PICO: a portable audio effect box for traditional plucked-string instruments

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ABSTRACT

This paper reports the conception, design, implementation and evaluation processes of PICO, a portable audio effect system created with Pure Data (Pd) and the Raspberry Pi, which augments traditional plucked string instruments such as the Brazilian Cavaquinho, the Venezuelan Cuatro, the Colombian Tiple and the Peruvian/Bolivian Charango. A fabric soft case fixed to the instrument`s body holds the PICO modules (the touchscreen, the single board computer, the sound card, the speaker system and the DC power bank). The device audio specifications arose from musicological insights about the social role of performers in their musical contexts and the instruments' playing techniques. They were taken as design challenges in the creation process of PICO`s first prototype, which was submitted to a short evaluation. Along with the construction of PICO, we reflected over the design of an interactive audio interface as a mode of research. Therefore, the paper will also discuss methodological aspects of audio hardware design.

Author Keywords

Portable Audio, Mobile Music, Plucked-string instruments,

CCS Concepts

• Applied computing → Sound and music computing Human-centered computing → Mobile devices • Human-centered computing → Empirical studies in ubiquitous and mobile computing

1. INTRODUCTION

The research behind PICO focused on Latin American musical traditions where portability is a regular feature, since performers play the music in vernacular contexts such as festivities and bohemian commemorations. For instance, ethnomusicologist Thomas Turino examines the courting ritual associated to the Charango by suggesting that the instrument channels both, desire and anxiety between the lovers [1]. This ritual occurs in some Peruvian countryside towns' markets where Charango players court ladies with the instrument. While the social role of these performers constitutes an inspiration in the creation of the system, the research looked into musicological studies as well as playing techniques to determine the demands that the system should attend. Although the expected PICO users are both, traditional performers and experimental musicians concerned with these instruments, the device can be also attached to other global instruments such as the ukulele or even an acoustic guitar. PICO adapts spectral analysis strategies, signal processing procedures and human-computer interaction techniques to a musical context where technology is usually alien.

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The device provides a portable real time audio system capable of: (1) increase the instrument energy while preserving the original timbre, and (2) processing the signal allowing the performer to extend the repertoire of timbre nuances.

PICO emerged as a tangible result of an academic research conducted in the Research Center on Sonology at the São Paulo University Music Department, in Brazil. This research addresses a multicultural and trans-disciplinary approach to audio technology design. Its contribution to the NIME community is related to the applicability of audio technology to traditional music, and with the spreading of interactive audio concepts and procedures on an active folk musical context. In order to tackle such a task, the research is supported on some methodological findings developed in the field of design studies [2], [3] which have been adopted by other NIME researchers [4]. By interpreting these ideas, we create a practice-based research methodological model focused on audio interface construction. It was already adopted in the building process of other devices [5], [6]. The model envisages four stages: analysis, synthesis, experiment and validation. Each one of them will be described in the sections of this paper. Our description will be preceded by a theoretical exposition of the model, and then it will give the details of our particular implementation taking PICO as the case study.

In addition, we also embraced concepts and insights usually discussed by the NIME community. The Hyperinstruments project leaded by Todd Machover from the early 1990 at the MIT [7] encouraged a direction on experimental instrument making where technology is capable "… to give extra power and finesse to virtuosic performers" [8]. Projects devoted to augment traditional instruments are particularly relevant [9-12] since they have taken into consideration the original acoustic proprieties in the design of novel interfaces. On the other hand, PICO assumed the challenge of creating interfaces free from physical constrains [13] by exploring portability as a necessary feature of audio interfaces. Portability has been investigated extensively by interface designers giving rise to a new set of music interaction modes [6], [14],[15], mainly with the popularization of smartphones, touchscreens and single-board computers. Regarding the augmentation of string instruments the concept of active control [16] has gained attention in latest years. Attaching actuator and sound transducer systems to the acoustical instruments` body is another way to take advantage of the original capabilities. Although our device adapted a speaker system instead of an actuator one, projects such as the IRCAM's smart instrument [17] as well as other experimental and commercial interfaces augmenting the acoustic guitar suggests alternative directions for PICO future prototypes.

