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Thomas Hélie, Charles Picasso, Robert Piéchaud, Michael Jousserand, Tom Colinot. Variations on the Snail-Analyser and its spectral estimates for the accurate tuning of musical sounds: a strobe tuner like display. 31st International Electrotechnical and Computer Science Conference ERK 2022, Sep 2022, Portoroz, Slovenia. <hal-03782993>

HAL Id: hal-03782993

<https://hal.science/hal-03782993v1>

Submitted on 21 Sep 2022

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Variations on the Snail-Analyser and its spectral estimates for the accurate tuning of musical sounds: a strobe tuner like display

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Abstract—The Snail-Analyser software combines a high-precision method of spectral analysis with a visual rendering that is musically consistent. In this paper, we consider the visual rendering of a tuning device used by the musical community, the strobe-tuner, and propose to make it benefit from the analysis process of the Snail-Analyser. The graphical user interface is composed of a classical set of 12 dials (one per chroma) made of rotating wheels with concentric periodic patterns (one per octave), the immobility of which expresses the exact tuning of the targeted notes. But instead of using the audio signal to strobe the wheel patterns, the process extracts the demodulated phase related to each targeted note. Each phase is converted into a wheel angle, so that the concentric (but not interlocked) rotating patterns provide independent tuning indicators. Beyond the accuracy, an interest of this technology is to select the frequencies of the targeted notes in a modular way, according to musical choices (temperaments, modes, but also octave stretching, etc.).

Index Terms—signal processing, spectral analysis, demodulated phase, strobe tuner

I. INTRODUCTION

The ATRIM project aims to develop high precision real-time pitch and timbre analysis for musical wind instruments. The approach is to design and explore reactive visual renderings of the sounds produced by musicians, in forms that provide an accurate and informative real-time feedback during musical performance. A first objective is to develop reliable tools for musician testers at the end of the production cycle of musical instruments. A second objective is design visual feedback to help musicians adjust their motor control to their own targets¹

The authors thank the French Ministry of Higher Education and Research and the National Research Agency for the financial support of the ATRIM project. This project is collaborative work between Buffet Crampon and the STMS laboratory.

¹This means that the information should not be a judgement score but should provide accurate indicators that can be easily assessed by musicians.

for intonation, vibrato, glissando, timbre or playing effects. To this end, the main work is devoted to elaborate new indicators and visual renderings built on some accurate spectral estimates used in the Snail-Analyser, together with graphical interfaces designed in collaboration with expert musicians. This paper presents a first step in this approach, devoted to the accurate tuning of sounds and work on intonation.

The Snail-Analyser [1] incorporates a spectral analysis (patented technology [2]) combined with a display on a spiral representation: the center corresponds to the lowest frequencies, the outside to the highest frequencies, and each turn corresponds to one octave so that tones are organized with respect to angles. To outperform the accuracy provided by the Fourier spectrum (or other transforms), a post-processing is applied to the spectrum, that involves its demodulated phase. This signal provides a robust estimate adapted to the accurate tuning of musical sounds, that we propose to specially emphasise by considering a mapping to a visual rendering similar to the strobe tuner.

The strobe tuner is a high quality electro-mechanical chromatic tuner (patented in 1938 [3] and technologically refined later [4]) that is still used by expert testing-musicians. It is composed of 12 dials (one per chroma) made of rotating wheels with concentric patterns (one per octave), the periodicity of which is organised in powers of two. These wheels are enlightened according to the sound wave signal to produce a stroboscopic effect. This makes one pattern appear motionless when the period of one active spectral component of the signal coincides with a rotation time that leaves the cyclic pattern invariant. More recent non-mechanical versions are also available [5], [6].

