INFORMATION RETRIEVAL OF MAROVANY ZITHER MUSIC WITH AN ORIGINAL OPTICAL-BASED SYSTEM

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ABSTRACT

In this work, we introduced an original optical-based retrieval system dedicated to the music analysis of the *marovany* zither, a traditional instrument of Madagascar. From a humanistic perspective, our motivation for studying this particular instrument is its cultural importance due to its association with a possession ritual called *tromba*. The long-term goal of this work is to achieve a systematic classification of the *marovany* musical repertoire in this context of trance, and to classify the different recurrent musical patterns according to identifiable information. From an engineering perspective, we worked on the problem of competing signals in audio field recordings, e.g., from audience participation or percussion instruments. To overcome this problem, we recommended the use of a multichannel optical recording, putting forward technological qualities such as acquisition of independent signals corresponding to each string, high signal to noise ratio (high sensitivity to string displacement / low sensitivity to external sources), systematic inter-notes demarcation resulting from the finger-string contact. Optical signal characteristics greatly simplify the delicate task of automatic music transcription, especially when facing polyphonic music in noisy environment.

1. INTRODUCTION

The *marovany* is a tall zither in the form of a rectangular box built from recycled wood products. The metallic strings, measuring up to 1 m 20, and mostly coming from brake cables type motorcycle, are stretched on each side of the box. They are nailed at each end on an easel, made of wood or metal, and are raised by battens whose places along a string determines its pitch. Musically, each set of strings forms, like the famous tubular zither *valiha*, an alternating diatonic scale. The repertoire of the *marovany* consists of a succession of melodic phrases most often played in arpeggios. There is no vertical writing properly speaking in this music, excepting a few punctual chords. However, the high tempo at which notes are played, combined with the facts that strings are barely muted within a musical phrase and that they often resonate with each other, confers to this music a complexity of analyse comparable to that provided by polyphonic music. Wood type, sizing and number of strings of a zither are not fixed. One can indeed find zithers made of light or heavy weight wood, measuring from 1 to 2 meter in length, possessing from 8 to 12 strings on each side, with battens also ranging from 2 cm to 0.5 cm in height (it is known that bringing strings closer to the soundboard produce more powerful sounds, according to an effect called *mafo be*, "louder"). The zither used for our study, whose photo is given in the figure 1, possesses 13 strings on each side, with a pitch range covering more than two octaves.

In addition to its pure musical interests, the study of the *marovany* zither presents a major interest as its take part in a possession cult called *tromba*. This particular type of trance is "musically induced" in that the possessed person is stimulated by the music played. In the context of trance *tromba*, the mode of playing of the *marovany* mainly consists of a quick succession of melodic motifs, progressively transformed through multiple obsessing repetitions. This instrument is often accompanied with a rattle called *kantsa*, built from recycled cans filled with grains and nailed to a wooden handle, which constitutes with hand-clapping the rhythmic base of this music. This social context of trance associated with the *marovany* zither likely determines its musical repertoire. Indeed, music related to possession cults often carries identifiable information able to make some complex connections between music and symbolic extra-musical entities [1]. A large part of the *marovany* repertoire may therefore take the form of an association table between musical formulas and certain divinities [2]. Another functional aspect of the *marovany* during *tromba* is that it greatly participates to the collective effervescence conductive to the trance itself, through specific uses and progressions of musical patterns. In order to better understand these two aspects of the link existing between *marovany* zither and trance *tromba*, an analyse of its repertoire must be performed, with a systematic inventory of musical patterns and air/divinities associations. Within a larger picture, studies dealing with neurophysiological mechanisms within trance events [3, 4] could benefit from precise musical data provided by our system.

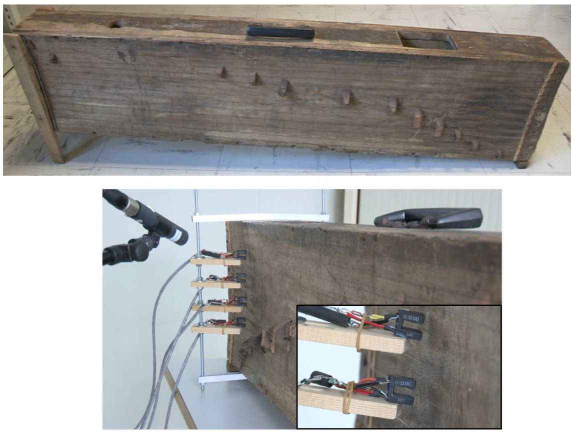

Figure 1: *Photo of a zither marovany (on the top) and of the implemented optical-based system, with the details of sensors in the close-up (on the bottom)*