2. ANALYSIS: MUSICOLOGICAL INSIGHTS ON PLUCKED-STRING INSTRUMENTS

The Analysis stage started with the recognition of a cultural frame in which a complex problem could be identified. According to

Buchanan, [18] complex problems can be distinguished by their large amount of indeterminacy, since there are different possible explanations or proposed "solutions". By reviewing some references on the topic the researcher should collect general tendencies, concepts and subject fields which can be taken as guidelines. What should drive the Analysis is the conception of a device capable of facing the questions investigated.

The PICO project enquired into socio-historical and performative aspects of the Latin American plucked string instruments, determining which could be enriched by technology, and which do not. Concerning the organological evolution [19], [20], [21] we found a shared European root. The Spanish Vihuela and the Portuguese Cavaquinho arrived to Central and South America in the 16th and 17th centuries. During a period of about 200 years several plucked-string instruments emerged as the miscegenation between Iberian (western), native Indigenous and Afro cultures. Although all of them have changed some original characteristics (size, tuning, building materials, number of string orders), the Charango seems to have been subject to more radical transformations [22]. Depending on its construction, each instrument has achieved a unique configuration and timbre, both with strong nationalistic connotations, since these instruments comprise the cultural heritage of Brazil, Colombia, Venezuela, Bolivia and Peru.

We also took into account performative concerns in our analysis. The Cavaquinho, Cuatro, Tiple and Charango players have developed virtuoso right-hand techniques. These techniques not only demand high accuracy rhythmic abilities but also include a set of percussive effects performed with the fingers and with the hand`s palm. It is also worth mentioning that these strumming or repique playing techniques give shape the folk genres such as the Brazilian Samba and Choro, the Colombian Bambuco and Pasillo, the Venezuelan Joropo, and the Peruvian Huayno. Although this traditional music is supposed to be played by a group ensemble, it is usually reduced to a single player. Since social events frequently demand the presence of a musician, the instrument mobility becomes a critical factor for players. As a result of our observation we pointed out a set of four general tendencies on this musical tradition, diverse faces of a complex problem. They were treated as design challenges in the next research stages.

3. SYNTHESIS: DEFINING THE DEVICE'S SPECIFICATIONS

In the Synthesis stage the researcher should concretize the tendencies collected in the Analysis on defined design tasks and features of the new device. While complex problems suggest several possible solutions, the synthesis stage requires taking the decisions that help to choose and discard options for the project. The choice of suitable materials is an example, since what should be clear in the Synthesis stage are both, the device`s specifications and the actions taken in the Experiment.

We identified portability as an original feature of the Latin American musical instruments; therefore we transported this quality to the interface attached to them. Portability was diversified in pragmatic design topics such as weight, size and location of components. We opted for globally available and affordable materials for the first prototype: a Raspberry pi version 3 unit with Pd vanilla version installed. Then we tried with different input modes. While technology use to be alien to these musical traditions, ease of use as well as the incorporation a portable speaker system to the instrument's body became design challenges.

With regard to the nationalistic connotations of the instruments, we went into a deterministic approach to timbre analysis by attending spectral descriptors. With the first goal in mind, *increase the instrument energy while preserving the original timbre,* we extracted from an audio sample helpful data in determining timbre identity. Particularly the spectral centroid, which is a commonly accepted criterion in defining the brightness [10], was successfully implemented in the PICO auto EQ module. This module takes the frequency value of the spectral centroid from a 2 seconds audio sample, and then this value is implement as the center frequency of a parametric EQ. Since the parametric EQ is applied with a 30% of intensity, it slightly enhances the instrument brightness. The performer should be able to re-equalize the instrument's audio signal according to the spectral centroid on the fly. The auto EQ module works as a preset of the main EQ. It was not implemented in the evaluated prototype.

