Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation

P.O. Box 5800
Albuquerque, New Mexico 87185

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subject: Release notes for SIRHEN version 0.4

The current release of SIRHEN retains all features and functionality documented in version 0.2 [1]. Numerous bug fixes have been made since that time, and several improvements have been made based on user feedback. Changes in version 0.4 include:

- Revisions to the color display of STFT images.
- Frequency bounding (static or dynamic) in calculating histories.
- The ability to import previously analyzed data, restoring all previous settings.
- Estimators for signal noise fraction and frequency/velocity uncertainty.

Additional details are provided below.

Color display revisions

Intensities in STFT images are mapped to a color scale for display purposes only—history extraction is always performed directly on the STFT power spectrum, independent of the color scale settings. Version 0.4 uses logarithmic color scaling by default, though linear scaling (the default setting in version 0.2) is still available. Logarithmic scaling is helpful for identifying signal content over a large dynamic range.

Version 0.4 has a larger variety of color maps available than previous releases. Each map displays the intensity range with a specific color range.

Name	Span
jet*	blue to yellow to red
gray	black to blue red
rainbow	red-orange-yellow-green-blue-indigo-violet
red	black to red to white
green	black to green to white
blue	black to blue to white
cool	cyan to magenta
hot	dark red to white
spring	pink to yellow
summer	green to yellow
autumn	red to yellow
winter	blue to green
bone	blue-black to white
copper	black to bright copper
pink	shades of pink (sepia)

* Default setting

Each color map can be inverted by the user. For example, inverting the gray color map causes strong features to be displayed black on a white background (like photographic negative), suitable for printing the STFT spectrum on paper.

Frequency bounding

A new feature in this version bounds the frequency range used when calculating velocity histories. "Define frequency limits" is located under the "Data" menu on the Analysis Screen. Activating this feature converts the STFT spectrum and history plots to absolute frequency, which may result in axis rescaling; no rescaling occurs if the plots already display absolute frequency.

Two types of frequency bounding—static and dynamic—are supported. Static bounding places fixed upper and lower frequency bounds across the entire signal, preventing the history calculation from moving outside this range. Dynamic bounding allows the user to define a time-dependent boundary on the history calculation. Clicking the left mouse button on the STFT image defines the center of the frequency bound at a particular point in time. An arbitrary number of these points may be selected; pressing the right mouse button indicates that selection is complete. Once the frequency center line is defined, the user must specify a frequency width. Frequency widths may be refined later, maintaining an existing set of central locations.

Frequency bounding is not typically needed for PDV measurements of a single Doppler shift. It is a powerful tool in more complex measurements, but careless use may lead to unphysical history calculations. Avoid using overly narrow frequency ranges in dynamic bounding!

Importing previous sessions

History files exported from SIRHEN may be loaded back into the program, restoring all settings from the previous session. This features is located on the "Program" menu on the selection screen. Loading a previous session resets the program, discarding all current settings.

SIRHEN exports from version 0.3 or later contain a header describing how the analyzed. An example header is given below.

```
SIRHEN signal export (21-Nov-2010 20:16:10)
     inputfile=./152_Ch2.txt
     reference=           -Inf   -1.00000e-06
    experiment=   -2.54920e-06   +1.85410e-07
 ref_frequency=   +4.23971e+09
    time_shift=              0
        frange=           -Inf           +Inf
        fwidth=           +Inf
  flimitpoints=
  tlimitpoints=
      duration=   +2.64000e-09   +1.00000e-08
          skip=   +2.64000e-09   +1.00000e-09
        method=         robust
       overlap=              0
    wavelength=   +1.55000e-06
      removeDC=            yes
        vscale=              1
     Nduration=           1024
         Nfreq=           1024
        window=        hamming
 normalization=         global
       scaling=            log
          clim=            -40              0
           map=            jet
     invertmap=             no
        vlevel=              0
          Time       Velocity      Intensity
   -2.54418e-06   +6.00474e-01   +7.42984e-01
   -2.54314e-06   -8.78220e-01   +7.19573e-01
```

The header archives parameters from a previous session, which can be restored by any user at a later time. The export and restore process is system independent. For example, the header above indicates that signal data was obtained from a file called `152_Ch2.txt`, located in the same directory as the export file. As long as they are kept together, the files can be moved to another location and imported back into SIRHEN. Signal and export files in different directories can also be moved as long as the relative locations are maintained.

User-edited history files can be imported into SIRHEN. Since only the header is required in this process (numerical columns after the header are ignored), it is also possible to create "history" files outside of SIRHEN that can be "restored" into the program. This functionality is powerful but recommended for advanced users only. All supported header entries are displayed in the above example, with one entry per line. Field names appear to the left of the equal sign, while field value(s) appear on the right. Lines without an equal sign are ignored, extraneous white space is omitted, and declaration order is not important. The "inputfile" entry, which defines the PDV signal file, is mandatory, but all other information is optional. Most fields contain either a single text entry or 1–2 numerical values, the meaning of which should be obvious from the SIRHEN documentation [1]. The "duration" and "skip" fields are slightly more complicated: the first value describes the value used for STFT spectrum images while the second value (if present) describes the value used for history calculations; if only a single value is present, it is used in both the STFT and the history calculation. Two fields—"flimitpoints" and "tlimitpoints"—may contain an arbitrary number of values to define dynamic frequency bounding (discussed in the previous section).

