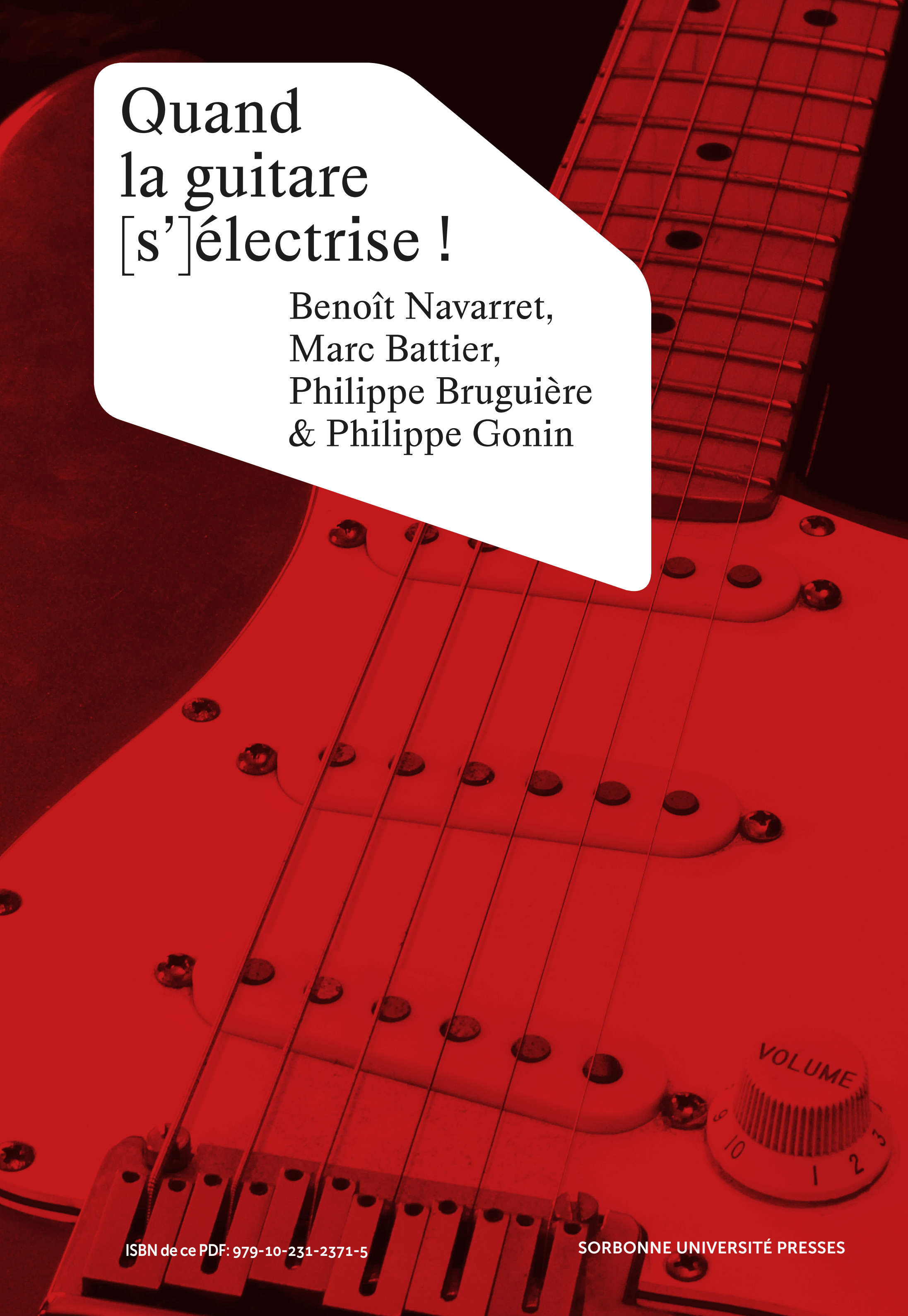
Quand la guitare [s’]électrise !

Benoît Navarret,
Marc Battier,
Philippe Bruguière
& Philippe Gonin



ISBN de ce PDF : 979-10-231-2371-5

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MusiqueS

La guitare électrique serait-elle l'instrument emblématique du XX^e siècle ? Son histoire a marqué plusieurs générations de musiciens et d'auditeurs : sa sonorité et sa puissance (qu'elle doit aussi à ses composants externes : pédales d'effets, amplificateurs et haut-parleurs), sa versatilité, son impact visuel et toutes les significations qui lui ont été associées en font un objet incontournable, une véritable icône planétaire.

Et pourtant l'étude scientifique de son histoire, de son répertoire ou de sa technologie n'a fait que commencer, tout en allant en s'amplifiant. Peu connue, la recherche menée autour de cet instrument mérite qu'on s'y attarde, tant les approches possibles sont riches et variées : car l'instrument ne peut s'étudier en-dehors de son contexte, ni sans raconter l'histoire de ces pionniers qui se mirent à bricoler des formes hybrides d'instruments, puisant dans l'organologie classique en la mêlant aux techniques de la radio, du microphone et de tout ce que « la fée électricité » a pu apporter en matière d'innovation sonore. L'on ne peut aussi ignorer la construction symbolique de ces figures mythiques, les *guitar heroes*, qui font rêver les foules et alimentent les fantasmes de nombreux amateurs. Sans oublier la multiplicité de ses usages, du club intimiste aux gigantesques stades ou festivals, de son expérimentation dans la musique contemporaine au refus délibéré de la virtuosité dans des genres plus nihilistes, et même dans certaines pratiques religieuses !

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QUAND LA GUITARE [S']ÉLECTRISE !

