checked for any failures in the flattening, the data selection or the return rate filtering. A close comparison will be made between the normal points from both event timers.

References

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- M. Wilkinson. Implementing consistent clipping in the reduction of SLR data from SGF, Herstmonceux, 21st International Workshop on Laser Ranging, Canberra, Australia, November 5-8, 2018, <<http://cddis.gsfc.nasa.gov/lw21/>>

Figure 5(a) Return rates as calculated by the new interval method (light blue), a smoothed profile (pink) and the background threshold (black). 5(b) The pass residuals and the removed data plotted in pink.

