

TumTá and Pisada: Digital Dance and Music Instruments Inspired by Popular Brazilian Traditions

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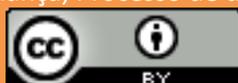
Abstract: This paper presents the development process of TumTá, a wearable Digital Dance and Music Instrument that triggers sound samples from foot stomps and Pisada, a dance-enabled MIDI pedalboard. It was developed between 2012 and 2017 for the use of Helder Vasconcelos, a dancer and musician formed by the traditions of *Cavalo Marinho* and *Maracatu Rural* from Pernambuco, Brazil. The design of this instrument was inspired by traditional instruments like the *Zabumba* and by the gestural vocabulary from *Cavalo Marinho*, to make music and dance at the same time. The development process of this instrument is described in the three prototyping phases conducted by three approaches: building blocks, artisanal, and digital fabrication. We analyze the process of designing digital technology inspired by Brazilian traditions, present the lessons learned, and discuss future works.

Keywords: New interfaces for musical expression; Digital musical instrument; Digital dance and music instrument; Design process, Inspiration from tradition; Brazilian musical instrument.

TUMTÁ AND PISADA: INSTRUMENTOS DIGITAIS DE DANÇA E MÚSICA INSPIRADOS PELAS TRADIÇÕES POPULARES BRASILEIRAS

Resumo: Este artigo apresenta o processo de desenvolvimento do TumTá, um Instrumento Digital de Dança e Música vestível que dispara samples sonoros com batidas de pé no chão e Pisada, uma pedaleira MIDI habilitada para dança. Eles foram desenvolvidos entre 2012 e 2017 para o uso de Helder Vasconcelos, dançarino e músico formado pelas tradições do Cavalo Marinho e do Maracatu Rural de Pernambuco, Brasil. O design destes instrumentos foi inspirado em instrumentos tradicionais como a Zabumba e no vocabulário gestual do Cavalo Marinho, para fazer música e dançar ao mesmo tempo. O processo de desenvolvimento deste instrumento é descrito nas três fases de prototipagem conduzidas por três abordagens: blocos de construção, manufatura artesanal e fabricação digital. Analisamos o processo de design de tecnologia digital inspirada nas tradições brasileiras, apresentamos as lições aprendidas e discutimos trabalhos futuros.

Palavras-chave: Novas interfaces para expressão musical; Instrumento musical digital; Instrumento digital de música e dança; Processo de design; Inspiração pela tradição; Instrumento musical brasileiro.



TumTá and Pisada:¹

Digital Dance and Music Instruments Inspired by Popular Brazilian Traditions

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1. Introduction

*TumTá*² is a wearable instrument in the form of a pair of insoles to be placed inside the shoes. The gestural design of the instrument was focused on the foot-stomping gesture with the heels. The mapping is straight-forward, relating the stomping to the triggering of sound samples; the sound volume depends directly on the stomp's intensity. The samples' selection can be done through an auxiliary interface called *Pisada*, which consists of a series of pads that can be stepped on and which are distributed across the floor.



Figure 1: *TumTá* insoles and transmitter hardware

The development process has taught some lessons about the conception and production of Digital Dance and Music Instruments (DDMI) (Tragtenberg *et al.* 2019; Tragtenberg 2017), a class of digital instruments that enhances expression through body and sound at the same time. Another exciting aspect of this process was the

1. [Editor Note: This paper was made using a \LaTeX template and has some adequation facing the docx template.]

2. Videos available on <https://youtu.be/m4q6iD513pY> and <https://youtu.be/d0F54u015-w>

artistic context that guided its development. Instead of following aesthetic principles from hegemonic western cultures, which is a common bias in most of the NIME research Hayes and Marquez-Borbon (2020). Similar to other decolonial latin-american approaches like Cadavid (2020), this process was based on grassroots popular Brazilian traditions, taking our local culture as a driving force for the development of new technology (Barbosa et al. 2015). This aspect has a lot to contribute to the Computer Music field and may be best suited for musicians and dancers based on similar traditions.

2. Motivation

The *TumTá* started from a demand of the artist Helder Vasconcelos, who wanted an instrument that produced sound from dance gestures with a direct relation. The development of an instrument for music and dance was quite challenging. We found that the bibliography mostly differed between Digital Musical Instruments (DMIs) and Interactive Dance Systems (IDSs). Few references shared a perspective for expression through both art forms at the same time. During this research process, we developed the concept of Digital Instruments of Dance and Music (DDMIs) (Tragtenberg et al. 2019).

The development of *TumTá* began in 2012 and featured several prototype development stages with frequent evaluation meetings with Helder Vasconcelos. The design process was focused on Helder's use and guided by his artistic needs, without having been tested by any other user until 2017. This process happened without any funding, concomitantly with other works, and without a research laboratory infrastructure.

2.1. Helder Vasconcelos

Helder Vasconcelos is an renowned artist for his work as a musician, actor, and dancer. His artistic education took place in the *brincadeiras* of *Cavalo Marinho* (a popular theater from Pernambuco, Brazil) and *Maraçatu Rural* (tradition linked to the carnival of Pernambuco). In the nineties, he acted as a musician playing percussion instruments and eight-bass accordion in the band *Mestre Ambrósio*, where he also danced and performed characters during concerts. He also created two solo performances: "*Espiral Brinquedo Meu*," which the primary language was theater, and "*Por Si Só*," mainly driven by dance. In this second solo, he used Interactive Dance Systems created by Armando Menicacci³ to produce sounds and projections from his dance.

