Magpick: an Augmented Guitar Pick for Nuanced Control

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ABSTRACT

This paper introduces the Magpick, an augmented pick for electric guitar that uses electromagnetic induction to sense the motion of the pick with respect to the permanent magnets in the guitar pickup. The Magpick provides the guitarist with nuanced control of the sound that coexists with traditional plucking-hand technique. The paper presents three ways that the signal from the pick can modulate the guitar sound, followed by a case study of its use in which 11 guitarists tested the Magpick for five days and composed a piece with it. Reflecting on their comments and experiences, we outline the innovative features of this technology from the point of view of performance practice. In particular, compared to other augmentations, the high temporal resolution, low latency, and large dynamic range of the Magpick support a highly nuanced control over the sound. Our discussion highlights the utility of having the locus of augmentation coincide with the locus of interaction.

Author Keywords

Augmented instrument, magnetic sensing, subtlety, nuance, locus of interaction, ancillary gestures sensing

CCS Concepts

•**Applied computing** → **Sound and music computing;** *Performing arts;* •**Hardware** → *Sensor devices and platforms;*

1. INTRODUCTION

In virtually all musical instruments, the set of gestural features that contribute to the production of sound is bounded by the physical constraints of actuation. In the case of the guitar, even if we were to consider the movements of the pick solely, only those involving an interaction with the strings (e.g. plucking and releasing the string, sliding on the string) actually have an effect on the sound [23]. Many other naturally occurring gestures, the so called *ancxillary gestures*, could potentially be used to control sound production [6, 23]. For instance, continuing with the example of the guitar, the movements of the pick pre- and post-pluck and the movements of the pick above the strings could be used as performance material.

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Figure 1: The Magpick is composed of two parts: a hollow body (black) and a cap (brass).

The challenge is to find ways to sense the movement of the pick with respect to the guitar with high resolution, high dynamic range, and low latency, then use the resulting signal in a way that is compatible with existing guitar technique. Ideally, the pick should also be minimally invasive and should not require additional hardware to be installed on the guitar.

The Magpick (Figure 1) is an augmented guitar pick (plectrum) that consists of a hollowed custom-designed pick with several loops of wire embedded within it. When the pick moves within an ambient magnetic field, such as that created by the permanent magnets in an electric guitar pickup, an electromotive force (voltage) is induced in the coil, which is proportional to the rate of change in magnetic flux. In the context of guitar playing, this signal is related to the speed of movement, the angle of the pick with respect to the guitar body, and the proximity of the pick to the pickups. As a consequence, the voltage generated in the wire embedded in the pick de facto provides information about the gestures of the plucking hand.

The wire is connected to a small preamplifier embedded in a box that can be worn on the wrist. The output of the preamplifier is connected to a Bela audio processor [10], where it is combined with the signal from the guitar to produce a new output signal that modifies or extends the sound of the guitar. This solution accurately responds to the speed, location, and intensity of the pick movements in the pickup area with a wide dynamic range. Especially important is the fact that the signal in the pick is also generated by motion above the strings (not touching them) as well as by strums and plucks.

In the next section we present existing attempts to augment guitars and guitar picks, then in Section 3 we detail the technological implementation of the Magpick. In Section 4 we present a user study with 11 guitarists, who used the Magpick over a period of 5 days. The findings and implications are discussed in Section 5, and Section 6 summarises the contributions of this paper and presents possible future directions.

2. RELATED WORK

The Magpick is situated within an approach to digital instrument design where a focus on subtlety, nuance, or control intimacy [24] takes priority over the navigation of high-dimensional parameter spaces. Tanaka [18] observed of the subtlety of acoustic instruments that "the clarity of interaction then goes beyond the simple question of parameter and event mapping of 'what controls what' to a more high-level analysis of how different gestural inputs are used to derive the different types of articulative signals." A recent trend has been the development of instruments with continuous audio-rate sampling of relatively few control signals (often only one) [22, 12, 17], from which a rich gestural language can translate into the articulation of complex signals whose musical output is readily grasped in an enactive way [24] even if the digital system makes no attempt to segment or classify the gestures producing the signals.