Malagasy zithers, and more particularly the *valiha* (made of bamboo), that is considered as the national instrument of Madagascar and from which the *marovany* is derived, have already been subjected by numerous ethnomusicological researchers [5, 6]. However, as far as the authors know, there is currently no large-scale systematic analysis and classification of its repertoire, based on precise musical (rhythmic, modal, structural properties) and extra-musical (functional roles, symbolic content) criteria. To provide a deep insight into musical functionalities of the *marovany* in the context of trance *tromba*, investigations on the field must be undertaken, which systematically monitor and characterize musical patterns to statistically evaluate their occurrences over different trance sessions (e.g. for the recurrence or structural roles of certain musical motives), and to draw correlations between musical, behavioral and symbolic information over the time of a trance (e.g. for the way musical formulas are renewed and the impact it has on the possessed). A systematic study of such concordances should allow to establish the catalogue raisonné of the common repertoire of the *marovany* zither players in context of trance *tromba*. The automation of this process is made imperative as a manual transcription may be cumbersome, considering that trance sessions can last several hours and that there is no manuscript support for this music. Also, the complexity of this transcription (due to speed of playing, polyphonic characteristics, noisy environment) implies a great variability in hand-made results, making them prone to errors without possible estimation of their quality. Standard audio-visual devices recording each trance(e.g. see an excerpt of a trance video and other audio-visual material about the *marovany* on the web page of [7]), which allows the analysis of the behavioral indices mentioned above, do not provide an optimal support for music transcription of *marovany* music, as they exhibit competing signals within a noisy environment. To remedy this problem, this paper presents in section 2 an optical-based retrieval system dedicated to in situ recordings of musical airs of the *marovany* zither. This system was further integrated to an acquisition and processing chain aiming to perform music information automatic retrieval, presented in section 3.

2. CONCEPTION OF AN OPTICAL-BASED RETRIEVAL SYSTEM

Several constraints must have been considered in the choice of the recording system. Intrinsic constraints to the *marovany* mode of playing firstly, including its speed, the different modes of attack and string muting, the polyphonic sequences (due to intermittent chords and mutual resonances induced by the strings). In addition to that we have exterior constraints, such as external sound sources (mainly the rattle, hand-clapping of the audience, vocal interjections of the possessed), environmental (high humidity and heat) and technical (unreliable electrical sources) conditions. It is then preferable to avoid using too sensitive and preamplified systems (e.g. 48 V phantom powering), which could degrade very quickly. The accumulation of these constraints make the overall audio signal hard to acquire and process. The optical-based system of music acquisition described in the following has been conceived to optimize the task of automatic music transcription, attempting at best to comply with all these constraints.

Optical-based systems have already found various applications, such as metrological measures of string displacement [8, 9] or a MIDIfication [1] of a piano through the Moog piano-bar technology [10, 11]. Our system, illustrated in the figure 1, is closer from this second application, although distinguishing itself through the desire to integer as accurately as possible a great number of physical parameters characterizing the sound quality of the instrument. The selected optical sensor are slotted optical switches consisting of an infrared emitting diode and an NPN silicon phototransistor. It has a fork design, with the string placed between the two branches as illustrated in the close-up of the figure 1. On one side, the light-emitting diode (LED) emits a light beam whose diameter is 0.5 mm and wavelength 940 nm. On the other side, the phototransistor has a peak of sensitivity at 850 nm. When the string passes through the laser it modulates the output current of the sensor, accordingly to the surface of the laser shadowed by the string. In order to maximize the dynamic of the optical signals and obtain sharp transient attacks, the narrowest possible diameter for the laser is used. Such sensor then acts as a digital switch with a robust sensitivity to string displacements. An enhanced low current roll-off is used to improve contrast ratio and immunity to background irradiance. The power pack of the optical sensors needs a continue tension of 5 V, and is thermally isolated, which makes it well aligned with field conditions. Two compact portable digital recorder ZOOM R16, allowing the recording of 2 x 8 tracks simultaneously, are used for data acquisition of optical signals. Those are directly saved in the Cubase software. A synchronous audio signal of reference is also recorded with a microphone Neumann KM 184 mt. Sampling frequency for all recordings is 44.1 kHz, with 16 bits.