Helder had a clear guideline for the development of *TumTá* and *Pisada*: the autonomy of use, so he would not depend on other people to use the technology. This demand was detected during his second solo, in which the technical setup required a very specialized team. After the first performance, this team could not tour with him, so the sensors and cameras for real-time interactivity could not be used and, therefore, the interaction was replaced by pre-recorded media.

He also had a specific demand for the functional requirements of his instrument and how he would make use of that the device:

I wanted very objectively a MIDI trigger on the heel that when I hit it on the floor it gave me an information, because all the rest I already had in my head [...] in a nutshell I wanted a

3. Armando Menicacci is a research choreographer and professor of new media for interdisciplinary performance at *Université di Quebec à Montréal (UQAM)* and one of the first users of the "*Isadora*" programming environment.



Figure 2: Helder Dancing/Playing *TumTá* during his performance

deeper sound on the right foot and a higher pitched sound on the left foot, that was exactly the relation of the *zabumba*: the *bacalhau*⁴ in the left hand and, if you are right-handed, and the mallet in the right hand. I wanted to reproduce exactly that on my right foot and on my left foot, which is precisely the *zabumba*'s 'Tum' and the *bacalhau*'s 'Tá'. So that's why the instrument ended up with that name. I wanted a 'Tum' on the right foot and a 'Tá' on the left foot. Although I already glimpsed several things. (Interview with Helder Vasconcelos)

This reference to the *Zabumba*, an instrument widespread in many genres of Northeastern Brazilian music, shows how *TumTá* presents an instrumental inheritance (Calegario 2019). The idea of an instrument that can trigger only two percussive sounds, one high-pitched and another low-pitched, could be seen through hegemonic traditions as an instrument without much expressivity or diversity (Jordà 2005). However, in popular Brazilian music and many other traditions, there are several instruments pervasive to various genres that are undoubtedly expressive and diverse with sounds of just two pitches.

This search for expression, both musical and corporal, is a recurrent element in Helder's trajectory, and he credits his formation to those traditions in which this relationship is latent. In these traditions, the artist systematized his learning process into a list of principles for making music, dance, or theater. His principles are based on the idea that a gesture or a sound starts from a common essence, which he calls the generating impulses:

The generating impulse of something that can become a dance, a song or a theater is the same. So I do not see it separately. It will all depend on the artistic necessity. What do I mean? What do I want to say? What do I want to build? [...] This creative impulse can become a character, it can become a choreography, or it can become a beat, a rhythm, or a song. [...] I don't see them as three integrated things or three separate things. In the place of the creative impulse, I don't think what it will be. (Interview with Helder Vasconcelos)

From this theoretical background, Helder sought an instrument capable of revealing this common essence of gestures and sounds. For him, the instrument should be capable of instantly translate the impulsive quality of the footfall's impact on the ground with the impulsiveness of the sound produced. Our challenge was to develop a device for measuring the foot stomp's impulsiveness in real-time and mapping it into sound.

2.2. Artistic References

As well as searching for an instrument with an instrumental inheritance of the *Zabumba*, the choice of this gesture of foot stomps with the heel had an inspiration in the dances of *Cavalo Marinho*, that many dance steps share this bold stomping:

This expression in *Maracatu* and even more in *Cavalo Marinho*, it is in the contact of the foot with the ground. We call it *Trupé*, the dance, the movement. It is a very percussive movement very naturally between the foot and the floor. So it comes from my school from the traditions that I participate in. This is already like this, so it was just a matter of empowering, saying, 'what if it actually made some sound out of that?' (Interview with Helder Vasconcelos)

4. The *Zabumba* is a Brazilian percussion instrument played with a mallet and thin stick called *bacalhau*



Figure 3: Totó Teles and *Cavalo Marinho Estrela Brilhante* from Condado(PE) - Brazil *brincadores* dancing a *trupé*

The steps of *Cavalo Marinho* have the attribute of marking very characteristic a rhythm and common to several rhythms of Brazilian popular music. It is the same rhythmic cell of the *baião* that usually is played by a *zabumba*:

In several *trupés* of *Cavalo Marinho*, we already do that [playing *baião* rhythms], even without making that sound, but we already play the *zabumba* thing. The *baião*, the classic form of 'Tum Tum Tá Tum Tum,' you play it with your foot, even without sound, dancing *Cavalo Marinho*. That's why it was so objective for me: 'If I have this, it will appear' (Interview with Helder Vasconcelos)

In the Brazilian context, during the design process of a new musical instrument, we believe that it is powerful to use local cultural inspirations to provide alternatives to European and North American references that govern the music technology industry. We believe that this approach has the potential to lead to unique, creative, and innovative results. Several musical instruments invented in Brazil directly references local traditions, such as the *guitarra baiana*, the *tantan*, the seven-string guitar, and the *berimbau*, to name only the most popular ones.

This tight connection with a cultural tradition contributes to the degree of instrumentality (Hardjowirogo 2017) of *TumTá*. This fact allows the musicians to perceive it as a proper musical instrument and also to create a pact with the audience (Siegel 2009) on understanding what sounds are connected to which gestures. These aspects are a rare situation for a new instrument. Typically, for new instruments, the audience does not know what to expect from the interaction. A dance with rhythmic attributes of the foot contact with the ground strengthens the recognition of the dance made with the instrument and incorporates a gestural repertoire of this tradition. Several other tap dance traditions already carry an intimate relationship of percussive musical creation with footsteps, bringing this mapping strategy an attractive potential for expressiveness.

