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TiFrAn: a new tool for analyzing light-curves

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Abstract. We present our new program package TiFrAn (Time Frequency Analyzer), a tool which was developed for analyzing variable star data.

The main properties of TiFrAn:
- An extension to the Tcl scripting language: it makes it possible to write flexible scripts.
- Includes standard methods (DFT for unevenly sampled data, least square fits, etc).
- Time-frequency distributions (TFDs) for continuous data sets.
- Complex, repeatable tasks, automatic processing of large amount of data.
- Flexible postscript output for figures and for the full log of the data processing steps.

1. Time-frequency distributions

Time-frequency representation of a non-stationary signal yields information about characteristics of the data set in the time-frequency plane. The disadvantage of the linear transforms (such as wavelet) is that they cannot provide high resolution in both the time and frequency domain. TiFrAn applies the general formalism of the bilinear time-frequency transformation called kernel method (Cohen (1995)). By using a two dimensional kernel, different types of distributions (Cohen's class) can be defined with the following form:

$$C(t,\omega) = \frac{1}{4\Pi^2} \iiint s^*(u-\frac{\tau}{2})\, s(u+\frac{\tau}{2})\, \Phi(\theta,\tau)\, e^{-j\theta t - j\tau\omega + j\theta u}\, du d\tau d\theta$$

where s is the signal and $\Phi(\theta,\tau)$ is the kernel function that determines the specific properties of the distribution.

Special cases of the general kernel give well-known distributions (e.g. $\Phi(\theta,\tau) = 1$ is equivalent with the Wigner-Ville transformation). Interference terms (cross-terms) of multi-periodic signals can be reduced by selecting a suitable kernel.

Several kernels are implemented in TiFrAn, most important samples are shown in the following table.

Distribution	**Kernel $\Phi(\theta,\tau)$**
Wigner-Ville	1
Pseudo-Wigner	$e^{-\frac{\theta^2}{\beta^2}-\frac{\tau^2}{\alpha^2}}$
Choi-Williams	$e^{-\theta^2\tau^2/\sigma}$
Zhao-Atlas-Marks	$e^{-\alpha\tau^2 \frac{\sin\theta\tau/2}{\theta\tau/2}}$

In addition to the Cohen's class of distributions, the Short Term Fourier Transform and the Morlet Wavelet are also implemented in TiFrAn.

2. TFD of noisy data

Astronomical data are usually noisy and unevenly sampled, thus the data should be in-

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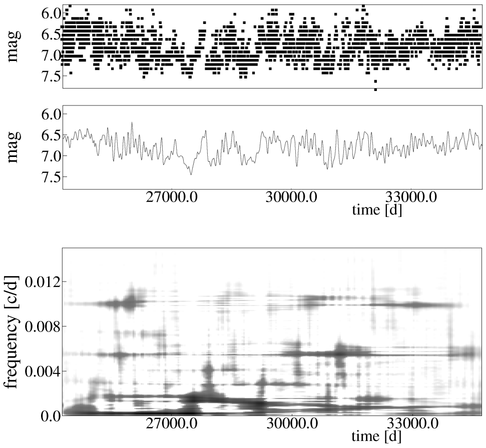

Fig. 1. Light curves (original and smoothed) of X Her (upper panel) and the Choi-Williams distribution of the smoothed data (lower panel).

terpolated and smoothed. It makes some difficulties in the application and interpretation of TFD's. TiFrAn's scriptability can be used to perform Monte-Carlo simulations of the whole processing, including the spline smoothing interpolation of the raw observational data.

Our sample application shows the report of the error analysis of the TFD of the light variation of X Herculis, a semiregular variable star. For this test we calculated the Choi-Williams Distribution (CWD) of the data (Fig 1). Gaussian white noise with a standard deviation of 0.2 was added to the individual brightness estimates, then the noisy data was averaged, smoothed, interpolated and analyzed.

Repeating this procedure, the average and the standard deviation (the "error bars") of the time-frequency distributions were calculated by a Monte-Carlo simulation (Fig 2). The error estimates are used to calculate the most possible (noise limited) range of the TFDs Fig 3 shows the upper and lower limits of the estimated ranges (<CWD> ± 2* stnd-dev(CWD)).

Our tests show that the main features (like the different modulation of different frequency components) are significantly present in the TFD. The applied TiFrAn script can be easily modified to perform the same test on different data and in different steps of the processing sequence (averaging, smoothing, etc.).

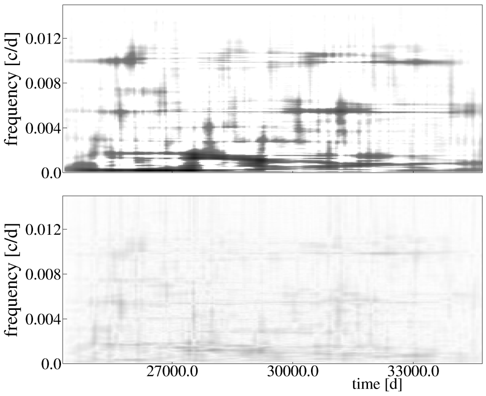

Fig. 2. Average distribution (upper box) and standard deviation (lower box) of the data set.

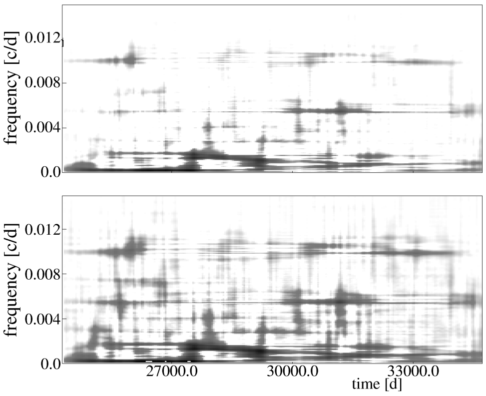

Fig. 3. Upper and lower limits of the estimated time-frequency ranges.

More information (including the scripts used for this paper) can be found at the homepage of TiFrAn: http://www.konkoly.hu/tifran.

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