Turning specifically to the guitar, the potential of technology to extend its possibilities has a long commercial and academic history. Particular emphasis since the early 1980's has been given to augmenting the guitar rather than the pick [15], including Zeta Mirror and Roland GK-series MIDI guitars using hexaphonic pickups, or the more recent Moog Guitar and Vo-96 that electromagnetically actuate the guitar strings. Electromagnetic string actuation, which first came to prominence in the guitar world with the 1978 EBow [1], remains a regular topic of research at NIME [8]. The interested reader can find a recent review of augmented guitar systems in [11].

With respect to augmented guitar picks, there is a long history of various sensors being integrated into picks, mostly using force, bend and vibration sensors, or electrical contacts with the strings. One of the first examples of sensor-augmented guitar pick dates to 1977: The Raymond Lee Organization patented a guitar pick containing a microphone [4]. A 2014 patent of an augmented guitar pick [3] shows a physical pick design containing a cavity to hold an electronic sensor. In 2007 Vanegas presented at NIME a MIDI pick that uses a force-sensing resistor on a guitar pick to control musical events via MIDI [21]. In order to control different aspects of the performance, the player has to vary the pressure on the guitar pick. Although this is a clever solution to control the augmentation from the pick itself, it obliges guitarists to learn and perform unconventional gestures.

The most recent augmented guitar pick is the PLXTRM by Vets et al. [23]. PLXTRM is a sensor-enabled guitar pick that includes an accelerometer, a piezo vibration sensor, and a copper surface intended to make electrical contact with the strings. It is used with a guitar pickup featuring a separate audio output for each string and with a digital signal processing system designed to detect gestures from the pick. By comparison, the Magpick uses a different sensor technology that works with any pickup and does not require any additional installation on the guitar.

The Magpick works by sensing changes in magnetic field. Electric guitars have one or more pickups below the strings in the area where guitarists typically strum. Each pickup contains a set of high-strength permanent magnets that produce an ambient magnetic field around the pickup that extends above the strings. The motion of the Magpick through this field generates an electrical signal that provides information about the gestures of the guitarist's plucking hand in the vicinity of the pickups.

3. TECHNOLOGY AND DESIGN

The pick itself contains a hollow channel with 4 loops of copper magnet wire around the interior perimeter (Figure 2).

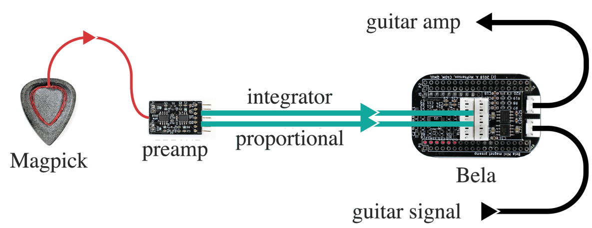

Figure 2: The architecture of the Magpick system.

By Faraday's Law, a change in the magnetic flux through the loop enclosed by the wire will generate an electric voltage proportional to the rate of change. This is the same basic principle that underlies every magnetic pickup, including the pickups in the electric guitar, but its application in the Magpick presents an engineering challenge for two reasons. First, the signal of interest is generated by the movement of the Magpick relative to the permanent magnets in a nearby guitar pickup. The Magpick is operated by human hands, so its speed of motion will be relatively low compared to the velocity of a vibrating string. Second, the Magpick contains only a few turns of wire, instead of the hundreds or thousands of turns found in most magnetic pickups. Since the generated voltage is proportional to both the rate of change of magnetic flux and to the number of turns, the output of the Magpick will be much smaller than other magnetic pickups, on the order of microvolts.

3.1 Sensor Design

To maintain a usable signal-to-noise ratio with such a small signal, two specialised amplifier circuits were created of different topology. Figure 3a is a non-inverting proportional amplifier of gain $(1+\mathrm{R2}/\mathrm{R1}) = 304$. The OPA1612 op-amp features an extremely low voltage noise density of $1.1\mathrm{nV}/\sqrt{\mathrm{Hz}}$. R1 and R2 are thin film resistors, with the smaller than usual 3.3Ω value of R1 minimising the Johnson (thermal) noise in the feedback path. Because the Magpick has a source impedance of $< 1\Omega$, Johnson noise is negligible in the source signal itself. The proportional amplifier provides an output voltage that scales with the velocity of the Magpick relative to the pickup magnet. It is suitable for detecting high-frequency transient events such as the snap of the pick following plucking a string.