Each string is equipped with an optical sensor to get individual signals. Two constraints have been taken into account in the placement of these sensors, attached on a vertical bar exterior to the instrument (see figure 1). On one hand, the system must not be too cumbersome and disturbs the playability of the instrument. On the other hand, the measuring point of string displacement may create a bias in the amplitude measure. Indeed, as this displacement consists of a superposition of vibratory modes, defined as a succession of nodes and anti-nodes, if a sensor is placed on a modal node the energy contribution of the corresponding mode is null. To answer these two constraints, the bar of sensors is positioned near the easel, in such a way that the playing zone is less disturbed and that the sensors are roughly placed on the ascending slope of the anti-node following directly the easel-related node common to all modes.

The figure 2 represents the spectrograms of the audio signal and four optical signals (after post-processing, see section 3) respective to four distinct strings, recorded on a traditional tune called *Sojerina*. As it can be seen, optical signals offer a high signal to noise ratio and sharp transients, both in the attack phases (end of plucking) and release (beginning of plucking with the contact finger-string). The independence of each string is well respected, each sensor detecting solely the vibration associated to its string. In addition to that, we have a good separability of successive notes of a same string, with inter-notes blanks resulting from the instants of finger-string contacts. Eventually, such a system of acquisition decomposes a multi-source audio signal into simple identifiable components, simplifying more particularly the complex analysis of a polyphonic sequence by processing individually several monophonic sequences. Another advantage of the optical technology is that it allows a straightforward conversion of string displacement to MIDI format files. Such signals also make easier

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[1] Acronym meaning the in-situ conversion of an acoustic instrument into its homologous MIDI.

their post-processing for analysis, and are well suited for applications to real-time.

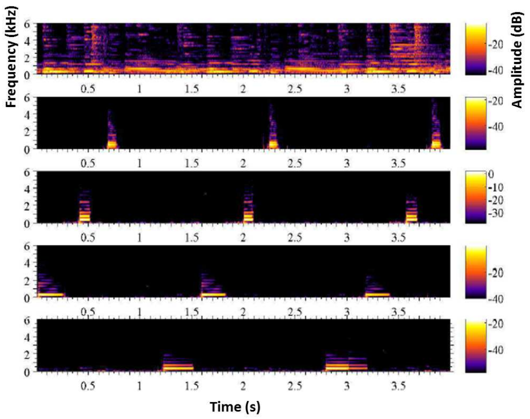

Figure 2: *Spectrograms of the signal audio (on the top) and its decomposition in four optical signals (on the bottom) extracted from a Midegana air*

We now present a short comparative study on the acoustic characteristics of audio and optical signals. After post-processing optical signals (see section 3), five acoustic descriptors have been computed on a set of thirty pairs of notes {audio;opical}, played separately and let in free oscillation until extinction. The used descriptors are defined as follows:

AT , the attack time (in s) is defined by the necessary time for the signal to reach 95 % of its maximal energy E_{max}

$$s(n = AT) = 0.95E_{max} \tag{1}$$

D , the physical duration of the signal (in s) will be defined as the time during which the signal energy remains between 5 % and 95 % of its maximal energy E_{max}

$$D = \{n/s(n) > 0.05E_{max} \ \& \ s(n) < 0.95E_{max}\} \tag{2}$$

E , the energetic level rms (in Pa) of a signal is defined by

$$E(k) = \sqrt{\frac{1}{K}\sum_{k=1}^{K} |(x + kN)|^2} \tag{3}$$

computed for K successive frames of N samples ;

HD, the Harmonicity Detector (unitary value without dimension) is an indicator of harmonicity. The principle [12] is to automatically scan the spectral density of a signal with a comb filter whose fundamental frequency F_0 and varies within a given range of interest. When the valleys of this filter coincides with the peaks of an harmonic sequence for a particular F_0, their product will result in a very weak value which traduces the presence of an important harmonicity. Mathematically, we define it as

$$HD = min(\frac{E_{pond}}{E_{init}}) \tag{4}$$

Descriptors	At	AD	dB	HD
E(Δ_D)	0.0129	0.4366	0.23	0.26
σ(Δ_D)	0.0028	0.11	0.15	0.09

Table 1: *Average E and standard-deviation σ of the acoustic absolute differences between optical and audio signals for the descriptors At, AD, dB, HD*

with $E_{init} = \sum |Y(k)|^2$ and $E_{pond} = Filt(k, k_o)E_{init}$, where Filt is a comb filter defined as Filt = $2(1-|cos(\frac{\pi F}{F_0})|)$.