À la mémoire d'André Duchossoir (1949-2020)

MusiqueS

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Issue des travaux interdisciplinaires soutenus par l'Institut Collegium Musicæ de l'Alliance Sorbonne Université depuis sa création en 2015, la série « MusiqueS & Sciences » est une collection dont le but est de susciter, développer et valoriser les recherches ayant pour sujet les musiques, passées et présentes, de toutes origines. Elle invite ainsi à mêler les disciplines des sciences humaines et des sciences exactes telles que l'acoustique, les technologies de la musique et du son, la musicologie, l'ethnomusicologie, la psychologie cognitive, l'informatique musicale, mais aussi les métiers de la conservation et de la lutherie.

*

Le Collegium Musicæ – institut de Sorbonne Université – regroupe des organismes de recherche et de formation spécialisés dans le domaine musical. Il favorise, depuis sa création en 2015, les travaux menés en interdisciplinarité entre sciences exactes, sciences humaines et pratiques musicales. La collection « Instrumentarium », consacrée aux instruments et familles d'instruments, est la première des séries de publications issues des travaux scientifiques du Collegium Musicæ. Suscitant le croisement des regards entre acousticiens, musicologues, musiciens et luthiers, ces travaux permettent la confrontation inédite de données et analyses acoustiques, organologiques et techniques, historiques et culturelles, ainsi que celles relevant de la création et de l'innovation.

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Benoît Navarret, Marc Battier,
Philippe Bruguière & Philippe Gonin (dir.)

Quand la guitare [s']électrise !

SORBONNE UNIVERSITÉ PRESSES
Paris

Ouvrage publié avec le concours du Collegium Musicæ
et de la faculté des Lettres de Sorbonne Université.
Les SUP sont un service général de la faculté des Lettres de Sorbonne Université.

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CHAPITRE 5

AUGMENTING THE GUITAR: ANALYSIS OF HYBRID INSTRUMENT DEVELOPMENT INFORMED BY CASE STUDIES

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GUITARE AUGMENTÉE : ANALYSE DU DÉVELOPPEMENT D'INSTRUMENTS HYBRIDES, APPUYÉE PAR DEUX ÉTUDES DE CAS

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ABSTRACT

Based on an analysis of the electric guitar as an augmented instrument, this article presents research work on the augmentation of both electric and acoustic guitars conducted by the author these last five years. The first case study addresses the control of electric guitar effects through a series of works on sensors attached to the guitar and operable by the instrumentalist. New gesture-sound interactions are created in the instrumental connection, enabling the introduction of signal processing control in the gestural vocabulary of the guitar. The second case study focuses on strategies for gesture data extraction from a hexaphonic audio signal captured on the guitar. Signal analyses in the temporal and spectral domains offer a certain amount of descriptors that can be used for the control of signal processing. The third part of this presentation is on the augmentation of the acoustic guitar (nylon and steel strings) by introducing active acoustics. This term refers to vibrations in the guitar body through acoustic actuators. By doing so, the acoustic sound can be doubled by electronic sounds, and a "capture – processing – actualization" loop can be established on the instrument. Thus, a hybrid electroacoustic guitar is created, allowing to work on an aesthetic of "electronic chamber music": a mixed music without traditional speakers where electronic sounds originate directly from acoustic instruments.

BIOGRAPHY

Otso Lähdeoja is researcher, composer and guitarist. He holds a Ph.D. from University of Paris 8 Vincennes – Saint-Denis and has conducted various research-creation projects during these last fifteen years. Otso Lähdeoja creates musical works for solo and ensembles, sound art works, multimedia installations and works in contemporary dance companies. He toured around Europe, the United States, South Korea and India. He is currently an Academy of Finland post-doctoral fellow at the University of the Arts, Helsinki.

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RÉSUMÉ

Partant d'une analyse de la guitare électrique en tant qu'instrument augmenté, nous présentons une suite de recherches sur l'augmentation de la guitare électrique et acoustique, effectuées par l'auteur durant les cinq dernières années. En premier lieu, nous abordons le contrôle des effets de la guitare électrique par une série de travaux sur des capteurs attachés à la guitare et *opérables* par l'instrumentiste. De nouveaux couplages geste-son sont ainsi créés dans la relation instrumentale, permettant d'introduire le contrôle de traitement du signal dans le vocabulaire gestuel de la guitare. Dans un second temps, nous présentons la stratégie d'extraction de données liées au geste à partir du signal capté sur la guitare en hexaphonie. Des analyses du signal effectuées dans les domaines temporel et spectral offrent un ensemble de descripteurs qui peuvent être employés pour le contrôle de traitements du signal. Le troisième moment de l'exposé traite de l'augmentation de la guitare acoustique (cordes nylon et acier) par l'introduction de l'acoustique active. Par *acoustique active*, nous entendons des vibrations induites dans le corps de la guitare par des actuateurs acoustiques. Le son acoustique de la guitare peut ainsi être doublé par des sons électroniques, et une boucle de « captation – traitement – actualisation » peut être instaurée sur l'instrument. Une guitare hybride – électroacoustique – est ainsi créée, permettant de travailler sur une esthétique de « musique de chambre électronique » : une musique mixte sans haut-parleurs traditionnels, où les sons électroniques émanent des instruments acoustiques.

BIOGRAPHIE

Otso Lähdeoja est chercheur, compositeur et guitariste finlandais. Titulaire d'un doctorat de l'université Paris 8 Vincennes – Saint-Denis, il a dirigé de nombreux projets de recherche-création au cours des quinze dernières années. Otso Lähdeoja produit des œuvres en solo et pour ensembles, des installations sonores et multimédia et collabore avec des compagnies de danse contemporaine. Il a effectué plusieurs tournées en Europe, aux États-Unis, en Corée du sud et en Inde. Il est actuellement chercheur post-doctorant de l'Académie de Sciences à l' Université des Arts à Helsinki, Finlande.