3. Development Process

The development of *TumTá* started with the simplest and fastest solutions to trigger sounds from foot gestures. The prototypes were gradually evolving and acquiring increasing complexity and robustness. To overcome challenges, physical and functional we created prototypes to enable a practical evaluation of each solution proposition. The team's collaborative evaluation brought up positive and negative points of each solution, and the discussion directed the approach we should take for the next prototype.

Pisada was developed to be an accessory for changing *TumTá* sample pairs. However, it followed a parallel development process and ended up also as an independent Digital Dance and Music Instrument, serving for many more purposes. That is why we will present it in a separate section of this paper.

We started off the project with quick and dirty prototypes using off-the-shelf technology from game controllers (Nintendo Wiimote and Microsoft Kinect). Deciding on the wearable sensors' approach, we used an Arduino with some shields for connecting a DIY pressure sensor and an XBee transceiver to a Pure Data patch through an artisanal approach for the electronics and case. After validating the idea, in the next prototyping phases, we improved the system's robustness and size. For that, we (1) used digital fabrication tools, (2) designed custom PCBs and laser-cut enclosures, (3) assembled a better transceiver, and (4) developed a more user-friendly software interface.

In sum, we took three approaches during development, which are ready-made building-blocks, hand-crafting, and digital fabrication. These approaches were analyzed to develop the Prosthetic Instruments, which showed

some similar challenges we faced creating a new instrument for the specific performance of artists that were not the hardware developers (Hattwick *et al.* 2014).

In the subsections below, we described the challenges and advantages we face in each part of the process.

3.1. First Prototyping Phase: Building Blocks

In one of the initial meeting with Helder Vasconcelos, some researchers from the MustIC research group used off-the-shelf building blocks prototypes that were assembled on the same day. Jerônimo Barbosa presented a prototype made with Microsoft Kinect with which the whole body's quantity of movement activated a state machine. This prototype did not directly relate to gesture and sound, but a more abstract connection and did not relate to what Helder was seeking. The second author presented a different prototype during the meeting, which was built using a Wiimote from the Nintendo Wii console. The game controller was roughly taped to the dancer's ankle, and a simple mapping strategy was created with OSCulator⁵. When the sensor's accelerometer data passed a threshold, the system trigger MIDI notes. Despite the high latency and size of the controller, this prototype brought a positive reaction in Helder:

Since the first test with the Wii tied with masking tape, and it was very, very, very stimulating. I already felt something happening [...] that first test already had a stimulus to say 'if it works I'll use'. (Interview with Helder Vasconcelos)

This Wiimote solution represents a general approach, having been one of the standard interfaces of the NIME community for a while (Nymoen 2015). This first stage made clear the artist's choice for a wearable system, which was an essential constraint for development. We discarded the camera-based solution's option because of many factors, for example, the need for lighting calibration, the possibility of occlusion, or the high latency of the cameras.

Even though the building blocks were not as small and with a fast reaction, it was enough to validate the idea, which leads us to improve the next prototypes in size, sensing accuracy, and gesture-to-sound latency.

3.2. Second Prototyping Phase: Artisanal

Once established that the instrument would be a wearable device, we began to develop more responsive prototypes with the clear goal of having lower latency. We crafted the first prototype with a pressure sensor (FSR 402 from Interlink) connected to a protoboard and an Arduino UNO. Every time the pressure went beyond a threshold, it triggered a MIDI note that triggered a sound in a DAW. We performed tests by tapping the sensor with a finger on a table and perceived outstanding responsiveness with practically no latency.

Nevertheless, when we did the first tests with the sensors inside the shoes, the sensors broke on the first week of tests due to the sensors' fragile structure and heavy pressure load of the foot stomps. We also tried a piezo sensor, but no matter how much hot glue we put into protecting it, it always broke on the first stomps. The wearable system's ruggedness, especially for dancing, is a great challenge for the hardware developer. Similar problems were found by the MIT Media Lab team while developing the Expressive Footwear:

5. <https://osculator.net/>

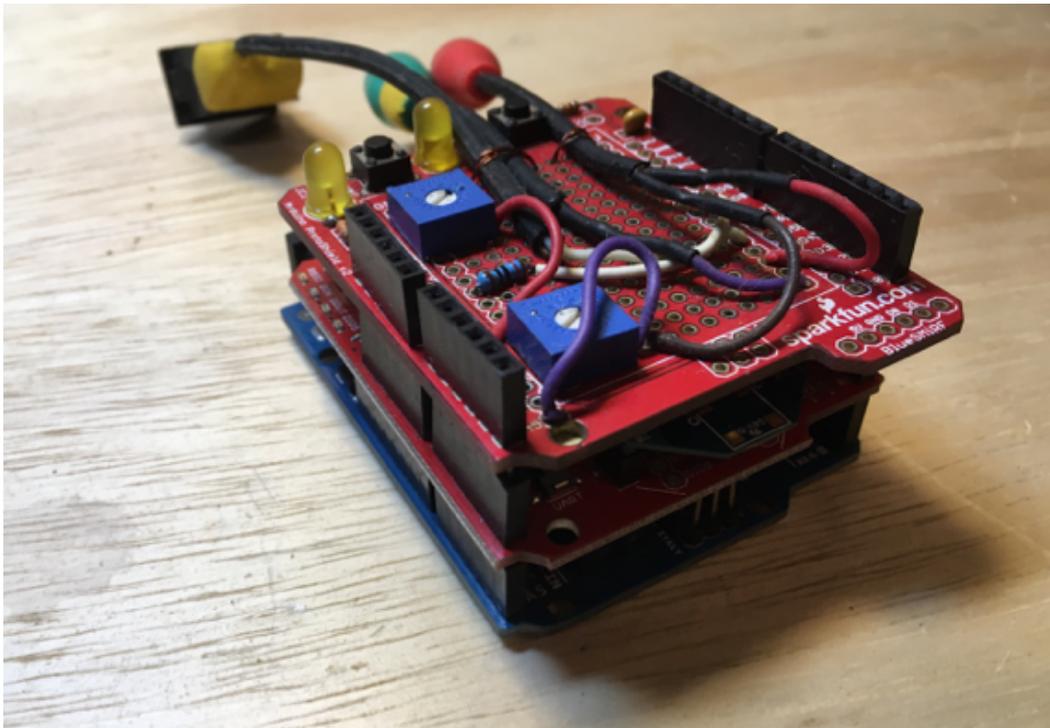


Figure 4: *TumTá's* second prototype made out of Arduino Uno with shields (to be enclosed in a travel soap case)

A dancer's foot is indeed a hostile environment for sensitive electronics, and as we have been reminded repeatedly by experience, everything needs to be well attached or latched down - anything that can move will sooner-or-later break of. (Paradiso 2000)

We migrated to a do-it-yourself sensor alternative with conductive foam that the XBee radio had come. This alternative was inspired by a tutorial published on the Instructables portal by Kyle McDonald (McDonald 2008). This prototype showed a much less accurate reading than the purchased sensor and presented a very noisy signal, but it was very robust at impact.

The next prototype was made out of an anti-static insole made of conductive foam. We used conductive stainless steel (Bekinox VN 12 / 2X275 / 175S / 316L from Bekaert) for the electrodes, which presented an excellent resistance to impact. Sensors previously created with small pieces of conductive foam had the problem of sliding during use, a problem solved when the sensor was shaped as an insole by fitting perfectly inside the shoe. The whole stack Arduino Shields⁶ enclosed inside a plastic traveler's soap-dish, fixed with an elastic bandage around the waist.

Another challenge for developing wearable instruments that we found refers to the electrical noise of the human skin. We noticed a noise in the sensor signals when the foot came in contact with the sensor. It was necessary to coat the insole with a rubber (neoprene) to isolate this noise's circuit. Any solution with a conductive line, lacking electrical insulation, is subject to these noises.

Even with several problems in these prototypes, it gave a much better solution than the taped Wiimote, allowing him to give his first presentation to a broad audience at "Mostra Rumors" in São Paulo's Itaú Cultural main theater, part of the Rumos Itaú Cultural dance award for 2012-2014. The artisanal solution did not

6. This artisanal approach also used Arduino Shields building blocks. Instead of using custom soldered breadboards, this accelerated a lot the hardware development process.



Figure 5: DIY sensor made out of a conductive foam insole and conductive thread electrodes

allow an autonomous use, needing a specialized professional to fix software and hardware bugs that were still frequent. This approach was very customizable but gave unstable solutions that could improve ruggedness, size, and user-friendliness.

3.3. Third Prototyping Phase: Digital Fabrication

With the arrival of Fab Lab in the city of Recife, we had access to a laser cutter, with which we were able to take advantage of techniques of digital fabrication. This approach enabled us to create better enclosures with greater accuracy and robustness. We also started manufacturing our PCBs with the laser-cutter, which led to much more rugged circuits that did not present bad contact issues from fatigued wires. The new circuits went through several stages of development (Figure 6), seeking a smaller size and a more trustworthy connections with fewer wires.

We also had several problems with the wireless transmission. The XBee s1 module had a good range of places without many 2.4GHz devices (Mainly wifi and Bluetooth devices), but as the noise grew, the shorter was the range it worked. For a fast solution, we changed to an equivalent, more powerful transmitter (XBee Pro S1) to have a strong signal even in electromagnetically noisy places. Packet loss was somewhat inadmissible for the low fault tolerance that the condition of artistic presentation demands.

The circuit to process the analog signals from the sensor has undergone several changes to improve the subtlety of control. The circuit we used initially caused a small variation in the sensor's analog signal. The Arduino's analog-to-digital converter (ADC) transformed the voltage readings between 0V and 3.3V into 10-bit unsigned integers, that is, between the values 0 and 1023. As the step variations changed only a few tenths of volts, this resulted in high granularity data. This fact caused the sensor noise to be generally louder than the signal to be measured, requiring only powerful steps to be detected. We made changes to the analog

