CANVAS: Clock Analysis, Visualization, and Archiving System
A New Software Package for the Efficient Management of Clock/Oscillator Data

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Abstract— **Few software packages exist which address the particular needs of the time and frequency community in analyzing and simulating clocks or oscillators. None is open source. We offer the source code for a set of tools which aims to incorporate commonly used clock analysis and simulation algorithms. The goal of this release is to promote further development of the package by distributing the effort.**

I. FEATURES

The U.S. Naval Research Laboratory (NRL) began development of CANVAS[1] as a package for quick plotting and analysis of all internal as well as various external data related to its clock/oscillator research and development activities. Though written in the MATLAB®[2] language, it is anticipated that some routines will likely be rewritten in lower-level languages such as C or FORTRAN to improve speed. All source code is freely available (**https://goby.nrl.navy.mil/canvas/**). Highlights of the package include standard time-domain variance/covariance calculations, Allan Variance/Covariance, Modified Allan Variance/Covariance, Hadamard Variance/Covariance as well as standard frequency domain periodograms. A rudimentary noise type detection algorithm is also employed. For each variance measure, error bars may be requested which take into account noise type and the appropriate equivalent degrees of freedom [1], [2]. Interactive zooming of the data may be performed, polynomials removed, smoothing algorithms applied, etc. A key feature is that most algorithms are applied only to the data currently visible in the plotting window. Thus, for example, a user may calculate variance measures based on data isolated by zooming onto the desired portion of the overall data series. Also, CANVAS can simultaneously handle multiple time series, either in the same plot, or alternatively in stacked plots (see **Fig. 12**). A routine to estimate the instabilities of N clocks given N-1 clock difference measurements and taking into account nonzero clock correlations is also included (see [3], [4], and [5]). In addition, CANVAS includes a set of routines for simulating clock/oscillator noise, including pure power-law noise ([6], [7]) as well as fractionally differenced noise processes ([8], [9]). Additional code and sample scripts are also available for integrating other data sources and databases and for building custom dialogs to fit the specific needs of individual users. A web forum has been established to promote further development of CANVAS at https://goby.nrl.navy.mil/canvas/.

The MATLAB source code is included and many routines may be used individually or collectively through the GUI provided. Though CANVAS is written in the MATLAB language, one may obtain executable binary versions of the package, which do not require MATLAB to run. Currently, binary versions are available only for Windows and Linux.

Fig. 1 shows the GUI main figure window for CANVAS with two sample clock series loaded. Analysis functionality is obtained from a quick tool palette along the left of the CANVAS figure, from menus, or from context menus obtained by right-clicking various plot objects. **Fig. 2** and **Fig. 5** show the accompanying command windows which show various ASCII output from commands. Clicking the pink SPECVAR (specialized variance) button brings up the SPECVAR dialog window as shown in **Fig. 3**. For each series plotted in the main CANVAS window, a separate line will exist in the SPECVAR dialog where one may adjust various parameters used by the specialized variance measures.

[1] Trademark and patent pending.
[2] MATLAB is a registered trademark of The Mathworks Inc.

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14. ABSTRACT
Few software packages exist which address the particular needs of the time and frequency community in analyzing and simulating clocks or oscillators. None is open source. We offer the source code for a set of tools which aims to incorporate commonly used clock analysis and simulation algorithms. The goal of this release is to promote further development of the package by distributing the effort.

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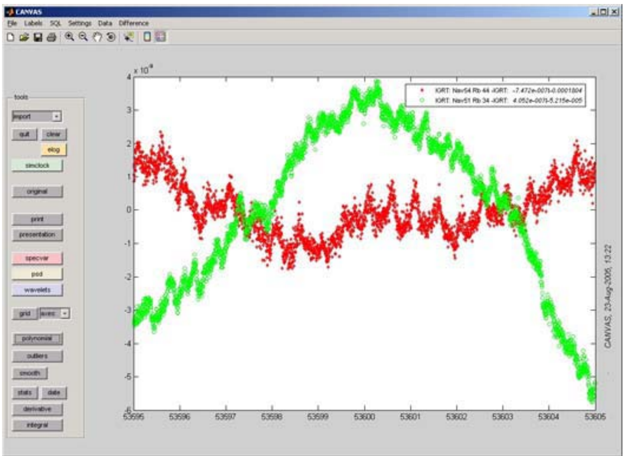

Figure 1 Main CANVAS GUI window showing quick functionality tool palette on the left and main plotting area on the right.