The descriptors E and HD are evaluated relatively to arbitrary references respective to the types audio and optical. Absolute acoustic differences between these two types of signals are simply quantified through the operator $\Delta_D = |D_{Audio} - D_{Optical}|$, where D represents a given acoustic descriptor. The table 1 presents the results of this operator, showing that the distortional impact of optical-based acquisition mode (not really physically correlated to human auditory perception) is minor when considering temporal profiles. However, spectral content shows more significant differences. An observed tendency is that the harmonic structure of optical signals is stronger, which can be explained by the fact that a direct measure of string displacement privileges its fundamental frequency ans its harmonics in the observed vibratory behavior, minimizing the effect of coupling with the more complex modes of the soundboard. The difference on the amplitude may take important values when a string vibration excites strongly some of the soundboard modes, which allows a very efficient energy transfer from the string to the table.

3. APPLICATION TO MUSIC INFORMATION RETRIEVAL IN THE CONTEXT OF TRANCE *TROMBA*

Information retrieval for music transcription can be classed into several levels: the low-level (pitch, note attack and duration), sufficient for the constitution of a partition, and the high-level (tonality, instrument recognition), which asks for more global and complex notions. Our chain of transcription consists of an acquisition data system (described above) and a processing part including analyse algorithms which will determine the durations, the pitches and the amplitudes of the played notes. These information will then be compiled into a MIDI file, which can be read and edited on any audio sequencer and score edition program.

Once optical signals are properly acquired, their transcription does not pose any specific difficulties. Figure 3 represents a block-diagram of the different functions constituting the analyse chain, from the acquisition to the computational processings of the *marovany* note detection and acoustic characterization. The post-processing of optical signals is as follows. Because of memory concerns, sequences of 5 s are first imported in the software Matlab. An adaptive filtering [13] is then applied to optimize the signal to noise ratio, mainly deteriorated by parasite noise coming from electronics and mutual resonances of strings [2] This algorithm of denoising takes as inputs segments of noises, and allows their subtraction to the signal by minimizing a prediction error with a least-mean square optimization. A 0.049-s hamming window with a 0.005-

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[2] Although this acoustic phenomenon is considered as a disturbing noise in our situation of low-level transcription, it takes an important place in the definition of the instrument timbre.

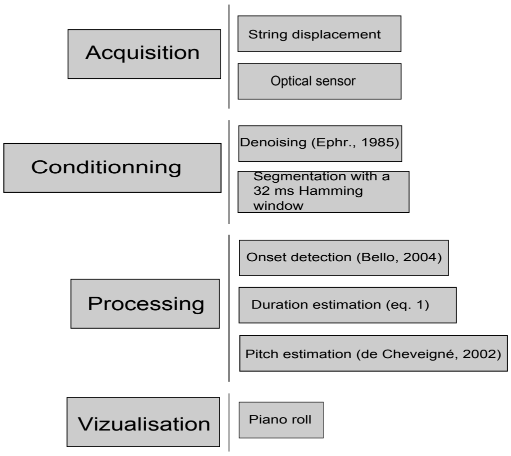

Figure 3: *Block-diagram of the different functions constituting the detection and acoustic characterization algorithm*

s overlapping (that is 11.6 ms, providing a temporal resolution whose order of magnitude is similar to the time attack) scans the entire sequence. Each onset of notes is detected using a spectral difference which takes into account the phase increment, as introduced by [14]:

$$\hat{X}_{k,n} = |X_{k,n-1}| e^{j(2\phi_{k,n-1}-\phi_{k,n-2})} \tag{5}$$

with n the index of each window. As *marovany* sounds consist roughly of a superposition of short stationary sinusoids, the occurrence of an onset generates a peak in the prediction error defined by

$$r(n) = \sum_{n=1}^{N} |\hat{X}_{k,n} - X_{k,n}| \tag{6}$$

Windows for which this residual exceeds a fixed threshold are validated as onsets. From this detected onset, the descriptor E (eq. 3) is computed for the neighbouring windows to search the local maximum $E_{max}(i)$ associated with the note i, assuming this maximum is located near the onset, as expected for notes played by plucked string instruments. Then, E is computed on all the windows following the onset until the energetic value decreases below 5 % of $E_{max}(i)$, which may then be read as an adaptive note-specific energy threshold, or until another peak in the residual r is found. This estimation allows us to deduce the note duration (eq. 2), and its amplitude by averaging the energy over all windows within the note. We are not interested in the absolute amplitude of the notes, but only in their relative values within an air, in reference to a value determined by the MIDI gain. Once all notes are detected, the pitch is estimated within each window, using a robust algorithm derived from the autocorrelation method for pitch estimation [15]. Figure 4 represents the evolution of a waveform signal processed through this algorithm.