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INTRODUCTION

This article discusses instrument augmentation on the basis of two research projects conducted on a series electric and the acoustic guitars, spanning over a decade. Instrument augmentation is defined as the addition of electronics on existing music instruments in order to augment their sonic palette. The text details the rationale of instrument augmentation and provides a rough outline of its historical developments. A first case study presents an augmented electric guitar and the related research results. A second case study of a presently on-going project details the design of an active acoustic augmented guitar. Beyond presenting the technological details of the instrument augmentation projects, this article is intended to constitute an analytical summary of a sustained practice, reflecting both on the achievements and the challenges of instrument augmentation, as well as on the conceptual and cultural foundations of such a practice. The argumentation points towards the pre-eminence of aesthetics in the entire design process, viewing technology as a cultural product and its development as a series of aesthetic choices. Finally, the text presents the practice of augmentation as a hybrid form in itself, combining "maker culture" with artistic practice and academic research.

AUGMENTED INSTRUMENTS – RATIONALE AND DEVELOPMENTS

Instrument augmentation can be thought of as the introduction of an electronic graft on an existing music instrument, with the aim to augment the sonic and expressive possibilities of the instrument. By definition, an augmentation is thought to be electronic – analogue and/or digital – thus adding an electro-technological layer on an acoustic instrument, or, in the case of an instrument that incorporates electronics by default, augmenting the scope and complexity of the design. The rationale of instrument augmentation stems from a pragmatic perspective on electronic instrument design, with the explicit will to build on the existing traditions of both instrument craftsmanship and playing. Our current instrumentarium is viewed to constitute an invaluable resource of musical interfaces and actuators perfected over centuries. Moreover, the required skill set of a professional level musician is achieved through intensive years of training, themselves backed by a millennial tradition of musicianship. From an instrument augmenting perspective, it would be counterproductive to discard these cultural assets in order to make the transition into the domain of electronic musicianship. In this sense, instrument augmentation is a conservative practice as opposed to more radical "tabula rasa" kinds of electronic music instrument designs, which might even view the established traditions of musicianship as an obstacle for the full blossoming of electronic music making. Indeed, to some extent, the cultures of electronic music seem to carry the heritage of the Acousmatic agenda which aimed to prove the performing musician altogether useless (For instance, in 2016, a discussion panel statement by Kees Tazelaar on his electronic music praxis proclaimed : "I have no need for the musician"). Instrument augmentation can be viewed as a compromise wishing to preserve the instrumental tradition in parallel to creating a pathway to electronic musicianship. It dreams of uniting the best of both worlds and aspires towards a fully integrated and fluid live-electronic music making.

The historical developments of instrument augmentation go hand in hand with the birth and maturation of live electronic music, stemming from the musical avant-garde of the 1960's. In the cluster of innovative – and even revolutionary – works of that era, it is difficult to state a single seminal piece. Rather, one is drawn towards a set of artistic figures of that time. On one hand, John Cage and Karlheinz Stockhausen were the first to introduce electronic manipulation of an acoustic sound with Cage's Cartridge Music (1960) as well as Stockhausen's *Mikrophonie I* and *Mixtur* (1964). However, these pieces approach electronic capture, processing and broadcasting of an acoustic sound from a composer's perspective, aiming for a general electro-acoustic aural impression more than creating new expressive dimensions for the instrument or the instrumentalist.

On the other hand, a less iconised development of electronics in music instruments was brought forward by David Tudor and Gordon Mumma, almost in temporal parallel with Cage and Stockhausen. Tudor and Mumma, both accomplished instrumentalists, started experimenting with electronic grafts on instruments and can be viewed as the founding fathers of the practice of live-electronic music centred on instrument augmentation, in synergy with other members of the Sonic Arts Union such as Robert Ashley, David Behrman and Alvin Lucier. In order to illustrate the avant-garde nature of the work accomplished by these artists, David Tudor's piece *Bandoneon! (a combine)* (1966) staged a performance where the artist controlled an entire sound and light environment from his instrument. "Tudor, sitting on a sixteen by twenty-four foot platform surrounded by electronic equipment, played his bandoneon, and the sounds of the bandoneon were processed electronically, switched between twelve loudspeakers placed around the space, used to vibrate five sculptures on moving carts, and used to control video images and lights" (Chabade, 1996). In parallel, Gordon Mumma was developing his "Cybersonic" approach to augmenting the French horn and trumpet: In his piece Hornpipe (1967), The sound source is a French Horn fined with a special mute containing a microphone. The sounds from the microphone are fed to the two cybersonic consoles (transistorized sound modifiers). "The cybersonic console monitors the resonances of the horn in the performance space and adjusts its electronic circuits to complement theses resonances" (Holmes, 2002).

From 1987 onwards, Tod Machover introduced "Hyperinstruments", acoustic string instruments augmented with digital audio and control data (Machover, 1992). His "Opera of the future" team's work served as an impulse to numerous subsequent augmentation projects, such as augmented percussions (Aimi, 2007), and violin bow (Young, 2002). Daniel Overholt has been sustaining a research effort on the "Overtone Violin" for over a decade (Overholt, 2005). More recently, the guitar has gained academic attention and been the object of a number of systematic augmentation projects (Graham and Bridges, 2014), (Reboursière *et al.*, 2010). The research interest in augmented guitar persists up to date, with ongoing academic (Turchet *et al.*, 2016) as well as commercial projects such as the ToneWoodAmp and the SENSUS Smart Guitar.