Noise and uncertainty estimation

Noise fraction estimates are available under the "Data" menu on the Selection Screen. This feature is only available when a reference region has been selected. The algorithm (outlined below) assumes that the reference region contains several signal cycles of a single harmonic.

Consider a harmonic signal with frequency f containing random noise fraction σ.[1]

$$s(t) = \underbrace{\cos(2\pi f t + \delta)}_{s_1(t)} + \underbrace{\sigma R(t)}_{s_2(t)} \tag{1}$$

The power spectrum of this signal contains a peak at frequency f_0 along with a noise baseline. Figure 1 illustrates a power spectrum for signal containing 10% random Gaussian noise. Parseval's theorem provides a link between integrals of each component in the frequency and time domains ($w(t)$ is the digital window function, C is a constant).

$$I_1 \equiv \int \left|\tilde{S}_1(f)\right|^2 \, df = C \int w^2(t) \cos^2(2\pi f t + \delta) \, dt \approx \frac{C}{2} \int w^2(t) \, dt$$
$$I_2 \equiv \int \left|\tilde{S}_2(f)\right|^2 \, df = C \int w^2(t) \sigma^2 R^2(t) \, dt \approx C\sigma^2 \int w^2(t) \, dt$$

The noise baseline to harmonic signal area ratio (I_2/I_1) therefore equals $2\sigma^2$. The value of I_2 is approximately Bf_N (constant level times the Nyquist frequency). Combining these results with energy conservation:

$$\sigma^2 = \frac{1}{2} \frac{Bf_N}{\int \left|\tilde{S}(f)\right|^2 \, df - Bf_N} \tag{2}$$

leads to an estimate of the noise fraction given the total area in the power spectrum ($|\tilde{S}(f)|^2$) and the baseline level B.

To calculate noise fraction, SIRHEN locates and removes the harmonic peak from the power spectrum calculated from the reference signal. The remaining data (*e.g.*, the blue curve in Figure 1)

[1] $R(t)$ is a random function where $\langle R(t) \rangle = 0$ and $\langle R^2(t) \rangle = 1$ over many sample points.

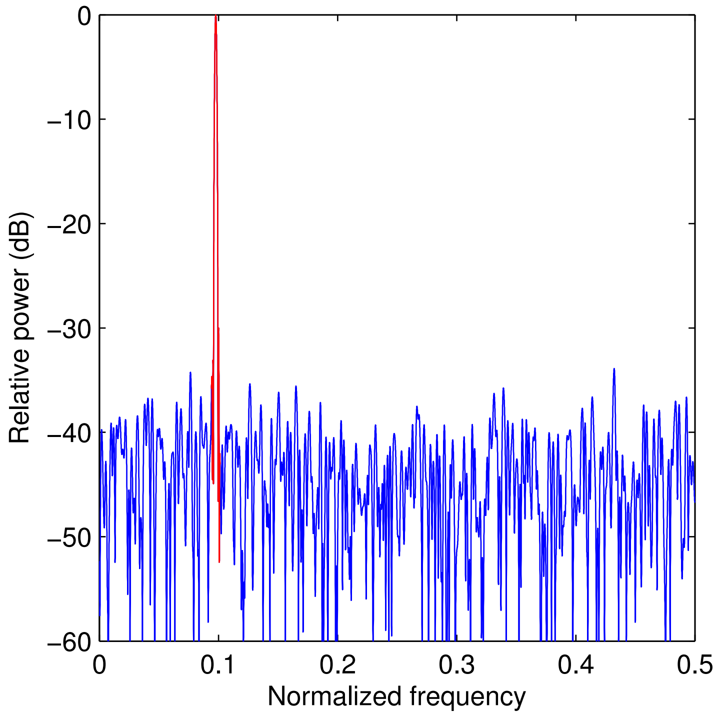

Figure 1: Example spectrum for noise estimation. The peak region is shown in red, while the baseline region in blue.

is then analyzed to determine the baseline level. Upper and lower estimates of B are obtained from the mean and median of the baseline. If the signal contains a single harmonic, the upper bound is a very good estimate of the noise fraction. However, this approach overestimates noise when additional harmonics (even those that are weak with respect to the primary harmonic) are present. In such cases, the lower bound (which is calculated from the baseline median) provides a much better estimate of the noise fraction.

The Analysis Screen ("Data" menu) estimates frequency uncertainty using an expression developed in Reference 2:

$$\Delta f = \sqrt{\frac{6}{f_s \tau^3} \frac{\sigma}{\pi}} \tag{3}$$

where f_s is the sampling frequency and τ is the analysis duration. The program internally compensates for the window function (replacing τ with an effective boxcar duration) and determines the 10–90% rise time for current history calculation parameters. Velocity uncertainty is simply the frequency uncertainty multiplied by half the specified wavelength (specified under "Options" $\rightarrow$ "General" menu).

References

[1] T. Ao and D.H. Dolan. SIRHEN: a data reduction program for photonic Doppler velocimetry measurements. Technical Report SAND2010-3628, Sandia National Laboratories, (2010).

[2] D.H. Dolan. Accuracy and precision in photonic Doppler velocimetry. *Review of Scientific Instruments* **81**, 53905 (2010).