This algorithm was evaluated on hand-labelled sequences taken from variants of *Midegana* and *Sojerina* airs (see below for details), containing information on the temporal location, duration, average amplitude and pitch. The tolerances for a correct estimation are fixed to 32 ms on the onset time and to 0.5 s for the duration. An application of the previous algorithm to the audio signal achieves performances between 50 and 60 % of correct note detection, whereas optical sequences provide satisfying results ($<$ 95 %).

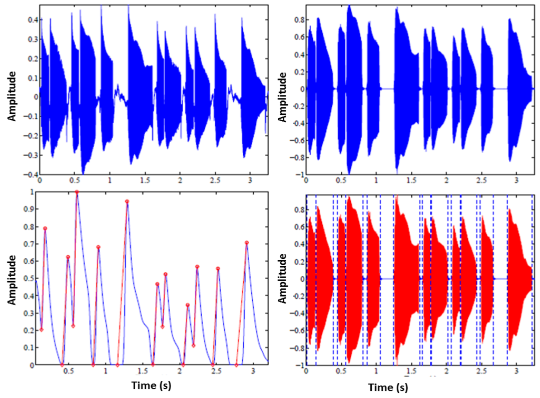

Figure 4: *Evolution of a waveform signal processed through this algorithm. From left top to right bottom: original optical signal, denoised signal, residual r with location of onsets, and segmented signals.*

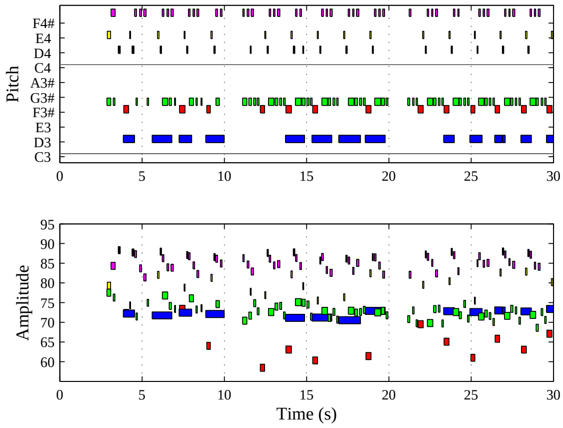

Figure 5: *Piano roll of an automatic transcription of a Midegana air*

We now propose two illustrations of this method through automatic transcriptions of two traditional Malagasy tunes, a *Midegana* and a *Sojerina* (audio files are available on the web page of [16]). These tunes have been recorded in Madagascar and played by the musician Velonjoro. Technical problems on the spot rendered several sensors inoperative [3], and each variant of the airs has been partially reconstructed from different repetitions of a same sequence. In spite of these constraints of a manual intervention to resynchronize the tracks and a superposition of distinct loops, the signals sound satisfactory, with a good preservation of the rhythmic vitality of Velonjero's playing. Figures 5 and 6 show the piano

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[3] The main goal of the mission during which these recordings were done was to test a prototypical version of our acquisition system [7]. The next one is planned for the summer 2013, and will benefit from a finalized and fully operational version of our transcription device.

rolls of these air variants. The piano roll is a means of representing graphically a MIDI file. On the vertical axis are the different notes, represented by rectangles either through their respective pitch (top graph) or their amplitude (bottom graph), and on the horizontal axis is the time. It is then easy to visualize the played notes over time.