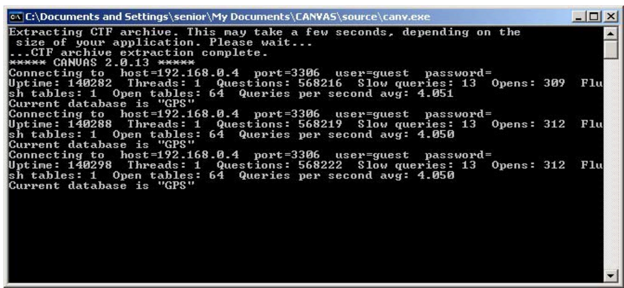

Figure 2 An accompanying command window displays output from various CANVAS commands or functions. Shown is the Windows-compiled version. Running CANVAS from within Matlab will display this information inside the Matlab command window.

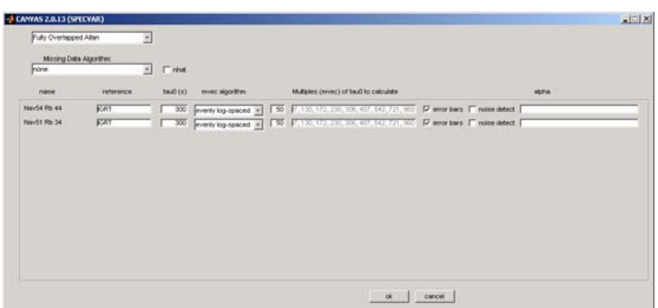

Figure 3 SPECVAR dialog which allows selection from the various time domain variance measures as well as the averaging intervals (τ) over which to calculate. When 3 or more series are loaded, one may also request N-cornered hat estimation (See **Figs. 8** and **9** for an example)

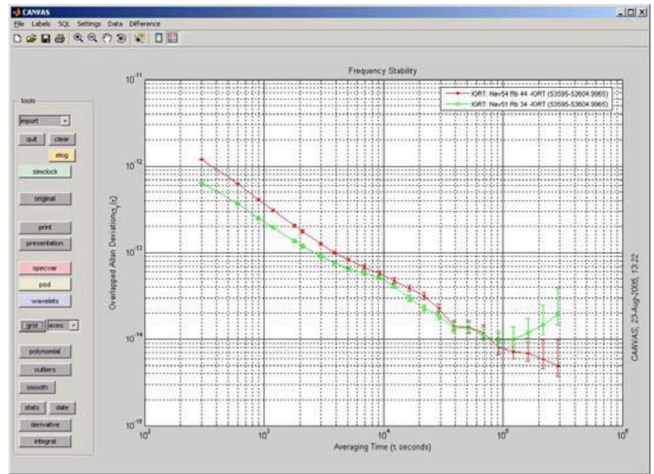

Figure 4 Output obtained from data shown in **Fig. 1** after selecting the Overlapped Allan Deviation from the SPECVAR button & dialog.

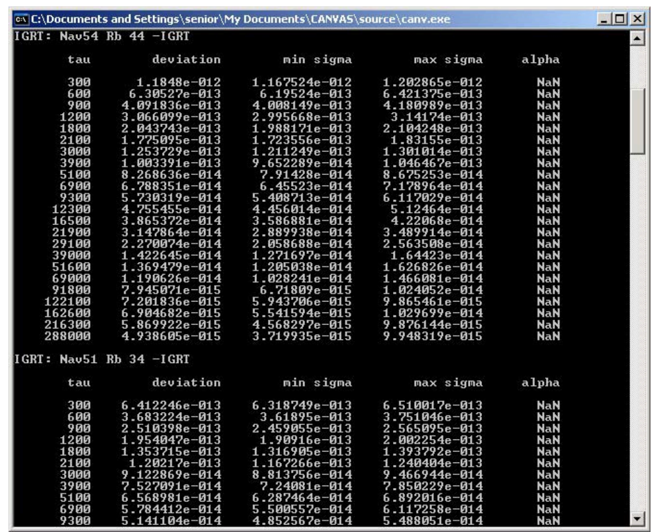

Figure 5 Accompanying command window for **Fig 4**. displaying ASCII output of the SPECVAR routine showing the specific values plotted in **Fig. 4**. This might for example be useful for cutting and pasting values into other applications