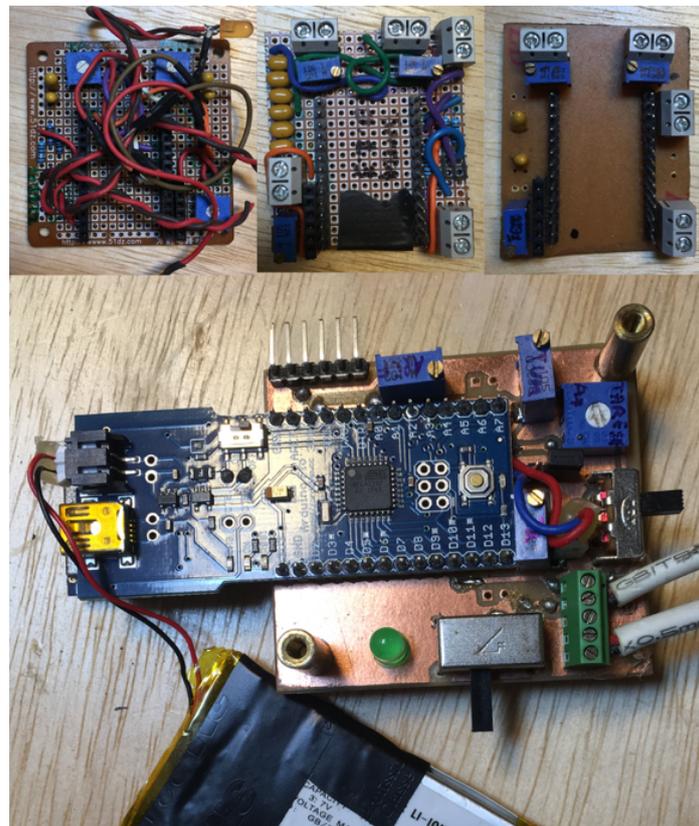


Figure 6: Successive versions of the prototype's PCB, improving its quality and reducing the amount of wires

circuit by adjusting the signal processing and the ADC reference voltage. The sensor continued to depend on heavy steps but allowed for dynamic control between weak, medium, and strong steps. It allows for very rough control and is the main point for future improvements.

The pressure between the floor and the dancer's foot was not as significant as the pressure variation's speed, that is, the pressure derivative. A piezoelectric sensor could be the solution, but the ceramic capsules were not rugged enough to be placed in a dancer's foot. To get around the problem, we included a gesture processing algorithm that calculated the pressure's derivative.

The stomping recognition used an algorithm (Figure 7) that the first step was responsible for storing the sensor data in a sliding window with the last five readings. A median filter averaged these five values to reduce noise from the sensors. For the last five averages, the program calculated a derivative approximation of the data with a backward finite difference algorithm. The derivatives' values were monitored through a Noise Gate filter, only considered when they passed a certain threshold. Then a peak detection algorithm detected a local maximum. At this instant, an event was triggered, and that maximum's magnitude was associated with the stomp's intensity. As the data presented at least two peaks for each stomp, we implemented a debounce algorithm to disregard peaks closer to 150 ms. The interval between two stomps was consistently longer than 150ms; hence our debouncing algorithm did not hinder the dance performance.

The pressure's rate of variation (numerical derivative) to detect the stomps allowed them to be differentiated from simple steps. When walking, the pressure ranges from minimum to maximum values as the weight is transferred from one foot to the other, but the pressure variation in each foot occurs very slowly. The detection threshold allowed to incorporate the range in which the derivative of the pressure corresponded to necessary steps, allowing the user to walk without triggering any sound. The stomps occur with a higher pressure rate variation, and the adjustment of this threshold was made with tests of walking steps against

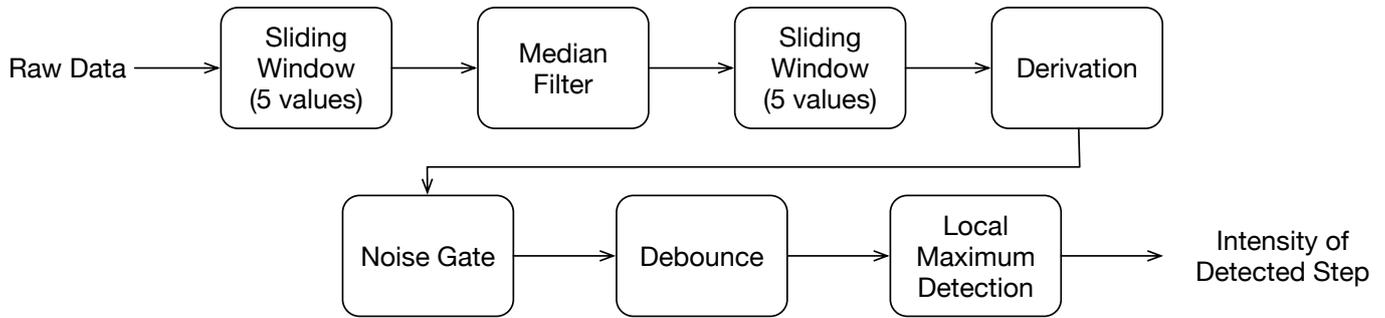


Figure 7: Sensor's signal processing to recognize the foot stomps

stomps.

If the system did not differentiate a common step from an active step, the instrument could cause the instrumentalist's immobility, characterizing the "Midas Touch" problem. Another straightforward but very effective solution to the "Midas Touch" problem was a simple and effective implementation of a switch to turn standby on and off. This switch disabled the instrument operation without turning it off (instrument initialization takes a few seconds). When the standby switch was turned on, the instrument turned into a regular shoe that allowed the dancer to perform any movement without hindrance.