In this paper, we propose to elaborate a reliable modular tuner with a similar visual rendering, by controlling the pattern rotations by the demodulated phase signals for all targeted

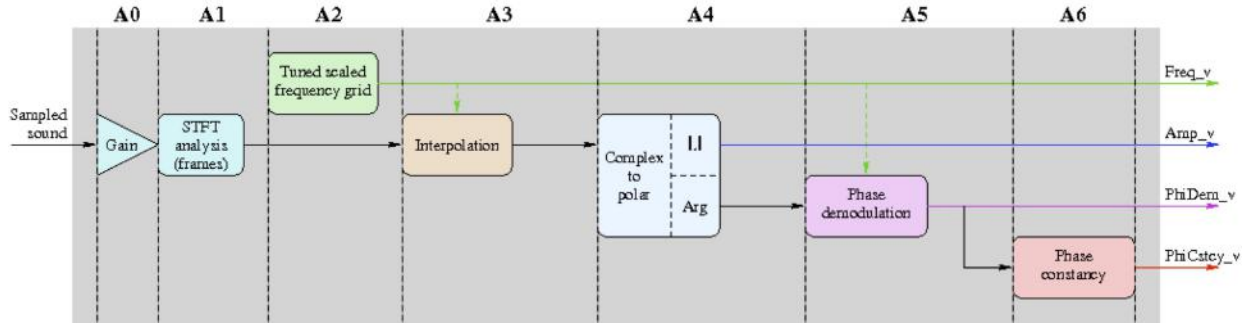


Fig. 1. Block diagram of the analysis process.

notes in place of using a stroboscopic effect.

The paper is organised as follows. Section II gives a reminder on the analysis process used in the Snail-Analyser. Estimates that improve frequency accuracy are illustrated on the Snail viewer in section III. Section IV presents the visual rendering of the strobe-tuner and the mapping of the Snail estimates to the graphical interface. Conclusions and perspectives are finally stated in section V.

II. REMINDER ON THE ANALYSIS PROCESS

The analysis process used in the Snail-Analyser is decomposed according to the block diagram depicted in figure 1. It sequentially applies to the sampled audio input signal (see [?] for more details): a gain (A0), a short time Fourier transform for successive frames (A1), the spectrum complex values of which are interpolated in block (A3) according to a vector Freq_v of tuned frequencies (A2), and converted into polar coordinates (spectrum modulus Amp_v and phase) in block (A4), followed by a process on the phase (A5-A6).

The process (A4-A5) is applied in the time domain. Denoting $\phi_{\text{Fourier}}(t, f)$ the spectrum phase of the frame starting at time t computed for frequency f (with value in Freq_v), it is composed of the two following steps:

(A5) build signal PhiDem_v as the demodulated phase

$$\phi_d(t, f) = \phi_{\text{Fourier}}(t, f) - 2\pi ft,$$

(A6) build signal PhiCstcy_v as the modulus of the output signal of a low-pass filter with cutoff frequency f_c , excited by the input complex signal

$$u_f : t \mapsto \exp(i \phi_d(t, f)).$$

The unit signal u_f is time invariant if the audio component locally analysed at frequency f (the spectrum bin) exactly oscillates at frequency f . Otherwise, it is rotating according to the frequency deviation between f and the frequency of the local component. In short, for each bin, the demodulation (A5) operates in a way similar to² a strobe (tuned at f) enlightening a clock rotating at the frequency of the local component, to

²The similarity holds for the slowdown property but not for the operational process: the strobe operates as a sub-sampling at times n/f whereas the demodulation is defined for all time t , which can be synchronised to the frame time-step.

produce a slower clock image formed by the circular signal u_f in the 2D complex plane.

As a consequence, the process (A6) returns a unit value if the frequency deviation is lower than f_c and a smaller positive value otherwise. In short, PhiCstcy_v provides an indicator of the rotation slowness of the circular signal u_f , that characterises the concordance (up to f_c) between f and the component frequency. A typical cutoff frequency range is from 1Hz (high resolution tuning) to 10Hz (musical play with notes, possibly with a soft vibrato).