Table 1. Creation of PICO technical specifications

Musicological Insights	Design Topics	Specifications
Performer carry the instrument along with them	Weight, size, location of components	Portability
Nationalistic connotations	Timbre analysis	Spectral Centroid auto-EQ
Virtuoso right hand techniques	Enhancing and extending timbre	EQ, Reverb, Chorus, Delay
Technology is alien	Speaker system embedded, affordable components	Ease-of-use

On the other hand, the right-hand techniques also help defining the system's specifications. While the second main project's goal was *processing the signal allowing the performer to extend the repertoire of timbre nuances*, we tried with different real-time audio processors observing whether they preserve the traditional instrument's playability or not. Aspects such as rhythmic accuracy, latency and percussive techniques were taken into consideration in the choice of the four real-time audio effects comprising PICO: EQ, Reverb, Chorus and Delay. The table 1 shows the processing of four theoretical conclusions extracted from the enquired cultural frame in the Analysis stage, and how they were transformed in technical specifications. Further more, it shows the diversification of such specifications in defined design tasks.

4. EXPERIMENT: MAKING THE PROTOTYPE

In this stage the researcher should create a functional prototype following the foreseen specifications achieved in the Synthesis. The Experiment envisages unexpected processes and new discoveries since handling the tools and materials provokes taking new decisions and adopting resources not taken into consideration initially. Even the mistake is considered, as a partial result in a testing hypothesis scenario. At the end of the Experiment a material manifestation of the research should be tangible through the device's features. The more critical sense the researcher has achieved during the Analysis and Synthesis phases, the more rewarding will be for other people to use the device.

Since the theoretical enquire suggested a shared set of instrument's qualities, PICO design should be able to attend these similarities. In this regard, we opted for a modular structure where the same circuit components will be attached to soft cases adapted to the diferent instruments' dimensions. We started making soft cases for the Cavaquinho and Cuatro and with these two instruments PICO was evaluated. PICO requires an already mounted acoustic pick-up system. Its design is intended to be complementary to these systems that are, meantime very popular and diverse in the acoustic guitar technology market. On the other hand, the choice of Raspberry Pi as the host of Pd through Pdlib [23] brought an experimental character to the project, by ensuring not only a community of support makers and coders, but also a set of available and affordable materials and patches to test.

4.1 Hardware

Regarding the components, we failed to find a better audio card than a USB generic one for our purposes. We tested other audio card shields such as the HiFiBerry and the Cirrus Logic without success. Although they had better audio specifications, they do not support simultaneous audio input and output, moreover the Raspberry Pi general IO pins get busy, preventing from using them for sending data input. On the other hand, because of their size and weight, portable Li-Po batteries were suitable to feed the system with 5v. We opted for using separate batteries, for the Raspberry Pi and for the LM-386 audio amplifier.

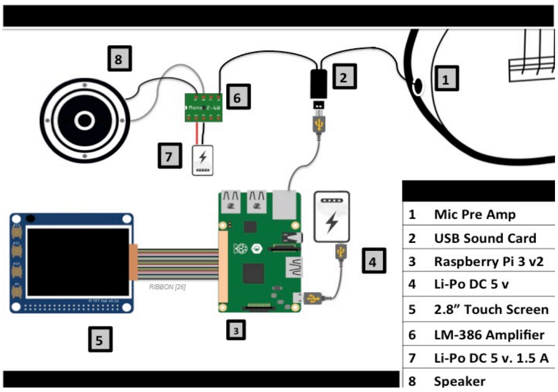

Figure 1. PICO circuit and components.