To detect slower, larger motions such as waving the Magpick above the magnets, a different amplifier topology is required. Figure 3b is an inverting leaky integrator with a corner frequency of $1/(2\pi\mathrm{C2R4}) = 0.7\mathrm{Hz}$. By integrating the incoming signal, the output provides an approximate measurement of the total quantity of motion of the Magpick. The ADA4522 zero-drift (chopper) op-amp is chosen for its extremely low input offset voltage (5μV) and low $1/f$ noise, allowing very high gains at low frequencies without being

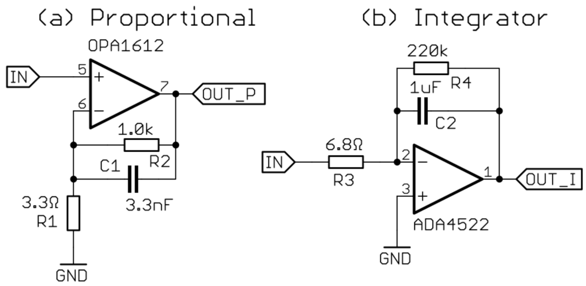

Figure 3: Schematics of the two preamplifiers.

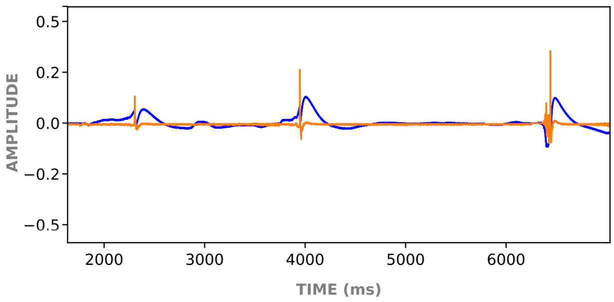

Figure 4: Representation of the integrator (in blue) and proportional (in orange) signals. The three peaks correspond to three upward plucks of a single string, with increasing speed of the plucking hand.

swamped by noise and drift. The low source impedance of the Magpick allows a small input resistor R3 to be used (6.8Ω), and the same input signal can simultaneously drive both amplifiers.

The amplified signals (which we'll now refer to as *pick-signals*) are connected to two analog inputs of a Bela embedded audio processing board [10], which was adopted for its extremely low latency [14]. The signal from the electric guitar (*guitar-signal*) itself is connected to a third input. In the Bela board the three signals are combined using audio computation (details in the following section) to generate the signal to be sent to the guitar amplifier.

3.2 Sound Design

The most significant features of the pick-signals are: (i) they are created only when the guitarist strums over the pickup area (as opposed to over the fretboard, for instance); (ii) they also respond to pick motion above the strings (not necessarily touching them); and (iii) they sense the intensity of movement with a wide dynamic range.

We spent several months studying the characteristics of the *proportional* and *integrator* signals (Figure 4 compares the two signals for a specific gesture) and to combine them with the guitar-signal to create interesting musical output. In this section we present three classes of possible combinations, which are schematically represented using Pure Data in Figure 5 (video examples can be found as supplementary material).

3.2.1 Envelope control

The most direct combination of the pick-signal with the guitar-signal is a simple multiplication of the two (Figure 5-left). The product of the multiplication is a signal whose amplitude is controlled by the pick-signal and whose spectral content is that of the guitar-signal. As a result, the sound of the guitar is unchanged except for the volume, which depends on the intensity of the pick-signal and thus on the way in which the pick is interacting with the magnetic field of the pickups. The resulting sound can be described as a **volume swell**: the attack and release of the notes are always gradual as they are in effect controlled by the Magpick approaching (attack) and leaving (release) the pickup area, which is never a sudden action.