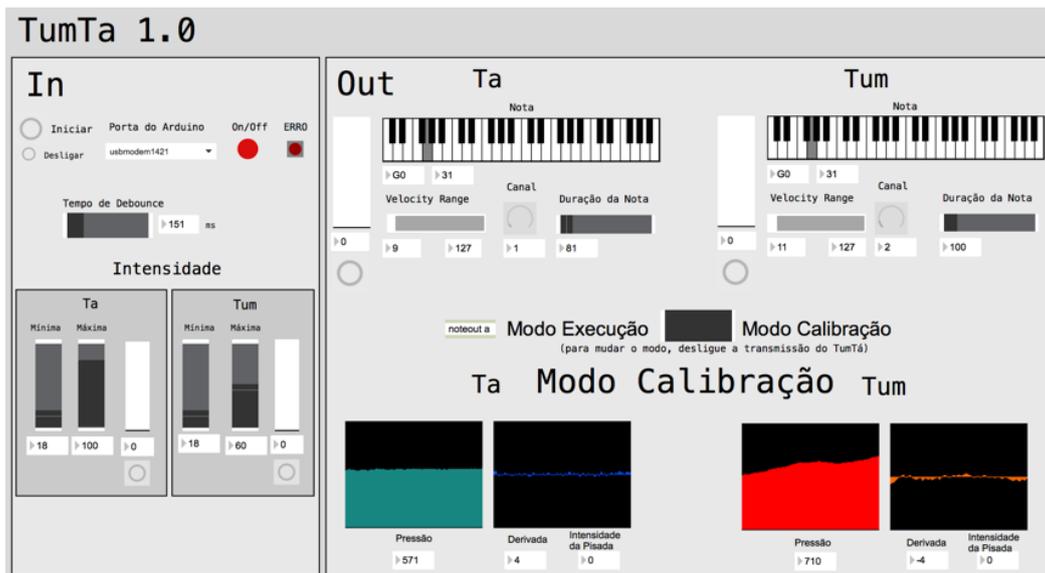


Figure 8: Max/MSP patch for mapping the sensor data into MIDI note triggers

For improving the usability, a Max/MSP patch was developed with an improved graphical user interface (Figure 8), allowing Helder to quickly understand how to calibrate his instrument and configure simple parameters like the dynamic range and MIDI notes and channels foot would trigger.

After almost three years of development, we came to a stable version of *TumTá*. With this version, Helder Vasconcelos used it in the debut of his third solo, "*Eu Sou*". It was possible to have a dynamics control between notes of weak, medium, or strong intensities with few nuances between them. The solo debut took place at the SESC Pompéia theater in São Paulo as part of an occupation for a month, where the artist also presented his other two solos. Throughout the show, the dance and music made with *TumTá* allowed much freedom for improvisation and control over the execution.

3.4. Future challenges

During development, the main technical problem was related to the UART serial protocol used to read data in Max/MSP from the XBee Receiver. After the last version, we noticed that the standard UART baud rates (9600, 19200, 38400, 57600, 74880, 115200 bps) have a considerable error in the Arduino we used. The Atmega328p with an 8MHz oscillator lead to errors from 0.2% to 8.5%. For other uses, these may be tolerable, but in our musical context, we noticed the instability of the data stream in the baud rates with higher errors, leading to frequently dropped packets.

The low priority of the FTDI⁷ driver reading USB serial data in the computer's operating system may have also contributed to considerable latency and jitter.

Recent studies have shown how solutions with Arduino communicating over serial ports with the Max [serial] object and the respective device drivers are unable to meet the high latency and jitter requirements of percussive musical instruments (McPherson *et al.* 2016). The authors suggest that the MIDI protocol should be used whenever possible. Even though the baud rate of 31250 bps is relatively low, it synchronizes with the microcontroller's clock value and does not drop any packet. It adds that the MIDI device USB drivers are optimized for a higher priority in the OS, considering its time sensitiveness. The common critiques around the limitation of MIDI messages to be limited to 7 bits (from 0 to 127) are not precise since the MIDI protocol can use Non-registered Parameter Numbers (NRPN), system Exclusive messages (SysEx), or other methods to send continuous data with a more extensive bit range.

Some even more recent research shows that Open Sound Control (OSC) and MIDI Over Bluetooth Low Energy (BLE) protocols with the readily available ESP32 microcontroller can deliver data with a latency below the 10ms accepted standard without the need of a hardware receiver (Wang *et al.* 2019).

Due to the artisanal nature of this sensor, it is hard to replicate it into similar products. The lack of sensitivity of the instrument for weaker foot stomps was a challenge that remained unsolved in this version because of the noisy signal from the sensor. It represented the most noticeable problem from the users that tested it.

Its sensitivity is so important [...] today, it is hard, he demands a lot. [...] it requires a certain posture and a certain pressure, a certain force for it to trigger the sound. [...] so it still has this tension [...] not triggering is very frustrating. It disorganizes a lot. It is as if you are going to play a note, you are going to play chord a piano and it didn't trigger any sound. [...] making it more sensitive, more precise in this way, that would also let me loosen up, it would increase the possibilities, because I would not be in this place of tension: 'Jeez, maybe it won't trigger anything (Interview with Helder Vasconcelos)

Another factor to be rethought is the need for a computer to operate the instrument; that is, we want the next versions to have a hardware sound unit to trigger the sounds. This factor would facilitate its use and logistics, allowing presentations to informal contexts and alternative places like squares, streets, and others. In addition to relying on the computer, it requires specific software that may be deprecated in future versions of the OS. It needs to have hardware that can have a 1/4" jack for triggering its samples and a USB and DIN MIDI output connector for more excellent compatibility with low latency with other gear.

⁷ Chip used to convert RS-232 serial protocol to USB

4. Related Projects

In last few decades, several instruments have been developed for foot control. One of the examples is cited by Paradiso is a system with piezoelectric sensors for tap dancers (Perna 1988). Jônatas Manzolli developed a similar device in 1997 for the performance AtoContAto with the dancer Christiane Metallo (Manzolli et al. 1998). Other examples are Tap shoe by Perry Cook (Cook 2001), Pikapika (Hahn and Bahn 2002), and Augmented Tango Shoe (Sinnott 2008). As follows, we selected two references to analyze with more details comparing to *TumTá*.