III. ILLUSTRATION ON THE SNAIL VIEWER

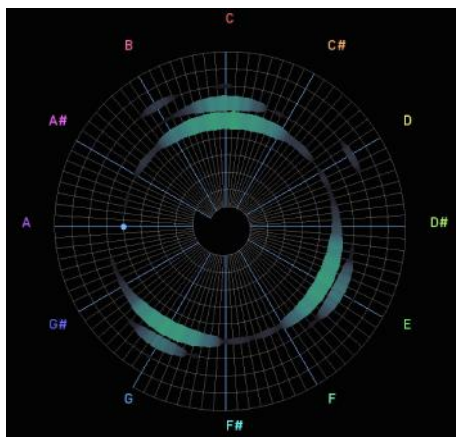
The Snail viewer is composed of a spiral skeleton (+1 round from the center is +1 octave, so that one angle corresponds to one chroma): the polar coordinates (ρ, θ) of the spiral are defined with respect to frequency $f \in [f_{\min}, f_{\max}]$ as

$$\rho(f) = 1 + \log_2(f/f_{\min}), \quad \theta(f) = \theta_{ref} + 2\pi \log_2(f/f_{ref})$$

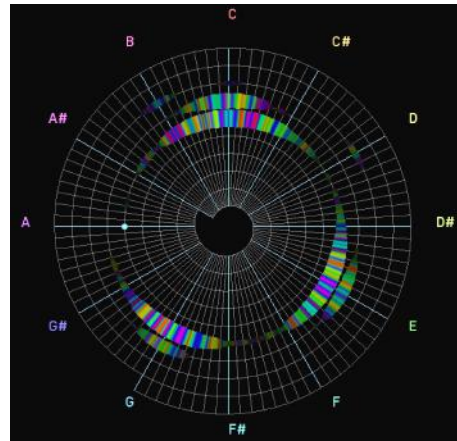
where f_{\min} and f_{\max} denote the lowest and highest frequencies to be displayed and f_{ref} is the tuning reference displayed at angle θ_{ref} .

Figure 2 presents a step-by-step summary of the use of the analyser estimates on this viewer. Sub-figure (a) displays the Fourier spectrum on the spiral: the magnitudes Amp_v are converted into loudness L_v (according to the ISO226 norm [7]) which is mapped to color and thickness. The sound components (notes C,E,G composed of a few harmonics) appear as large lobes (for a Hanning window, 50ms). In sub-figure (b), the colors represent the demodulated phases PhiDem_v (for a circular colormap): the color is time invariant at the exact frequency of each component whereas it sparkles (according to the phase rotation) away from this frequency. In sub-figure (c), the saturation for these colors is mapped to the phase constancy indicator PhiCstcy_v : the colored part isolates the exact frequency with a precision $\pm f_c$. In sub-figure (d), the thickness is multiplied by the same indicator PhiCstcy_v : this emphasises the isolated components with the same precision.

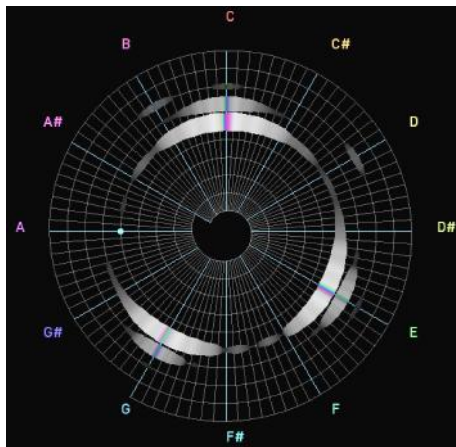
Comparing sub-figures (a) and (d) illustrates the improvement on the frequency precision provided by the analyser.