The *integrator* preamp was used in this case given its capability to detect low-frequency gestures. In this condition, *air-strumming* above the strings in the pickup area results in a tremolo effect: the signal created in the Magpick alternates a high signal (when the hand moves perpendicularly to the string, upwards or downwards) with a low signal (when the hand stops its movement to invert the strumming direction). In practical terms, this condition allows guitarists

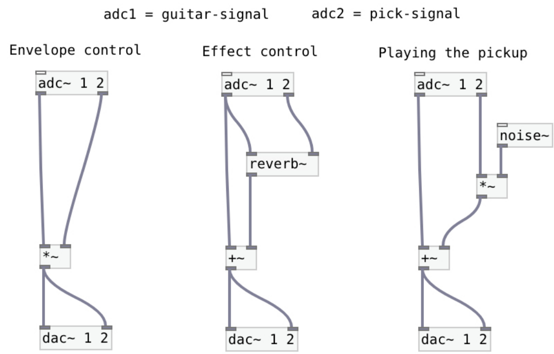

Figure 5: Pseudocode showing the three classes of sounds.

to control the envelope of the sound by moving the pick above the strings after the strings are plucked. As an example, to achieve a gradual attack, a guitarist would pluck the string(s) on the fretboard and slowly move the plucking hand holding the Magpick over the neck pickup. Then, she could air-strum above the strings to control the sustain.

3.2.2 Effect control

In this condition, the output is a combination of: (i) the guitar-signal sent to the output unprocessed plus (ii) an effected version of the guitar-signal with one or more parameters controlled by the pick-signal. Figure 5-centre shows a pseudo-code for a reverb effect in which the pick-signal is used to control a parameter of a reverb like the reverb time. The resulting effect can be compared to a reverb pedal whose *room size* level is determined by the interaction of the pick with the magnetic field of the pickups (pick-signal).

For the study described in the next section, we developed an audio-effect, which we named **harmonised delay**, that combines a typical delay with additive synthesis. This sound is created by delaying the guitar sound and adding its harmonic partials as identified by an FFT. To start with, the effect is triggered when the pick-signal goes above a certain threshold. Then, the intensity of the pick-signal influences two effect parameters: the number of the generated partials and the delay interval between them.

This solution allows guitarists to control the speed of the arpeggios directly from the pick: the more intense the strumming the higher the frequencies that are reached and the shorter the delay between them (in a range from 0 to 255 ms). Consequently, a high pick-signal reaches high frequencies and produces brighter harmonic sounds. The *proportional* preamp was used for its rapid transients. This effect indeed relies on a fast peak detection of the signal amplitude to determine the resulting sonic output.

3.2.3 Playing the pickup

In the third class of combinations, the guitar-signal is sent in output unprocessed; in addition to this, the pick-signal controls the volume of another sound source, which might or might not depend on the guitar-signal. For instance, in the case shown in Figure 5-right, the pick-signal controls the volume of a noise source. Independently of the guitar sound, which does not even need to be active, the movements of the Magpick over the pickup area create their own sound, giving the impression of being *playing the pickups*.

For our study we developed a sound design that we called **scrambled delay**. The last 5 seconds of the guitar-signal are stored in a buffer. Then a portion of the recorded audio is randomly selected and played back at the original speed.

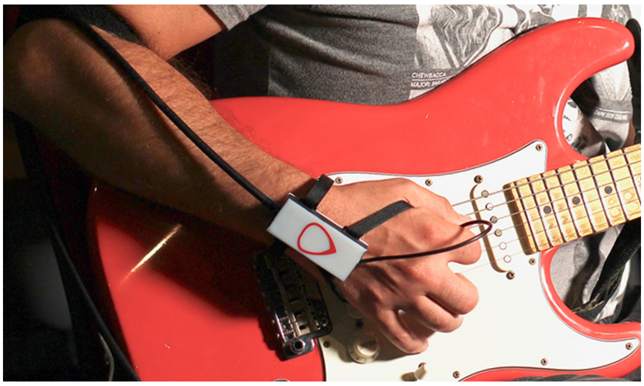

Figure 6: A close up of the wrist box, which contains the preamp board.