II. CLOCK SIMULATION

Two algorithms (labeled PPL and FD in the radio buttons of **Fig. 6**) have been included for simulating clock data, the algorithm of Kasdin ([5], [6]) for generating discrete pure power law processes and the Circulant Embedding algorithm ([7], [8]) for exactly generating fractionally differenced processes. Composite processes may be specified simply by entering more than one (up to 5) power law alpha and the corresponding level of noise. Noise level may be specified either as the Allan deviation at τ = 1 s, or as a spectral density by selecting the appropriate radio button (**Fig. 6**). Some limitations apply here based on the power law chosen. Finally, systematic offsets in phase, frequency drift as well as sinusoids may be added. **Figs. 6** and **7** show an example of 5 realizations generated using the Kasdin algorithm with White Frequency (α = 0) specified as having an Allan deviation of 1e-12 at τ = 1 sand a daily sinusoid of amplitude 1e-11, the data tabulated at 15-minute intervals.

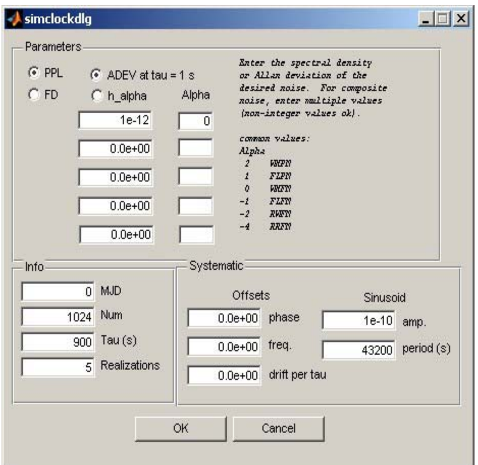

Figure 6 SIMCLOCK (Clock simulation) dialog. Users may select from two algorithms for simulating clock data as well as applying systematic offsets in phase, frequency, and drift as well as sinusoids.

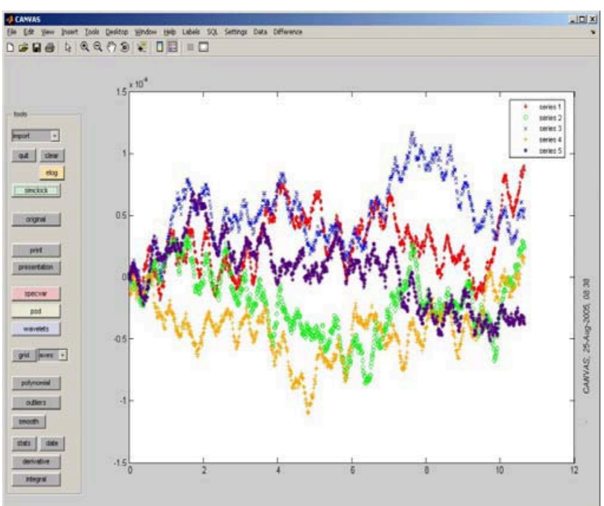

Figure 7 Five realizations of a WHITE FM process as specified in the SIMCLOCK dialog of **Fig. 6**. As the settings in Figure 6 specify, each process is a discrete WHITE FM process with Allan Deviation of 1e-12 at τ = 1 s and a sinusoid with period 12 hours.

Given the 5 realizations shown in **Fig. 7**, we may next select the SPECVAR dialog (**Fig. 8**) for calculating specialized variances. As the dialog above shows, we have selected an Overlapped Allan Deviation for each series and will calculate the deviation at 50 different averaging intervals, τ, evenly log-spaced. Error bars will be placed on each series. Notice we have also selected that N-cornered hat be performed and we have labeled each reference clock for each series as the same reference, which we've called "ref". Note that labeling a separate reference clock will result in separate N-cornered hat evaluations for each different reference listed. Finally, no noise-type detection has been requested, but instead we will use the default WHITE FM error bars (α = 0 for each of the 50 intervals) at each τ. The result of these selections is **Fig. 9**.