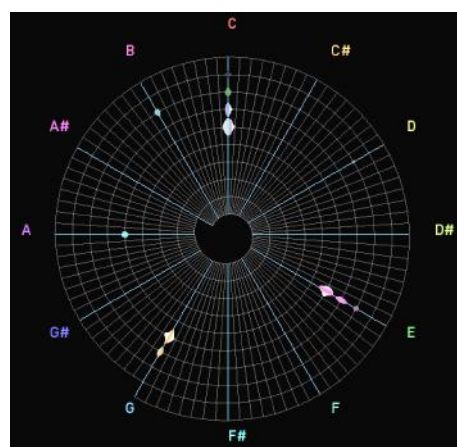
(a) Fourier spectrum magnitude



(b) Fourier spectrum phase (circular colormap)



(c) Fourier spectrum magnitude with emphasised slow rotating modulated phases (coloured part)



(d) Selected frequency components

Fig. 2. Views of the sound spectrum resulting from the successive stages of the analyser, represented on the spiral skeleton. The analysed sound is composed of three notes (C,E,G) tuned according to equal temperament. Each note includes the fundamental frequency and three higher harmonics.

IV. STROBE-TUNER VIEW

A. GUI description

The main view of Strobe-Tuner is inspired by the interface and layout of the conventional mechanical stroboscopic tuner (see figure 3, top). Twelve dials corresponding to the twelve pitches of the chromatic scale are displayed from left to right and bottom to top. The natural pitches dials (C, D, E, F, G, A, B) are displayed on the bottom line and the altered pitch dials (C#, D#, F#, G#, A#) are arranged on the top line with a half-dial translation to the right. Inside each of these 12 dials is a digital version of the visual pattern commonly used in mechanical strobe tuners, that is, 7 concentric rings composed of binary cyclic patterns, with a 2^k -periodicity from octave $k = 0$ at center to $k = 6$ at exterior.

In a strobe tuner, these rings are attached on a wheel that rotates at the frequency f of the targeted note (at octave 0). Then, when enlightened according to a sound wave signal that includes an active spectral component of frequency $2^k f$, the stroboscopic effect makes the cyclic pattern of the ring k appear motionless.

In the present work, the visual rendering is kept but the process for the animation of the rings is modified and the rings are no longer interlocked.

B. Mapping and illustrative result

In the development of this prototype application, the tuning accuracy is derived from the Snail-Analyser engine, packaged in standard library. Each ring is affected to the target frequency of the corresponding note, so that the frequency grid Freq_v is composed of 7 octaves \times 12 chroma = 84 values (rather than more than 2000 for the Snail visual rendering), covering C-0 to B-6 (16.3516Hz to 1975.53Hz for the equal temperament and the reference tuning frequency of 440 Hz).

The demodulated phase PhiDem_v derived for each frequency of Freq_v is assigned to the angle of the corresponding ring, providing individual rotation for each pattern (rather than for each wheel in a standard strobe tuner). This process allows to assess exact relative phase relations between the components represented on a same wheel (as Fourier series