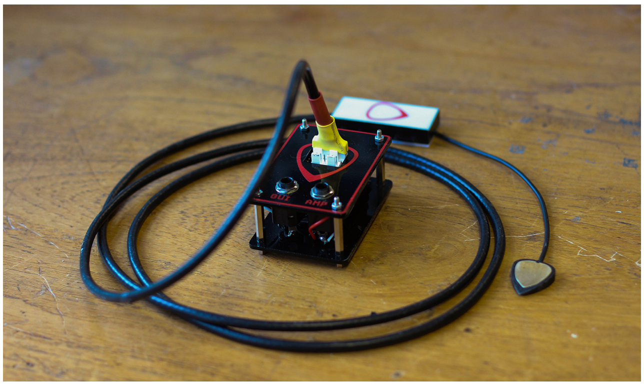

Figure 7: The Magpick system. Bela is embedded in the custom-design box in the centre.

The length of the selection varies each time randomly between 1 and 2 seconds. A fade-in and fade-out envelope is also added to each played-back sound to improve the homogeneity of the output. Two of these played-back buffers are active at the same time. The volume of the effect is controlled by the pick-signal using the *integrator* preamp. This sound can be used as a sort of reversed delay on top of what a guitarist is playing or might even "record" a short phrase as per normal playing and then play it back, scrambled, by moving the Magpick above the pickup area.

3.3 Physical design

The design and craft of the pick needed to take into account two practical aspects. First, the pick had to be made of durable material, due to constant friction with steel strings. Second, it had to allow the magnet wire to be embedded inside of it and a cable to come out of it. The shape of the pick was designed through a series of iterative prototypes. We initially used paper and clay prototypes, and we later moved to 3D printed models. The final shape (Figure 1) resulted in a quite thick object that comines the familiar aspect of a pick with an idiosyncratic aesthetic and allows enough space for the coil to be embedded. At the same time, the pointy shape with a thin tip allows fast picking. The pick has a hollow cavity, covered with a cap, to allow a copper wire to be wound inside. We tested several materials for 3D printing or injection moulding, and the final choice was informed by durability and grip quality, as well as by aesthetic and tactile components. In the end, we produced picks with different combinations of the two parts (i.e. the hollow body and the cap) in acrylic, brass, and sandstone, which differed in feel and weight.

In the present implementation, the preamplifier is built on a small printed circuit board that is external to the pick, which was placed in a small 3D printed box that is strapped to the guitarist‘s wrist or hand (Figure 6). The Bela processing board was embedded in a custom-designed box with two surface-mounted audio sockets connected to the board for connecting the guitar (line in) and the amplifier (line out). The box also hosted a third socket to connect a custom made cable attached to the wrist box (Figure 7).

4. USER STUDY

We conducted a user study to investigate the potential of the Magpick to extend the creative possibilities of electric guitars. We recruited guitarists through email, newsletters, and social media. We sought participants of varying gender, cultural background, musical style, and skill level. We employed a snowball sampling method, in which participants were asked to recommend others. 11 participants were recruited (8M/3F, 4 nationalities, average age 40.3). Each was assigned one of three sound designs: volume swell, harmonised delay, or scrambled delay.

4.1 Protocol

The whole study lasted five days and was approved by the ethics board at Queen Mary University of London and performers were paid £50 for their participation. On the first day, participants came to the university to collect the Magpick kit; then for three successive days they tested the system at home and the last day they brought back the kit. During the collection day, we presented our participants with the Magpick and connected it to the guitar they brought along and to a guitar amp. We let them try out the system for 10 minutes without giving them any information about its nature and we then explained them how it worked.

We asked participants to use the Magpick one hour a day for three consecutive days. Each morning we contacted them with a specific task to perform with the Magpick for that day. On day 1, we asked them to explore some creative uses of the pick. On day 2, we asked them to prepare a short piece of 2 minutes or less using the Magpick and to send over a video of them performing it[1]. On day 3, we asked them to notate the piece they composed the day before. We intended these activities to offer them some sense of purpose and to collect material for our inquiry.