Concerning the guitar, a parallel track to the history of its augmentations can be found in the evolution of the acoustic guitar into the electric, as well as the subsequent developments of analog and digital effects and control interfaces. These technological evolutions grew out of an entangled network of popular music culture, business and pioneering experimentation. For instance, when Adolf Rickenbacker introduced his electric "Frying Pan" guitar in 1931, it was in response to a demand in louder guitars motivated by the popular music ball orchestra culture, but also out of an entreprenourial insight and technological genius. The consequences of that invention were revolutionary, enabling the firther developments of the electric guitar and the vast network related musical cultures. In this analysis, an augmentation process is not at all synonymous with academic research, rather fuelled by popular culture and independent actors.

CHALLENGES TO INSTRUMENT AUGMENTATION

Combining instrumental and electronic musicianship is an idealistic project. Faced with the concrete realities of an augmented instrument's actual implementation and the musical use, one realises quickly the project's numerous inherent challenges. In the first place one encounters the issue of control: how to extend an instrumental quality to the electronic graft, giving the instrumentalist the possibility to actually play the electronics as she or he would play the acoustic instrument. Claude Cadoz has argued that the instrumental quality arises from an energy continuum between the embodied kinetic energy and its transduction into acoustic energy via a (electro)mechanical device such as a string or a microphone (Cadoz, 1999). In these cases there is no ontologial alteration in the signal chain; kinetic energy is transformed into acoustic energy, and eventually via electricity. In the case of digital conversion, the system's input energy (be it kinetic or acoustic) is sampled into a string of discrete encoded bits of information, arguably ontologically different from the continuous flux of energy. This discrepancy brings Cadoz to conclude that the computer does not create the conditions for an instrumental relationship. However, one may argue that with the high sampling rates an processing speeds portrayed by current computers, one is able to create the illusion of a continuity for the instrumentalist, and even implement a natural-like behaviour mimicking the reality via physical models. For the instrumentalist, the illusion of continuity and connection to the electronic sounds may create the necessary conditions for musical expression. In this sense, the digital processing in itself might not be an obstacle to establishing an instrument-like relationship with the augmentation.

The challenge of controlling the augmented instrument is related to the issue of mapping, *i.e.* relating gestural inputs to variables affecting the sound output. Regarding digital augmentations, there are two ways of producing and conveying control information to the sound processing computer: (1) sensors and (2) the instrument's sound either as audio-rate input to the system or via feature extraction from the audio. These two approaches are the available strategies for obtaining control signals from the instrumentalist and both of them portray assets and drawbacks.

Sensors, or physical measurement devices (including optic devices such as cameras), are widely used in instrument augmentation, and some sensor systems such as the IRCAM Hyperbow (Rasamimanana *et al.*) have been brought to an advanced level of development. Sensors may typically be added to the instrument's "playing environment", thus enabling new gestural accesses to directly control the sound processing variables. The classic example is the still omnipresent potentiometer controller, another example of a more recent and complex system would be finger tracking via the Leap Motion infrared camera system (Han and Gold, 2014). Incorporated on an augmented instrument, sensors may provide an efficient approach to control, as the instrumentalist has direct gestural and volitional access to sound manipulation. A sensor detects a gesture and the result can be made audible via perceptually efficient mapping.

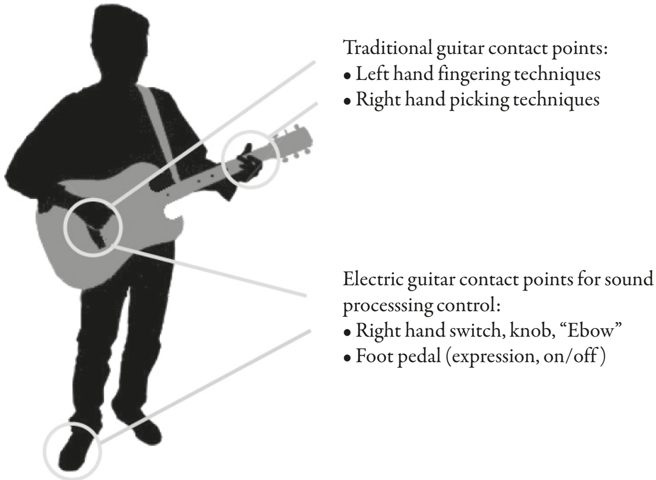
However, traditional instruments are complex systems deeply engaging the instrumentalist both physically and mentally, even to the limits of cognitive overload as portrayed by the difficulties of a beginner to successfully coordinate the gesture-sound action-perception loop. Thus, adding new control accesses to an already quasi-saturated interface might prove too complex for the instrumentalist to control, resulting in less enjoyable and fluid playing experience. For example, the *Sensus Smart Guitar*[1]

1 The *Sensus Smart Guitar*, developed by Mind Music Labs, online: https://www.mindmusiclabs.com. Accessed May 1, 2017.

(to be commercially released in 2018) incorporates eight gestural sensors in addition to the traditional guitar interface. It will be most interesting to see to what extent the guitar community will be able to adapt to the challenge of adding sensor control tasks to the playing.

Computational latency constitutes another challenge to the integration of electronics on an acoustic instrument. Latency is inherent to audio processing, even though with the current computing speeds basic audio processing latencies have been reduced to the threshold of perseption, perceptible latency occurs as soon as more complex time-domain or any spectral domain processing are involved. In the author's experience, a slight (ex. 20 ms) latency in direct signal processing on the guitar alters the perception of fluidity and response from the instrument, but does not constitute an obstacle for playing. Human being's remarkable plasticity allows us to adapt to new conditions, and new strategies are developed to cope with the slower response instrument. What happens, though, is that the playing style and aesthetics change. In a situation where fast articulations are impossible or produce an undefined sonic result, one naturally looks for avenues of expression in slower, possibly timbral musical materials. This being said, perception and response to latency are instrument specific: a 20 ms latency on a snare drum might prove to be an impossible case for player adaptation, since the whole instrument is designed for quick response and sharp attack partials. In the guitar augmentation projects developed by the author, a real latency obstacle arose with the introduction of audio extraction and analysis, involving Fast Fourier Transform (FFT) windowing and subsequent processing. For exemple, spectrum-based classification tasks proved to be too long to execute in a perceptual "real time" and could not be integrated into the augmented instrument, no matter what the level of adaptation the player would manifest.