Since the original idea was embedding buttons and knobs in the instrument`s body for controlling the Pd patch as well as led arrays for visual feedback, we tested with the MCP 3008 ADC and with Arduino. However weight and size constrains ended up tipping the scale towards an affordable and reasonably efficient touchscreen such as the 2.8" Adafruit FTF. Meanwhile, this option drives us to the creation of a Graphical User Interface in Pd for PICO. The Figure 1 locates the PICO components on the circuit.

Another challenging issue was creating the custom soft case holding the components. It was made with neoprene, a flexible fabric capable of envelope the instrument. With the collaboration of a fashion designer, we made pockets for each one of the hard components that are tied with Velcro tapes. The speaker, the audio amplifier and its DC battery as well as the touchscreen were mounted in foam structure attachable to the upper side of the instrument's body.

The location of components took into consideration the strumming techniques as a guide, leaving free of obstacles the instrument's lower side. Another criterion was sound projection. By locating the speaker as close as possible to the sound hole and orienting the speaker in the same direction, the acoustic and electric signals blend more organically. The figure

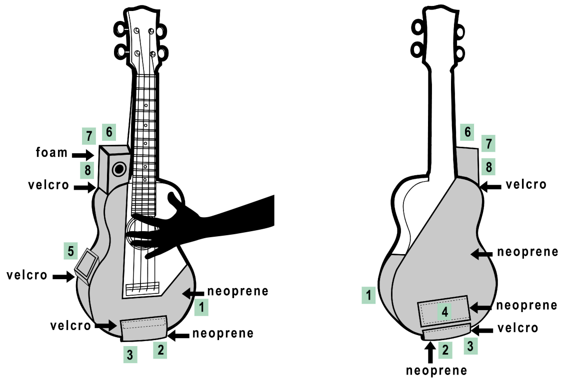

Figure 2. PICO soft case front and back view.

2 follows the same list order than the figure 1, but It shows the location of the PICO components in the soft case.

4.2 Software

The PICO software runs in the Raspberry Pi, it was created with Pd Vanilla version 0.48. PICO adapted a patch by Pierre Massat available at his extended guitar blog [24]. The patch`s structure is basically a 4 effects chain whose order can be altered in real time by the user. It uses various objects of the [iemmatrix] package. Since the original patch was from 2012 and intended to be run in Pd extended, it went through a huge transformation until successfully running it on the Pd portable version. It is worth highlighting that all the libraries used by PICO are easily installable in Pd Vanilla versin via the Deken plugin.

4.2.1 Audio application

Concerning the audio effects we tested with several open patch collections in Pd. We adapted the Equalization, Flanger and Reverb processors from the EarGram patch by Gilberto Bernardes, which deals with concatenated synthesis [25]. The spectral delay was adapted from a patch originally created by Frank Barnecht [26] and modified by Pierre Massat [24]. In addition to the effects, we include the i|o screen, showed in Figure 3, where the input signal can be leveled or canceled and the > button, in the upper-right side. It is responsible for moving to the right any desired effect in the processing sequence`s order.

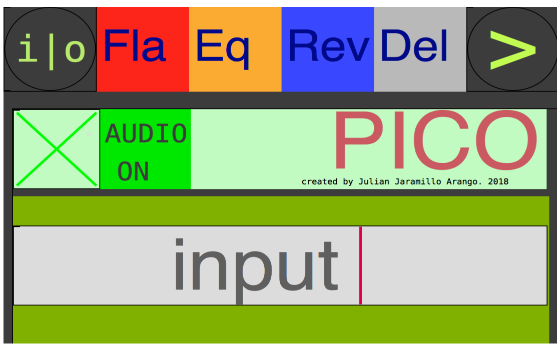

Figure 3. PICO's graphical user interface

4.2.1.1 Graphical User Interface

Although we tested successfully controlling our Pd patch from Processing and Open Frameworks, we opted for a simpler solution by choosing the graphical resources of Pd to create the user interface.