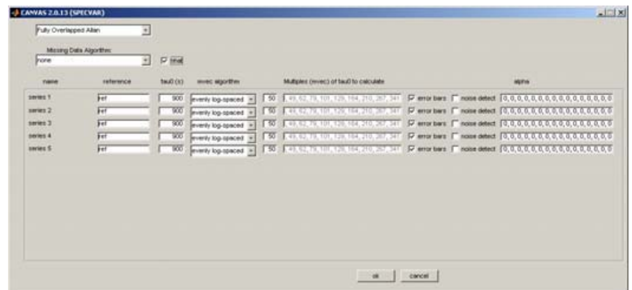

Figure 8 SPECVAR dialog. This dialog allows selection of various specialized variance measures and for each time series plotted in the main plotting window a separate line is shown in this dialog allowing the user to change various parameters including the minimum sampling interval, number of variances to calculate for each series and at what averaging intervals to calculate them. The user may also specify that N-cornered hat be performed. In this case, each unique reference results in N-cornered hat being calculated for the set of clocks with that reference.

Notice we have the additional deviation for the reference clock as per the N-cornered hat algorithm. Clearly, since each series of **Figure 7** was generated with the same 12-hour sinusoid, the N-cornered hat routine correctly identifies this feature as belonging to the reference, as evidenced by the large "hump" at τ = 10,800 s (one quarter of the 12-hour period) as well as harmonics in the frequency stability for ref above.

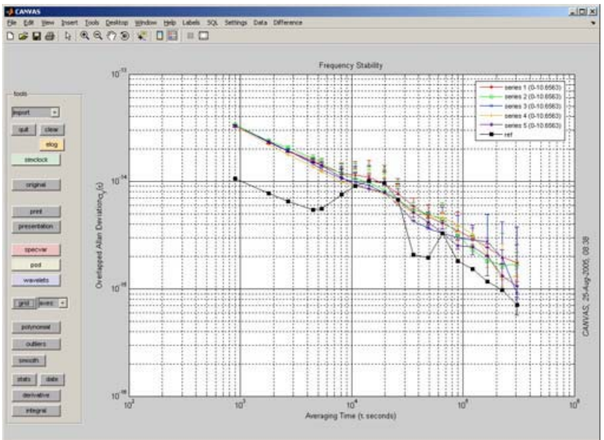

Figure 9 The result of clicking OK in the SPECVAR dialog shown in **Fig. 8**. Notice we have the additional deviation for the reference clock as per the N-cornered hat algorithm.

III. DATA ARCHIVING AND RETRIEVAL

The archiving component of CANVAS consists of the open source MySQL®[3] database server (http://www.mysql.com) as well as separate UNIX scripts for downloading and loading various data into MySQL databases/tables. Nearly all NRL data sources, including multiple GPS data sources, in-house clock measurement data, MET data, as well as a myriad of other telemetry data have been incorporated into MySQL in an automated fashion at NRL. Sample UNIX scripts, a single MySQL data source (see IGS Clock Products below), and all NRL data source dialogs have been included in this distribution so that users may have ample examples for building their own databases and CANVAS dialog windows. Users must obtain and install MySQL separately from this package taking note of any license restrictions from MySQL AB.

As a full example of integrating a data source, we have included an International GPS Service (IGS) Clock Products dialog window (see **Fig. 10** and the files igsdlg.m and igsdlg.fig), UNIX scripts for parsing & loading Clock RINEX files into MySQL, as well as a MySQL database containing IGS Rapid & Final clock products. Once MySQL is installed, users may either simply copy the IGS MySQL database to the appropriate folder on your MySQL server, or utilize the sample UNIX scripts to obtain the Clock RINEX files from the IGS and build the database manually. The latter solution will ensure that users have the latest data since the UNIX scripts can be scheduled to run regularly.

Note: The C++ mysql.cpp routine which interfaces Matlab and MySQL was written by Robert Almgren at the University of Toronto and permission was granted to include it in this distribution. For more information on this routine, see http://www.mmf.utoronto.ca/resrchres/mysql/.

Figs. 10 & 11 show two different dialogs for importing various data from MySQL into CANVAS. The IGS dialog of **Fig. 10** allows one to load IGS Rapid and/or Final clock estimates into CANVAS and should be fully functional for users once the above procedures are taken into account. **Fig. 11** shows a dialog for accessing NRL in-house clock measurement data as well as various NRL MET data. Though the source code for **Fig. 11** is included (tagntdlg.m & tagntdlg.fig) in the distribution, the data sources are not included and so this dialog will not function for most users. It is included only to show the versatility of the CANVAS design and to provide more examples of dialogs. **Fig. 12** shows the resulting data imported by making the selections in the TAGNT dialog as shown in **Fig. 11**. Notice that MET data were plotted separately from the clock data.