4.1. Miburi

The Yamaha Miburi was an interactive whole-body wearable system with several sensors distributed throughout the body. Japan's Yamaha Experimental Division launched it in 1994. The system consists of a blouse with six bending sensors in the arm joints, two hand controllers, each with ten pressure-sensitive buttons, and continuous controllers for the thumbs. The system also included two adjustable sized insoles with piezoelectric heel and toe sensors that detect tapping gestures. All these sensors were connected with a cable to a unit used as a belt. This unit communicated wirelessly (only for the version sold in Japan; for the exported versions, only a cable connection was possible) with a sound synthesizer unit with its amplifier.

The feet sensors and belt resemble *TumTá* a lot sensing only stomping discrete gestures and mapping them to MIDI. The main difference was that it connected to wires to the sound-producing unit, limiting the movement. Since we could not test it and no-one wrote about its ruggedness, it is hard to say that our solution is best suited for intense heel foot stomps. However, the designers' musical intention was much closer to other tap dancing traditions for the use of the foot's heels and tips.

4.2. Expressive Footwear

"Expressive Footwear" was developed by the Responsive Environments Group, coordinated by Joe Paradiso of the MIT Media Lab (Paradiso 2000). Its interface consisted of a pair of sneakers with 12 sensors that continuously send 16 raw data related to the feet' movement. It was developed to capture all the feet' gestural possibilities like flexion, inclination, position in three dimensions, turns, orientation, pressure against the floor, and foot stomps with the foot's heel or tip.

The instrument was inspired directly by the Miburi's foot module during a visit of Joe Paradiso to the Yamaha experimental division. He claimed to have been inspired by its insole, seeking to overcome its limitation by adding sensors for continuous feet gesture recognition. The main guidelines were to eliminate the wires connected the Miburi's insoles to the central unit, keeping all electronics wearable on the footwear. He sought a perception of continuous foot movement qualities rather than discrete shots, which increased the possibility of interaction for free foot gestures and gestures of interaction with the ground .

This instrument is different from *TumTá* because it is focused on sensing continuous gestures. It can detect more nuances of a dancer's movements, especially turns, jumps, and tiptoes stances. Even though it also detects heel foot stomps, the system is optimized for continuous gestures, sending any data that does not allow a low latency response to percussive gestures. This trade-off was taken into account for its design guidelines that differed a lot from ours.

5. Pisada



Figure 9: *Pisada* pads spread on the floor

Pisada, presented in Figure 9, is a DDMI designed initially for changing the sound banks of *TumTá* while dancing. Its sensor interface consists of ten square pads of 25x25 cm connected to a hub through, to be pressed with the feet. It holds the same functional principle as a regular MIDI pedalboard. The main difference is the size and structure of the larger and spreadable buttons around the stage, imposing fewer restrictions on body movement while pressing it.

Since it is a MIDI controller with ten buttons and ten pages that change each pad's function, it can serve for much more than a *TumTá* accessory. It allows several musical controls in DAWs and Synthesizers, such as turning on and off effects, triggering sounds, or selecting tones.

A traditional MIDI pedalboard usually has several buttons separated by a few centimeters from each other, requiring the user to stand in a region of space and make a slow and careful movement to push each button. The *Pisada* allows the control gesture to be anywhere on the stage and pressed during a dance without a cognitive restriction on the performer's movement.

The *Pisada* works as an incredibly safe, accurate, and straightforward to use a position sensor. It can detect a region with a radius of up to 10m by the length of its wires (which can be extended). Unlike computer vision techniques that require complicated procedures for adjusting brightness and configuring the division

of space, *Pisada* can detect when the artist is in some position with effortless installation and use procedure. Having tactile feedback and being a visible object allows much more precise temporal control than camera position detection systems.

Beyond the initial function to alter the samples triggered by *TumTá*, Helder Vasconcelos used it in his show "*Eu Sou*" in various ways like triggering playbacks for songs, activating and deactivated effects on his microphone, for recording live loops, triggering live recorded loops and activating or altering functions of other digital instruments like a tap-dancing floorboard with Tet Music's "Pulse Controller"⁸. *Pisada* was the instrument that placed the controls, usually on a backstage technician's hands, on the artist's feet.

It was made in an artisanal way with two galvanized iron sheets with rubber tabs on the corners. When it was pressed, the plates touch and close a contact measured by the microcontroller. When stepping, it sends a "note on" signal, and release sends a "note off" signal. There is only a simple debounce algorithm with a relatively high value of 300 milliseconds to ensure that a button is pressed once. They are all covered with black linoleum to be discreet on traditional stages.

In addition to the ten squared pads, two triangular pads are responsible for changing the button-to-MIDI-events mapping, in a metaphor of pages. The ten pages are shown in a seven segments LED display, allowing 100 different notes to be triggered. There is also visual feedback LED on each rectangular pad that lights up when pressed. The ten pads are connected to a central hub by long RJ45 cables of 10 meters, and this hub can be connected to a computer by a MIDI USB cable.

5.1. Future challenges

The instrument's simplicity made it very easy to use, but the artisanal building process takes too much time and is expensive since it uses thick iron sheets. It was also heavy and presented serious shipping problems that would make it difficult to travel with. The cables represent a problem because they need to be dispersed on stage, and the performer cannot step on it, only allowing them to be positioned on the edges of the used stage area.