We divided the canvas in a 6x4 matrix, generating fields where an adult`s finger fits. We used this empirical procedure to determine the button and slider sizes. Banners, signs and flags were kept as big as possible. Our challenge was, on the one hand, going beyond the simulation of analog controls by using, for example, 2D sliders; on the other, extending the interaction fields. The squares located at the upper side works as tabs opening a control screen for each effect.

5. EVALUATION: OBSERVING PICO PERFOMANCE

In the evaluation stage the researcher should give attention to the coherence between what was envisaged in the Analysis and Synthesis stages and what was achieved in the Experiment. In the Evaluation the results should be exposed to other people's eyes and hands, in order to verify if what they observe matches with what the researcher foresaw. It is expected that a systematic evaluation process can generate conclusions giving rise to adjustments in the device. Ideally, the evaluation will always take the research back to another Experiment, and several iterations will ensure that the project can achieve their purposes.

Figure 4. PICO first prototype for the Brazilian Cavaquinho.

Our goal in the evaluation stage was looking for evidence that concepts, such as portability, timbre preservation and strumming techniques playability were tangible to other plucked-string instrument performers. In other words, we intended to state if the real experience with PICO met the project`s goals. In this regard, we opted for a moderated and formative usability test [27], since rather than evaluate PICO as a commercial product, we want summarize possible adjustments and collect design recommendations by observing what aspects worked well for which users and which other were frustrating. The test was performed with the prototype shown in the figure 4.

Our test is issued-based [27], it lasts about half an hour and run in two parts. The first one measured PICO performance and was carried out by the observation of three defined tasks that each participant should complete. In the first task the user should adjust the balance between acoustic and electric signal. In the second one he/she had to try increasing the instrument`s power while preserving the original timbre, by using only the Equalization and Reverb effects. In the third task, the participants were invited to explore more radical timbre transformations by using the Flanger, the Delay and by changing the effect sequence order.

The second part of the test was dedicated to measure the performer's satisfaction by asking the participants to value their experience with the instrument. Each participant should choose among 3 levels (positive, neutral or negative) about 4 issues distributed in 14 questions. The enquiry addresses portability, timbre preservation, graphical user interface usability and audio performance. At the end of the enquire each participant should include other comments and suggestions.

Since the project was developed in an academic environment, most of the test's participants were classical and experimental guitar players. However, in order to achieve more representative samples, we went to traditional music academies in search of professional Cavaquinho and Cuatro players. During a period of six weeks we performed the test on 16 performers. We adopted the concept of severity [27], which weights the answers of each participant depending on his/her experience with traditional music, right-hand techniques mastery and familiarity with audio technology. The figure 5

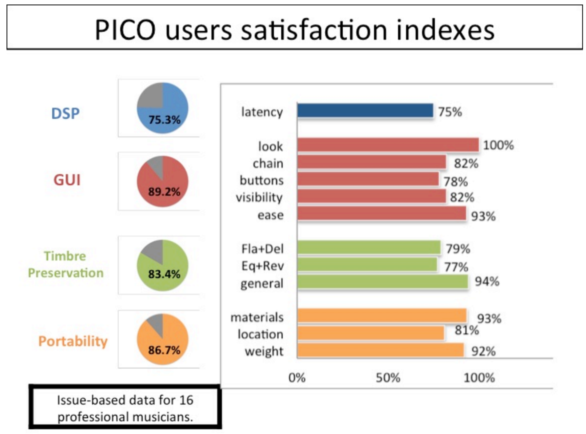

Figure 5. Satisfaction indexes of the issue-based enquiry.

shows the results of the enquiry.

In general, the PICO first prototype run satisfactorily during the test and it was positively embraced by the participants. Although all of them identified portability as a useful feature of PICO, some of them criticized the location of a speaker embedded in the instrument`s body. Moreover, in the free comments section of the enquiry one of the tested performers suggested using a surface transducer rather than a speaker. Surely, it will be taken into account in the next prototype.