Other relevant challenges to instrument augmentation include the absence of haptic return when using sensors. A sensor does not usually produce tactile feedback to the user, the only feedback allowing one to establish a functional action – control loop via the auditive or visual senses. Another challenge involves a possible discontinuity in aural perception when an acoustic instrument is processed and diffused through



1. Mapping traditional electric guitar contact points
© Otso Lähdeoja

a separate PA system. The acoustic radiation form the instrument and the loudspeakers produce two separate sound sources which can ruin the image of unity sought after in most augmented instrument designs. For the player as well as for the audience, this sonic discontinuity might correspond with a sensation of perceptual alterity.

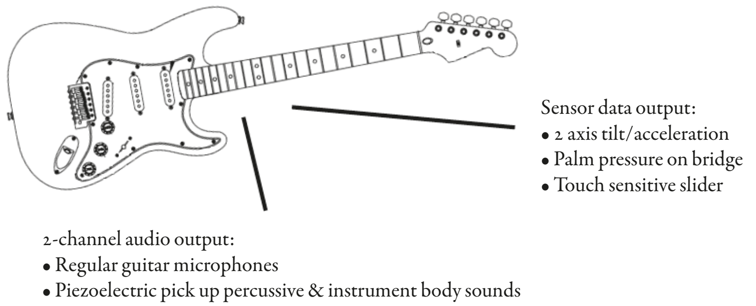
As this overview of challenges to instrument augmentation show, the process of adding electronics on the existing instrumentarium is essentially a set of compromises. So far, there has been no musical Swiss army knife coming out of the augmented instrument research, rather instruments augmented towards a specific aesthetic task, tinkered to allow new sonic possibilities to appear while closing off some others. On the other hand, pursuing an idea of universality might be futile in an actual cultural context. Small changes in instruments have proved to fuel immense developments in music making and listening. For example, one may consider the overdrive or distortion "effect" on the guitar. A simple process of overdriving and clipping an audio signal has given rise to a vast palette of distortion "colours", and with them, a vibrant array of musical styles, currents and undercurrents each making the most out of a specific distorted guitar sound. Cultural signification and effectiveness may not be at all congruent with the idea of an instrument's universality. Embedding too many possibilities on an augmented instrument might provide a vast but unfocused ensemble. The tools needed for an actual fertile music praxis seem to portray seamless efficiency concentrated on well defined sonic (and gestural) areas and allowing for refined interactions up to the limit of human perception.

CASE-STUDY ONE: AN AUGMENTED ELECTRIC GUITAR

The author of this article developed an augmented electric guitar between 2007 and 2013 within the framework of a PhD thesis at the University of Paris 8 Vincennes - Saint-Denis. The development of this first prototype of an augmented electric guitar was fundamentally driven by a personal artistic agenda involving solo performance and recordings, in connection with technological and academic research and publications. The work was conducted within an overall "Research – Creation" methodological framework where technological development and artistic creration were brought together in a mutually feeding loop.

The project started by an assessment of the available sensor devices as well as with an analysis of the electric guitar "playing environment", *i.e.* the "ecology" of gestures objects and affordances that are used in playing. A theoretical approach was developed in order to analyse the functional dimension of the electric guitar's playing environment, centred on the notion of "contact points". In this framework, a contact point is defined as "convergences between gesture and object which result in the production or modification of a sound" (Lähdeoja, 2008). The notion of contact points allows us to think in terms of a continuum between these three elements and to establish a "map" of their relationships in the playing environment. Figure 1 shows a sample mapping of the traditional electric guitar's contact points.

Based on the analysis of existing contact points within the electric guitar playing environment, novel additions were designed both with sensor interfaces as well as via the guitars output signal analysis and data retrieval. Four gesture-sound contact points were found to be particularly adequate, as depicted in **figure 2**:



2. Electric augmented guitar sensor and audio inputs © Otso Lähdeoja

1. Variation of the guitar's tilt and acceleration on the frontal and sagittal planes, corresponding to a number of movements naturally present in standing position guitar performances.
2. A piezoelectric microphone attached to the guitar's body, providing audio and derived data from guitar handling and body sounds such as percussive hits.
3. A pressure sensor attached on the guitar bridge at the natural location of the right hand palm.
4. A touch-sensitive surface potentiometer placed under the strings, to be used with the right hand fingers.

A sound processing patch was created in the Max/MSP programming environment in correspondence with the sensor inputs. The processing included a granular synthesizer and ring modulator controlled by the two-axis tilt sensor, a palm pressure controlled wah-wah effect, filter effects on the touch-sensitive slider and piezo-activated guitar body in order to drive a percussive sample sound engine. A demo video of a selection of gesture-sound couplings can be viewed at: https://vimeo.com/35067635.

A subsequent research effort was conducted in partnership with the Numédiart program in Mons, Belgium, aiming for computational extraction of all electric guitar regular playing techniques from the audio output. The idea being to have the computer "listen" to the player, automatically recognise different playing techniques and modulate the processing accordingly. A data set of audio files classified by playing technique was established, followed by audio descriptor analysis in order

3. The augmented electric guitar in erformance,
Quebec City, 2011
© Otso Lähdeoja

to find the salient features that could be tracked for each technique. This approach proved to be rather robust in non-realtime computing, with general detection rates close to 90%. However, the implementation of the salient feature recognition in a realtime framework was not successful at that time, leading to a further development towards automatic "augmented tablature" generation by Loïc Reboursière *et al.* (2013).