The fifth day participants came back to return the kit and we performed a video-recorded exit interview. We prepared a set of questions that we hoped would stimulate discussions about their experience with the Magpick and we asked participants to comment on the piece they recorded while playing back their video from day 2 (video-cued recall method), and to explain their notation. The interview was conducted by one of the authors who is an electric guitar player; this common interest and background helped engage the participants as peers.

4.2 Analysis

The analysis of the data integrates the transcripts of the interviews with the analysis of the playing techniques they exhibited in the piece they sent over on day 2, as independently analysed by two researchers. The interpretation of this data evolved with several iterations of thematic analysis. A deductive approach was adopted: we had pre-existing coding frames through whose lenses we aimed to read our research exploration.

[1]A selection of these videos can be found in the supplementary material.

5. FINDINGS

In this section we elaborate upon the innovative uses that guitarists made of the Magpick with a reference to the new knowledge that is generated for the design of augmented instruments. Given space constraints, further discussions on the benefits and drawbacks of the Magpick from the point of view of human factors and performance practice will be included in a dedicated publication.

5.1 Subtlety of interaction

Most participants were impressed by the extremely subtle control allowed by the Magpick on the musical output, which can't usually be achieved by any other means. William[2] (who used the *volume swell* sound design), reported: "*I just really like the fine response of it. You can get a lot more out of this in terms precision and speed. You can't get that much with a pedal*".

This subtle control is made possible by the precise sensing of the pick movements that is directly transformed into musical material. Notably, our participants did not have to undergo a long re-learning process to use the augmentative potential of the Magpick. Rather, its potential of being seamlessly integrated in typical guitar technique was evident from their first encounter with the Magpick. During the 10 minute explorations, some guitarists discovered at least part of the new interaction possibilities, which usually manifested as a moment of epiphany visibly marked by body language indicating surprise, facial expressions, and/or exclamations such as: "*Aha!*", "*I see, I see...*". After the epiphany, three guitarists switched within seconds to making music with the newly discovered behaviours. Thomas (*volume swell*), for instance, less than 5 seconds after the epiphany, strummed a chord and controlled the rhythm by waving his hand above the neck pickup.

The characteristic of being seamlessly integrated in ones' performance practice is particularly important for the discourse around dimensionality that has been discussed in our community [24, 18, 25]. The Magpick has a relatively simple behaviour that has a high degree of detail and immediacy. What the Magpick senses is a combination of pick position, speed, and angle but it is not easy to describe compactly in words. Nonetheless, guitarists managed to embody this new technology within seconds and use its creative potential straightaway. This finding suggests an approach to instrument design and augmentation that differs from a pursuit of high-dimensional control and from attempts to create a computational system that has an intelligent conceptual understanding of what the interaction means.

5.2 Locus of augmentation = locus of interaction

William offered another important comment related to innovative aspects of the Magpick: "*It's really interesting to have that control in your hand. You got this effect right in your hand you can use if you want very subtle changes or like extremely affected sounds. It's just right there, and you can just move the pick and it responds, as opposed to pedals. You can get a lot more out of this in terms of response as opposed to trying to get your foot kind of all over the place. It's just really the convenience and easier adjustability just by moving your hand*". As several other participants, he particularly enjoyed the double function of the Magpick that worked both as a pick and as a device to control the augmentations/effects with. On this respect, Isla (*harmonised delay*) reflected: "*I can control something at the same time as playing when it comes off and on: that's the advantage*".

[2]We will refer to participants using pseudonyms.

The augmented aspect of the Magpick can be controlled by interacting with the *hand-pick-guitar* system as one normally would, with minimum adaptation (e.g. pick angle and position, plucking intensity). In other words, in the Magpick the *locus of augmentation* coincides with the *locus of interaction*. The locus of interaction is on the pick, an object that guitarists traditionally use to pluck the strings, thus they have already internalised the sensorimotor skills to control its subtleties. By contrast, devices that guitarists normally use to control effects are either operated by a part of the body that guitarists have less precise control of (pedal), force guitarists to stop performing and move their hand in a different position (knob), or require that they hold a different object that completely occupies the hand and is only dedicated to the augmentation and not to the normal interaction (EBow).