While the overall perception of timbre preservation achieved 94%, when dealing with the effects the evaluations fell down to 77% and 79%. Maybe a learning phase is needed for some users before estimate this issue. While a significant group of participants commented things about this topic, what the evaluation shows is that this is a critical problem for musicians. Furthermore, it raises the question about how timbre de-characterization takes place.

A surprising result was the index measuring the graphical interface. Given the limitations of Pd in this field, we expected a lower evaluation. Nonetheless, the participants seem to have had no visible problem dealing with the buttons, sliders neither with the visibility of the signs. In fact, the vast majority of the tested performers found the graphical interface aesthetically appealing and easy to use.

Despite the perception of audio latency achieved to the lowest index of the enquiry (75%), it was observed recurrently during the first part of the test that the same participants that called the attention about latency immediately after playing the first notes, agreed with the fact that when including some effects the latency`s sensation seemed to decrease. However, this issue suggests a deeper search of an adequate audio card for the Raspberry Pi.

6. CONCLUSIONS

From the researcher`s point of view, being informed by musicological studies in the creation of an audio interface has been helpful and rewarding. Despite the help that musicological literature can provide to other music fields, its conclusions and findings often sinks in academic circles and rarely achieve tangible results. On the other hand, under the tenet of unorthodox modes of making music NIME research is more oriented to experimental aesthetics, than on traditional expressions. In this regard, one important conclusion that we have extracted from our research process is the finding of a field of mutual contribution between musicology and experimental lutherie.

As it was outlined, augmenting instrument`s capabilities can mean many different things. In the case of PICO, the musical instrument is taken as a cultural artifact, in other words as a material manifestation of social consensuses. In this regard, their expected users will determine the kind of augmentation that PICO can provide to traditional instruments. PICO can be useful for every performer in re-formulating the musical stage, but also in the classroom, in rehearsals with other higher-level instruments such as drums or brasses, in open public spaces such as the street, a park or the beach, or even in indoor spaces such as subway stations or malls. Moreover, with PICO, amateur and professional Cavaquinho, Cuatro, Tiple and Charango players can improve and color their repique techniques while enriching their performance features. On the other hand, guitar players familiar with effect boxes can expand their techniques to traditional plucked-string instruments. Even more, experimental musicians can explore unexpected expressive possibilities associated to traditional timbers.

The methodology adopted in the creation of PICO imposed a rigid schedule, since the duration of each stage was limited to three months. In this regard, meeting the previously defined deadlines was decisive in carrying out the research in one year. It is worth mentioning that the Experiment started before expected and most design insights emerged with the hands in the dough. A conclusion about our method is that each phase only finishes when the next one is already running. This overlapping suggests a transition in the designer's mind since each stage involves a different set of skills and competences.

From a more politically engaged view we would say that the materials chosen in the creation of PICO denounces unbalanced conditions in creating novel interfaces. This topic is infrequently discussed by US, European or even Asian and Australian researchers simply because in developed countries courier services works well. The unavailability of adequate electronic materials and the lack of distributors in South America reflect a region's serious economic and political crisis, but also invoke alternative strategies by designers. In the case of PICO the strategy consisted on adopting musicological studies to enrich conceptually the device construction process, which can be eventually made by anyone. In this regard PICO is a Gambiarra device [28] because some of the design decisions behind it were taken by precariousness, but it is also its strength, since the separation from the standards suggests a closer approach to their recipients. Maybe the PICO audio system would run with less latency with the Bela device, or the audio output could be better resolved with an active control system rather than a speaker one. The truth is that these materials are really hard to find in the region where PICO has a sense and where its possible constructors live.

This refection drives us to our last conclusion. PICO is a DIY project rather than a device for commercialization. Not only because it is a product of open technologies and knowledge, but also because the evaluation test reveled that even somebody that never worked with Raspberry pi, Pd and so, just by following a set of instructions, can handle with portable and reasonably easy-to-use effect box made with available and affordable materials.

7. ACKNOWLEDGMENTS

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