The instrument would benefit a lot by changing the material and structure to a lighter and more straightforward structure, and a robust wireless connection would surely be a much better alternative. Long cables are costly, reasonably short durable, and require much time to be positioned in space. It may also be interesting to add sensitivity to the pressure to afford new control possibilities.

The *Pisada* is a simple instrument developed with the premise of bodily expressiveness for precise musical control. It was designed to be robust, easy to learn, to have low latency, and precise responsiveness. It presents a straightforward, low cost and robust solution for the detection of position in space.

6. Sound design

The sound design of *TumTá* was all made in Ableton Live using its "Simpler" sampler instrument. The sampling technique was used for the simplicity and precision to trigger sounds from acoustic instruments from popular traditions and other electronic sound samples. Helder Vasconcelos triggered in his home studio his *Bombos* (an instrument similar to a *zabumba* used in his *Boi Marinho* tradition), *Preacas* (instrument from the tradition

8. <http://tetmusic.com/>

of *Caboclinho*, which consists of a percussive bow and arrow), a *Kaiãmb* (a shaker from Réunion Island). Some synthesizer samples were also played and also samples of his voice.

Both samples were recorded as one-shot sounds and parts of a loop playing a *baião* rhythm with the *Bombo*. In some sample banks, both feet were mapped to the same one-shot samples. On other banks, one foot was mapped to the *bacalhau* stick of the *bombo*, giving a high pitched sound, while the other foot was mapped to a part of a loop that needed to be retriggered in precise time to keep the rhythm going in the beat. Specific dance steps made rhythm variations retriggering the sample in shorter periods. The *kayamb* was triggered in a looped pattern with a sizeable decaying amplitude.

It was mapped in a way that each new *Pisada* pad pressed changed the samples. The group of samples that played loops were built in a way that new banks repeated the last samples with new layers added to it, in a similar way to the structure of Electronic Dance Music, allowing him to give more liveness to a performance that a building up rhythm with superposed layers of sound timbres.

6.1. Future challenges

A sampler's versatility was the right choice for the straightforward sound design based on traditions that rely only on acoustic instruments. A physical modeling synthesis would also be an exciting approach, giving more subtlety in random sound variations, typical from percussive acoustic instruments. However, it would lead to much more time and specific knowledge to be developed. This approach of allowing sound variations depending on velocity and random parameters could also be used in the *TumTá* sampling engine with many samples per foot. That would undoubtedly make the instrument a lot more expressive. The sampler also gives the instrument an exciting potential for the instrument to be adopted by other musicians and dancers to simplify customization and sharing of sound banks.

In literature, Sergi Jordà presents the concept of Diversity, that helps to define the concept of Music Instrument Efficiency (Jordà 2005). The instrument's diversity is subcategorized in Micro-diversity, related to performance nuances (how two performances of the same piece can differ), Mid-diversity, related to performances' contrasts (how distinct two pieces played with the same instrument can be) and Macro-diversity related to stylistic flexibility (how the instrument adapts to different contexts). From this perspective, *TumTá* could easily be considered a not very diverse instrument, from a simplistic perspective, it needs to have many controls to be diverse.

TumTá was designed to be as diverse as a *Zabumba*, that even though it can trigger small variations of two sounds, it has a high diversity in all dimensions. The current lack of diversity of *TumTá* is related to its low dynamic range of control, only detecting foot stomps that are too hard. An improvement in the sensor interface and better sound design with a more expressive sampler would improve its diversity and, therefore, its efficiency.

It is essential to reflect on the diversity of control of a digital instrument. A percussion instrument does not necessarily need to have a diversity of control like a piano, which has precise and diverse frequency control. Often the bias of making instruments for western traditions excludes percussive-based music, very common in Latin American and African traditions. We believe that a control diversity study for an instrument that emits only two sounds is not necessarily limited.

7. Conclusions

This paper presents *TumTá* and *Pisada*, which are two original Digital Dance and Music Instruments inspired by Brazilian popular traditions. This process pointed out was how music and dance traditions could influence the development of new technology and is a rich source of inspiration for the design of original NIMES. The instrument's development process was described in technical details, following three main prototyping phases that overlapped each other. However, each had a specific approach to Building Blocks, Artisanal, and Digital Fabrication. Both future instruments' challenges were presented separately and had a lot to improve, but are already used in professional artistic contexts with promising results.

The development process of *TumTá*, *Pisada*, and the sound design so far presented many future challenges that we presented in detail in subsections 3.4, 5.1, and 6.1. The main lessons we learned will help in further development cycles of these DDMI and inspire the design process of other creators. We present below some of the lessons learned:

- Using Building Blocks is a good approach for the first prototyping phase. Even though they are not customizable, they give quick answers to help initial design decisions.
- The Artisanal approach is perfect for obtaining highly customizable solutions. It gives freedom to have original ideas while it is time-consuming, not easily reproducible, and can lack reliability, accuracy, precision, or ruggedness.
- Digital Fabrication techniques can shorten the design process by giving accurate and reliable solutions with highly customizable prototypes. Nevertheless, the possibilities are much limited by the machine's constraints.
- Wearable devices for dancers need to be EXTRA RUGGED and need isolation because of the sweat.
- Wireless transmissions need to be powerful for long distances (beyond the noise around you)
- MIDI and OSC are always better solutions than custom serial protocols; there is no need for reinventing the wheel.
- Sample-based synthesis is excellent for percussive instruments and an accessible way to create sounds with a Brazilian musical identity.

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