LOOKING BACK AT THE AUGMENTED ELECTRIC GUITAR

Both development phases of the augmented guitar are illustrative of the balance of assets and drawbacks inherent to instrument augmentation, as discussed in section 3.

On the side of assets, the project succeeded in providing the means to realise that project, giving rise to two studio albums and numerous performances in Europe as well as in Canada and the U.S.A. For an instrumentalist formed in the tradition of improvised music, finding one's own distinctive sound – or "voice" is of foremost importance. It can be said that the augmented electric guitar enabled for a personal sound to emerge, transforming the electric guitar into an electroacoustic tool enabling a timbral approach to music: producing a large palette of sound colours, textures and materials beyond the regular electric guitar's sonic palette, that could be shaped via the sensor interfaces. The augmented electric guitar fostered several years of personal musical creation[2]. In that sense the effort led to meaningful results well beyond the "proof of concept" stage. Another success was the relatively wide diffusion of augmentation concepts via scientific publications in conferences and journals. The augmented guitar project was able to join in a lively and enthousiastic discussion amongst music interaction design researchers, and made its own mark within that context.

2 Two albums have been released with the augmented electric guitar: Otso, *Yonder,* Audiotong 2011, https://audiotong.bandcamp.com/album/yonder; Otso, *Dendermonde*, Elli Records 2016, https://ellirecords.bandcamp.com/album/dendermonde.

On the other hand, the idealistic project of fluid electronic sound control combined to guitar playing had to face the realities of cognitive limits and challenges in mapping strategies. In the framework of a performance practice, an evolutive selection took place. Only the most efficient, robust, easily and quickly accessed gesture-sound couplings survived the "real world" test, such as the frontal plane tilt mapped to a granular synthesizer, the touch-sensitive filter and the guitar body percussions captured via a piezo pickup. In this evolutive process, traditional electric guitar control hardware such as a pedalboard found its way to the performances, providing a familiar and robust way to switch patch configurations and use expression pedals. In this sense, incorporating "new technology" on an instrument didn't prove to be a game changer, rather an ingredient to add to an existing guitar playing environment.

The experience of playing such an augmented guitar was complex. The added layers of sensor input and processing made a definitive impact on the intuitive impression of the instrument, transforming a relatively simple "plug and play" guitar into a multitask environment demanding constant vigilance on many levels. The added cognitive load certainly affected the instrumental performance towards a slower, more cumbersome playing. Being tied to so many sensors, interfaces and cables robbed part of the physical sensation of liberty one may experience in performance and made performing feel like a whole-body precision task.

The results of this sensation of cognitive "asphyxiation" were reflected in the music. In improvisational practice, the temporality became longer, as lots of time would be spent managing the patch in order to find relevant sounds and textures. This process was judged too slow and uninteresting for display in performances, so the author decided to program easily accessible presets to the system. Thus a practice starting form improvisation gradually matured into a compositional one, where the sounds and sensor mappings of the whole performance were finally encoded into presets. In its turn, this pragmatic choice hindered the feeling of interactivity and fluidity of the system, leaving much less space for in-perfomance adventures which were the indeed initial musical starting point. The core practice – playing – suffered from the weight of the augmentation, leading to a gradual decline in personal passion for the augmented electric guitar.

Another element of frustration arose from a perceived lack of diffusion and enthusiasm towards instrument augmentation in the guitar playing community at large. The electric guitar and its related musical cultures are largely conservative, replaying and remarketing seemingly ad infinitum the iconic guitars, sounds and playing styles from the past golden eras. In the aesthetics and economies of mainstream electric guitar, there seemed to be little place for adventurous directions. This attitude was reflected in some contacts acquired with the industry representatives and other players where the augmented guitar was seen as a strange curiosity. The project naturally integrated a community of experimenters, at the crossroads of the "maker culture", electronic musicianship and the contemporary improvised music scene. Within these cultural frameworks, it is commonplace for everyone to develop, tinker and play their own devices. The augmented elecric guitar became a personal tool for experimental music creation. Subsequently, when the artistic momentum exhausted itself and the author's creative interest shifted elsewhere, the augmented electric guitar project became to an end around 2013. Two prototypes of the augmented electric guitar were implemented, the first on a standard Fender Stratocaster and the second one on a baritone "Subsonic" Stratocaster with no permanent installation. Neither of these instruments exist by the time of writing, although ample video, audio and written documentation remains.

CASE-STUDY TWO: AN ACTIVE ACOUSTIC GUITAR

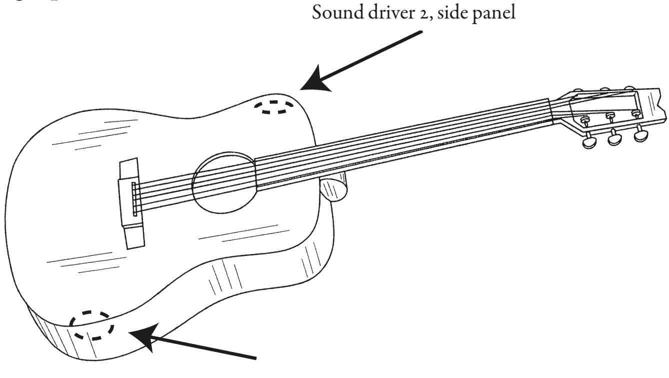
The end of the augmented electric guitar project corresponded with a personal aesthetic shift towards acoustic music and more ambient modes of sound diffusion then the cone loudspeaker. Several years of working with high decibel levels and heavy, aesthetically standardised PA systems created an aural fatigue and a desire for an electronic musicianship with a chamber music approach. In 2015, the author initiated the "Active acoustic augmented instruments" (AAAI) project at the University of the Arts, Helsinki, Finland, with the aim to create acoustic instruments with an added layer of electronic sound integrated into the instrument itself and radiating from the instrument. The AAAI project is running until

2018, and for the moment the team is working on active acoustic guitars (both nylon and steel string), double bass and violin.