The co-location between *interaction* and *augmentation* is a promising area of exploration. Some augmentations use audio from the original instrument to drive feature extraction and resynthesis [19, 16]. Other augmentations co-locate new sensors on top of existing parts of the body used to play the original instrument (e.g. TouchKeys [9] which adds position sensing to the keyboard, or the control of digital effects through the guitar whammy bar [5]). More commonly, the augmentation is controlled using parts of the body or dedicated movements that are typically not employed for this purpose (e.g. manipulating potentiometers [7], buttons or touchpads [2], proximity and pressure sensors [20]). In these cases, the musician cannot rely upon established sensorimotor skills and has to undergo a process of refamiliarisation, which is a deterrent to instrument uptake [13].

Coincident loci of interaction and augmentation also offer guitarists visual and proprioceptive information on the intensity of the effect. Isla explained that when she wanted to increase the level of the effect she would just move closer to one of the pickups, where the pick-signal is higher.

5.3 Effect ready to hand

When using the Magpick, guitarists do not have to decide when to activate and deactivate the effect, which is rather always ready to hand. Two participants noted that the intensity of the effect can be gradually controlled in all intermediate levels by means of strumming position and intensity. With traditional pedals this can be achieved only with an expression pedal or by adjusting the knob on the pedal, both options causing disruptions on the performance.

Having the effect ready to hand lent the augmented aspect of the Magpick to be meaningfully used even for a few instants, too. With this respect, William reported: "*With a pedal I think it's more like: Ok, I'm going to put this pedal on and use it for a while. This* (the Magpick) *lends itself to short changes in it*". The analysis of the videos of guitarists' pieces gave support to this idea: five of them clearly used the augmentative potential of the Magpick just for a few seconds to embellish the piece. James (*playing the pickup*) discussed: "*I used it to trigger the effect at the end of some phrases. I played three chords and then I wanted to trigger this effect to create an atmospheric thingy after the last chord. Then I went back back to a dry effect to triggered the effect again after three chords. I liked activating the effect at the tail of what I was doing and being dry in the middle*". Isla had a similar use of the Magpick. In her piece she mostly kept her plucking hand in between the pickups (no effect) and moved it on top of the bridge pickup (maximum effect) only at the end of the phrase to "*lift up the piece*".

Having a continuous control on the sound directly on the plucking hand allowed participants using the *volume swell* condition to have continuous control over the sustain of the guitar. This would be normally achieved by operating an expression pedal, which cannot be used for fast and subtle changes. With our technology, the envelope of the sound can be controlled by *air-plucking* the Magpick on top of the strings *after* a string is plucked. This property was particularly appreciated by all the participants that had the Magpick set with this sound design. Thomas compared the feature of controlling the sustain of the note to bowing the violin: "*You have the kind of control, like bow playing. You can keep the note and change the shape of the sound. This is really important*".

6. CONCLUSION

We presented a new technology for electric guitars that embeds our own aesthetic and values, which are shared by other designers of new DMIs [13], centered on exploring nuances in music performance. In comparison to guitar and pick augmentations that trigger events or add multiple dimensions of control, the Magpick explores the subtleties of a single signal source within the pick through high-bandwidth sensing. The signal behaviour contains a certain amount of redundancy, whereby varying combinations of proximity, angle, speed, and quantity of motion produce similar instantaneous outputs. This redundancy ultimately helps enable a wide variety of distinctive performance techniques that might have different trajectories over time or interact with traditional technique in different ways. That the locus of augmentation corresponds to the traditional locus of actuation (i.e. the plucking hand) forces an integration of gestural language between traditional and extended techniques, while the sound design that modifies the guitar signal and maintains the status of the augmented guitar as a single instrument rather than the first step toward a 'theme park one-man band' [18].

As we developed the Magpick as a research explorations there are several technical improvements that are possible, some of which have been mentioned by the participants of our study. In particular, the pick could be made wireless, embedding the preamplifier circuitry along with a battery (or even remote RF power), with a wireless transmitter sending the Magpick-signal to an external sound processing device. The Magpick-signal could also be provided directly to the performer as a control signal for other effects or instruments, such as through CV (control voltage) control for modular synths, or through a user-programmable board.

7. ACKNOWLEDGMENTS

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