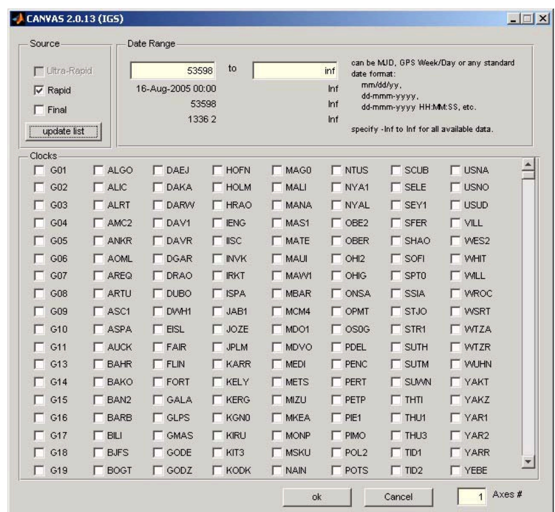

Figure 10 IGS Dialog. This simple dialog imports IGS Rapid & Final clock estimates from MySQL provided that the MySQL database server and the data source has been properly installed.

[3] MySQL is a registered trademark of MySQL AB in the United States, the European Union and other countries.

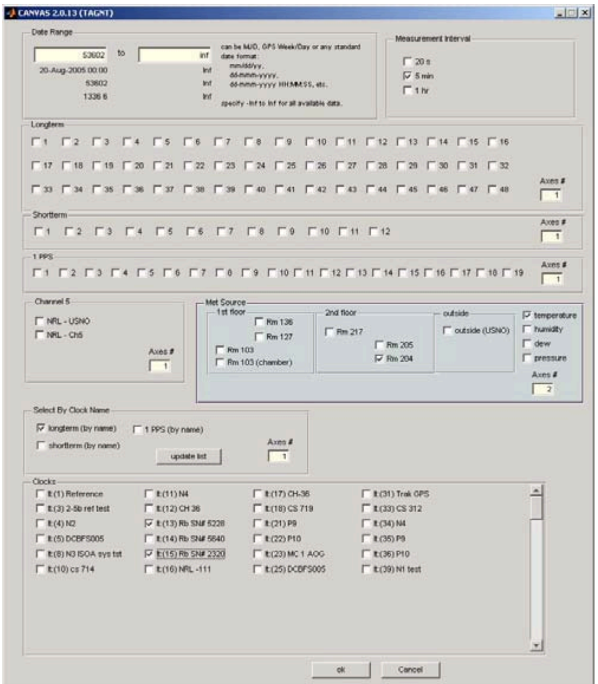

Figure 11 NRL_TAGNT Dialog. This dialog is an NRL in-house dialog for importing clock measurement and MET data from MySQL. The code for this dialog (and all dialogs) is included in the CANVAS distribution, though the data are not included.

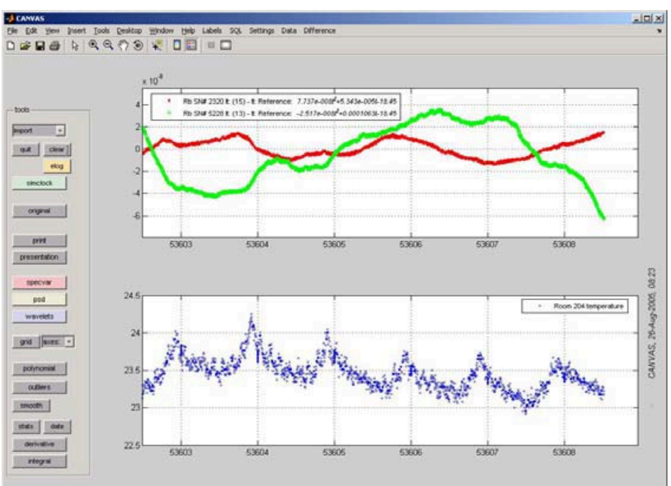

Figure 12 CANVAS main figure window after importing data from the TAGNT dialog as shown in **Fig. 11**.

References to specific software in this paper and in the CANVAS distribution do not constitute endorsement by the Department of Defense/U.S. Navy/U.S. Naval Research Laboratory.

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