In practical terms, "Active Acoustic Instruments" signifies the addition of sound radiating transducers in the instrument itself, creating a duplex sound source diffusing both acoustic and electronic sounds. Active acoustic instruments currently constitute an active research field, with relevant parallel research carried at the IRCAM (Benacchio *et al.*, 2013) and at Stanford University (Berdahl, 2013). First commercial products are also being released, such as the Tonewood Amp. The promise of the active acoustic technology is to provide an seamless merging of acoustic and electronic musicianship, bypassing amplifiers and loudspeakers, and ultimately embedding the entire electronics within the acoustic instrument. The goal would be a fully integrated electro-acoustic hybrid instrument. Up to date, the author has attempted several experimental designs of an active acoustic guitar, and also tested them in concert configuration with the related "Electronic chamber music" ensemble.

The author's first active acoustic guitar prototype was implemented on a Breedlove *c20* acoustic steel string guitar, with a design featuring a electromagnetic hexaphonic pickup (Übertar) and two Hiwave / Tectonic *32C30-4B* sound drivers attached under the soundboard. This initial design provided a proof of concept for the idea of activating the acoustic guitar's wooden structures as loudspeakers. Functional levels of volume and sound quality can be achieved by adding active acoustics on guitar. A sample video demonstrating a basic active acoustic guitar design can be viewed at: https://vimeo.com/135027177. Subsequently, a gestural control interface design was attempted using the Leap Motion infrared camera and its finger-tracking features, demonstrated in the following video: https://vimeo.com/178605545.

The second phase of active acoustic guitar design was motivated by a request by the Finnish contemporary classical concert guitarist Petri Kumela, who wished to explore an augmented classical guitar and provide his extraordinary concertist skills as well as repertoire for developing the instrument. Kumela plays principally the nylon string acoustic guitar, and it was agreed to center the development on nylon stringed instruments, ruling out electromagnetic pickups. Starting from these premises, a novel design with two vibration speakers mounted on the back and the sides of the guitar was implemented. The nylon string active acoustic guitar featured initially the Kremona *ng-1* bridge piezo pickup. The optimal vibration speaker placement on the guitar body was found in co-operation with Uwe Florath, a Helsinki-based Master luthier. The transducer mounted on the back plate drives the lower modes of the guitar, providing bass response and volume, while the side panel driver radiates treble frequencies and sharp attacks (**fig. 4**). The transducers are placed at a 90° angle, each radiating as a (pseudo) dipole speaker. Together they provide a complex radiation pattern reminiscent of the acoustic guitar's natural radiation, giving rise to a much more convincing aural impression than just one transducer or two transducers on a single plane.



4. Driver placement on the active acoustic guitar © Otso Lähdeoja

CHALLENGES TO ACTIVE ACOUSTICS

Overall, the active acoustic approach to instrument augmentation faces specific challenges, most prominently feedback and sound quality optimisation. An active acoustic guitar incorporates both pickup and output transducers on the same physical body, coupling them in a potent feedback loop. The omnipresence of feedback creates obstacles for achieving a high quality of sound output as well as a large diversity of processed sounds. In the author's experience, feedback is the foremost challenge in active acoustic instrument augmentation.

Strategies for overcoming the feedback issue in the AAAI context are being developed since 2016 within our team. The first approach was to design an "inverse impulse response filter" in order to counter the guitar's resonant modes' effect on the output sound. The idea is to measure the guitar's acoustic response coupled with the transducer system (impulse response [IR] measurement), providing a spectral "fingerprint" of the individual instrument. Based on the spectral data, an inverse convolution filter is implemented in order to cancel the guitar's resonant modes most prone to feedback. While this approach does give encouraging results, it is not an efficient enough remedy for feedback problems, due to the fact that an IR measurement and correction are only valable for one measurement point in the 3D space. A flatpanel speaker's frequency response varies according to the listening angle, and in our research, it has proven to be impossible to find a satisfying compromise filter covering all the angular variations. A second approach has been a more pragmatic time-domain equalisation, filtering out only the most prominent modes. This approach turns out to be more effective, both in cancelling the actual feedback as well as cheap in processing power cost. Currently the AAAI team is developing an adaptive EQ which actively "listens" to the guitar and filters out the frequency regions where it detects a build-up of energy. Other possible directions include active damping of the bridge at key frequencies, alternative pickup designs and positions, as well as physical decoupling of the pickup system from the sound board.

Beyond the feedback issue, we have found that the active acoustic guitar constitutes a challenging research terrain for sound design. Having trialed most classic electric guitar effects on the active acoustic guitar, we had to conclude that a direct translation form electric to acoustic is not sonically relevant. The effects do not come out as convincing as one is used to, and tend to sound like a second-class replicas. On the other hand, we have found very interesting results with alternative processing techniques, such as granular and audio-driven synthesis modules, pointing towards a dedicated processing vocabulary for AAAI guitars. This implies a fundamental shift from the idea of reproducing electric guitar sounds on an acoustic one towards a domain of altered and augmented acoustic timbres and soundscapes specially tailored for the acoustic guitar.

Finally, the issue of perpetual "duplex" sound has risen from a sustained practice of the AAAI guitar. Since the electronic graft doubles the acoustic guitar, there is no option to silence the acoustic part of the instrument. On the AAAI guitar, the acoustic sound is perpetually present, augmented by the "duplex" electronic sounds. In the longer run, this has became an obstacle for an extended use of the instrument ; there are many occasions where one would wish to be able to play only the electronic sounds in order to create contrast. Our team is currently working on different solutions to allow for the acoustic sound to be muted while continuing to play the instrument's electronic part. For the moment, the second nylon-stringed AAAI guitar has been played several times in concert within the Electronic Chamber Music ensemble[3], and a record is to be released in late 2017. The design process follows a continuous back and forth movement between artistic praxis and technological development.