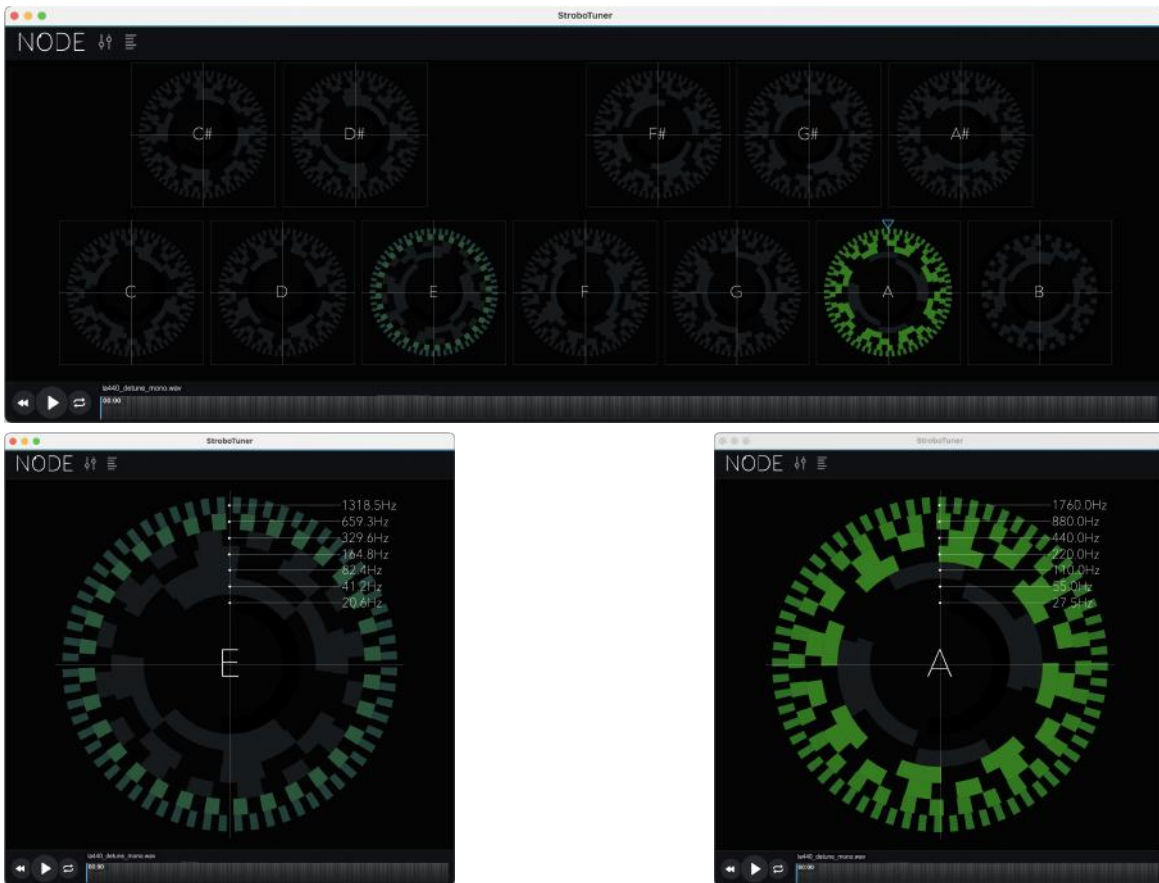


Fig. 3. Visual rendering of the stobe-tuner (global view and zoom on chroma E and A. The sound is a A note (220Hz) with several harmonics. Harmonics 1, 2, 4, 8 are clearly visible in the A dial: their demodulated phase are constant and the relative angle between patterns provide information on the exact phase of the Fourier series of the note. Harmonics 3 and 6 are visible in the E dial: their demodulated phases are not constant as the E chroma is tuned for the equal temperament. Harmonics 5, 7, 9 are close to C#, G, B: their demodulated phases rotates faster than $f_c = 2$ Hz so that the green color is not activated.

do) or to emphasise inharmonicity when the patterns appear out of synchronisation.

The color mapping for each pattern ranges from black to a vivid green through a mapping depending on the phase constancy index (PhiCstcy_v) and of the amplitude (Amp_v). Currently, the Hue is scaled linearly between a dark red and a vivid green, and Saturation and Brightness components follow a monotonic laws so that a component far from the expected pitch or with a low energy will be rendered black. Moreover, a threshold is used on the global energy of the signal as a visual filter to avoid overwhelming for the eye.

Figure 3 shows a result for a sawtooth wave at 220Hz with 8 harmonics (220, 440, 660, 880, 1100, 1320, 1540 and 1760 Hertz) with a high precision mode for the analysis engine ($f_c = 2$ Hz). Note that Harmonics 3 and 6, visible in the zoomed E section are a bit dimmed due to the slight difference with the expected target frequencies.

V. CONCLUSION

The representation of the Snail-Analyser estimates in the form of a strobe-tuner visual rendering appear to be relevant: In addition to the accuracy of the strobe tuners, supplementary information (phase relation between the harmonics in octave

relation) and modularity (the frequency of each note can be chosen independently) are achieved.

Further work will address temperaments (or musical modes and octave stretching), visual renderings of timbre, and new features such as real-time or recording/playback modes, to allow accurate and easy-to-read comparison between two instruments or musicians.

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