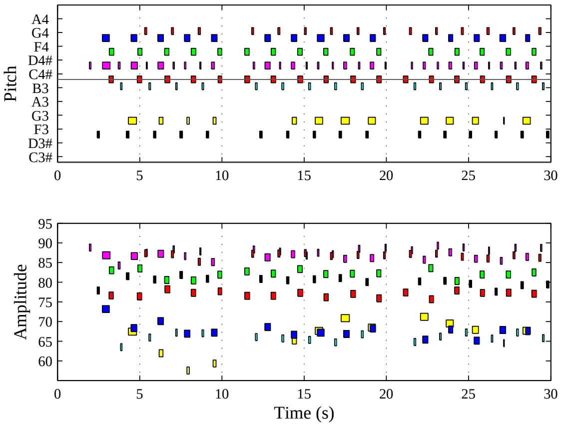

Figure 6: *Piano roll of an automatic transcription of a Sojerina air*

The precision of the proposed automatic transcription system is well adapted to the speed of play of the musician and captures properly certain rhythmic structures characteristic of the *marovany* musical repertoire, as shortly explained now. From top to bottom, the left graph of figure 7 superposes as a function of time the automatic transcription performed on the *Sojerina* tune, with the rhythmic base given by hand clapping (in MIDI clap) and the rattle *kantsa* (in audio track). The right graph of figure 7 superposes against time their audio signals, from top to bottom: hand clapping, rattle, original record and MIDI transcription. Comparing audio tracks, we can see that the original audio and the MIDI file resulting from the automatic transcription are well synchronized, although it lacks a few notes in the MIDI file due to missing sensors as explained above. We find the contrametric character of this music [17], as we see that the rattle accent is slightly out of sync with the pulsation given by hand clapping, intervening more on the off-beats. More precisely, it falls on the second 8th note of a ternary subdivision of the pulsation (each pulsation is divided into three 8th notes). In the MIDI file, there are two obvious thirds: D-F# et C-E, and then a descending arpeggio G-R-B. As these two thirds and the G are most frequently placed on the rattle accent, and not on the hand clapping, the zither plays indeed out of the beat. This characteristic is confirmed through audio tracks where we can see both in the original and the transcribed MIDI file, that a stronger intensity is present in the two thirds, in coincidence with the rattle accents.

4. CONCLUSION AND PERSPECTIVES

An optical-based recording system applied to automatic music transcription of the *marovany* zither in context of trance *tromba* has been introduced in this work. The signals acquired from the optical-based retrieval system and post-processed present optimal characteristics for this task, with easily identifiable musical features

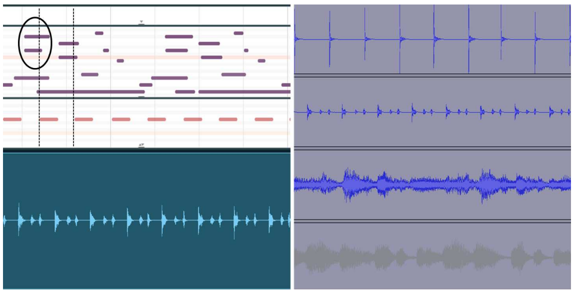

Figure 7: *On the left, superposition against time of the MIDI transcribed file of a Sojerina air with the rhythmic base given by hand clacking (in MIDI clap) and the audio track of the rattle kantsa. The two vertical bars indicate two beats given by the MIDI clap, and the encircled part illustrates the contrametricity of this playing. On the right, superposition against time their audio signals, from top to bottom: hand clapping, rattle, original record and MIDI transcription.*

extracted in a robust way. Among its conspicuous technological advantages, we can mention the high signal to noise ration, the multichannel output with independent signals corresponding to the played strings and the automatic demarcation between successive notes of a same string. Also, the low time-consuming computational method (as performing elementary operations directly on the acquisition buffers) is well suited for real-time analysis, allowing monitoring musical information simultaneously to events, and exploiting directly new findings on the field. In definitive, the multichannel output of such a device, insensitive to external sounds, offers an efficient alternative to the task of audio source separation, crucial to extract in-situ music information from the *marovany*. This system was conceived to meet the long-term demand of developing tools to perform a systematic classification of the repertoire of the *marovany* during trances, in a robust and automatic way.

Although the current interest in the *marovany* music deals with elementary musical information such as duration and pitch range of the notes, the need of reworking on audio data could be felt to integrate high-level information acoustic proprieties, including vibro-acoustic proprieties of the whole instrument, as the instrument timber, string shock modes, and the acoustic intensity. However, the optical system gives a complementary reliable support for following audio-based investigations, allowing a direct access to information simplifying complex problems linked to direct work on audio, such as the number of vibrating strings for studying the polyphony segments in a track.

Study of the *marovany* repertoire in trance *tromba*, founded on musical criteria, and complementing other behavioral indices observed with an audio-visual device and audio data, should bring original elements of investigation to the fascinating relationships between music and trance. Another application theme of such a system would be the Human-Machine musical interaction, through the OMAX improvisation IT environment [18] (developed from the OMax environment [19] in collaboration with IRCAM). Future musical projects could involve malagasy musicians in this environment, using MIDI data from our retrieval system. Questions of a more aesthetic character (acceptability of musical formulas derived from a known repertoire, oral transmission of this skill, musical interest in the amplification, virtual re-orchestration of a musical environment and real-time modifications of musical parameters) will be considered in future investigations following this direction.

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