CURRENT PERSPECTIVES

A third prototype of a nylon-stringed AAAI guitar is currently under development. The guitar is crafted by the preeminent Italian luthier Gabriele Lodi and will be equipped with a Schertler pickup system and custom-tailored transducer array. A dedicated feedback cancelation processing will be developed for this guitar. This prototype is made especially for Petri Kumela and is designed to be used as a concert guitar. A command for a first piece has been passed to the eminent Swedish contemporary composer Jesper, which will be premiered in 2018. The piece will mark the first large-scale exposition of the AAAI guitar to a wide audience. In parallel to the guitar, both AAAI double bass and violin designs are currently being developed.

3 A concert video capture of the Electronic Chamber Music ensemble featuring the active acoustic augmented guitar can be viewed at: https://vimeo.com/193250484 and https://vimeo.com/193250689.

A novel strategy for ensuring a wider diffusion of the instrument augmentation ideas brought forward in our projects has been sketched. It involves creating an open-access repository on the internet, featuring an online "cookbook" of augmentation receipes, ranging from physical modifications of the instrument to "how-to-do" tutorials and pieces of software. For this project, the entire range of Max/MSP patches used for signal processing will be reported to Pure Data – a free and open source signal processing platform widely used in the electronic music community. With this open platform, we wish to be able to diffuse the ideas and motivation in order to foster the development of all kinds of augmented instruments. The rationale is also to provide a counter voice in the on-going race for music and technology startups dedicated to restricting access to innovations by patenting. The open instrument augmentation repository will be online in the spring 2018.

ON THE AESTHETICS OF INSTRUMENT AUGMENTATION

On the basis of the acquired experience from the two instrument augmentation projects presented in this article, it is possible to draw some preliminary concluding remarks.

The foremost element that has drawn our attention is the fundamentally aesthetic nature of our instrument augmentation projects. At a first sight, such a project would probably seem essentially technological, driven by a agenda of human-computer interaction engineering and audio signal processing, combined with lutherie craftsmanship. However, as our research-creation methodology implements a tight loop between technological development and artistic praxis, it has become clear that every technological implementation involves numerous choices that are fundamentally motivated by aesthetic criteria. The aural impression of "how does it sound" has defined practically all of the output section design of our active acoustic systems, while the "how does it feel" question has been ruling the entire control input design. On the conceptual level, this constitutes an important distinction and a reversal of habitual roles. The reputedly objective engineering development is discovered to be submitted to primary aesthetic criteria, pointing to the larger notion of technology being fundamentally cultural, as brought forward by Bruno Latour (Latour, 1993), as well as to the stance that aesthetics might constitute a ventral key to the human cognition problem, according to Mark Johnson's embodiment theory (Johnson, 2008).

The pre-eminence of aesthetics over technology stems from the fact that these projects have been vitally motivated by a musical desire. A distant intuition of a sonic potential and its related performance praxis has been guiding the work since the beginning. The advantage of such affirmation of the pre-eminence of aesthetics is that the instruments have actually produced – and continue to produce – music that is meaningful in the current cultural context. In the area of novel and augmented instruments, the simple affirmation of a musical vitality is far from being obvious, as a large part of the designs do not actually make it to concert stages or published records. On the other hand the aesthetic nature of our instrument designs imply a predefined area of musical efficiency, contributing to the restricted diffusion these instruments have shown. As the designs feel and sound very personal, there is little motivation for other guitarists to adopt them. An important step is currently happening with the third nylon-stringed AAAI guitar, as the instrument is designed for Petri Kumela and a network of contemporary composers, far from the aesthetic palette of the author. It will be the first "letting go" of the augmented guitar, and it will be most interesting to see the near future evolutions of the instrument guided by other aesthetic goals.

Fundamentally, every project of instrument augmentation and novel instrument design is confronted to the basic question of "novel instrument for *which music* ?". As of today, the guitar represents a highly conservative instrument, carrying the weight of centuries (acoustic guitar) and decades (electric guitar) of established musical genres. It seems pointless to try to augment an instrument in order to play the same music that has been already played with it, such as an augmented electric guitar for rock music. The guitar and its players have already excelled in creating all the variants of rock sounds and playing techniques, nowadays carved in stone as aesthetic guidelines to follow. A 21st century digital remake of an already exhausted music culture would not seem like an inspirational perspective to the author. At the same time, why then employ an existing an iconised instrument in order to search for something musically new ? A possible answer portrayed by the augmentation projects presented within this article points towards the hyper-individualisation of instruments and practices readily perceived in the maker culture. Within this (yet rather marginal) cultural form, the hybridisation of aesthetics and technology is commonplace, both serving to create personal instruments, tools and artworks which become part of the builder's individual identity. The individualised instrument stands for a personal empowerment against normative technology as well as against mass-produced and mass-consumed music. In a technology-pervaded culture, one possible avenue for self-expression involves gaining expertise over the technology itself and warping it to suit one's personal aesthetic intuitions. It seems that the augmented instruments presented here have evolved within such a framework where artistic and research agencies are intimately joined, where the technological becomes a vehicle for the artistic and vice versa. The whole project becomes multifaceted ; at the same time musical and technological, artistic and scientific, practical and theoretical, to be actuated via different media ; music (both live and recorded), online video, writing, and software. Instrument augmentation practice, as portrayed by these examples, reflects the contemporary condition by constituting a hybrid form in itself, between instrument design and building, music creation and performance, technological research and academic enquiry.

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KEYWORDS

Augmented instrument, Guitar, Active acoustics, Live electronic music

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