

# Pencil Fields: An Expressive Low-Tech Performance Interface for Analog Synthesis

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## ABSTRACT

I present a novel low-tech multidimensional gestural controller, based on the resistive properties of a 2D field of pencil markings on paper. A set of movable electrodes (+, -, ground) made from soldered stacks of coins create a dynamic voltage potential field in the carbon layer, and another set of movable electrodes tap voltages from this field. These voltages are used to control complex sound engines in an analogue modular synthesizer. Both the voltage field and the tap electrodes can be moved freely. The design was inspired by previous research in complex mappings for advanced digital instruments, and provides a similarly dynamic playing environment for analogue synthesis. The interface is cheap to build, and provides flexible control over a large set of parameters. It is musically satisfying to play, and allows for a wide range of playing techniques, from wild exploration to subtle expressions. I also present an inventory of the available playing techniques, motivated by the interface design, musically, conceptually and theatrically. The performance aspects of the interface are also discussed. The interface has been used in a number of performances in Sweden and Japan in 2011, and is also used by other musicians.

## Keywords

gestural interface, 2d, analog synthesis, performance, improvisation

## 1. INTRODUCTION

Electronic musicians have been struggling with gestural control over electronic sounds since the beginning of electronic music. The high-dimensional parameter spaces of modern synthesis and processing techniques are not so easily explored with keyboards and other conventional playing interfaces, and a large part of the effort has been spent at design time, adjusting parameters and preparing the sound, with limited exploration and expression available at play time. As both an acoustic and electronic improvising musician, I strongly feel something is missing when performing with mouse and laptop, or with only knobs and faders. The sound-making is not connected to physical effort, which is so important for acoustic musicians, and which also have a strong impact on the musical output regarding phras-

ing and form. The importance of this kind of effort has been strongly advocated by, e.g., Joel Ryan [Ryan 1992]. Equally important are the visual performance aspects. A physical interface involving visible gestures not only helps the musician, it also helps the listener/spectator to follow the structure of the performance, and gives additional information about what is going on. Also, it helps her to some extent perceive a musician's intentions just moments before they happen, since physical gestures of the musician require physiological preparation. All this requires that the control-to-synthesis mapping preserves at least some discernible connection between gesture and music.

In this paper, I present a novel analog low-tech controller, which satisfy most of these requirements. Its development was motivated by a personal artistic need for gestural expression in analog sound synthesis, where no existing controllers could provide what I was looking for. It was inspired and informed by extensive research into novel mapping techniques for advanced digital instruments [Dahlstedt 2009]. It has since its premiere in May, 2011, been used in a number of performances in Sweden and Japan, both solo and with other musicians. The interface is also used by other musicians.

### 1.1 Background and previous art

The idea of a direct physical interface for analog sound is not new. Instruments such as Michel Waisvisz' Crackle Box, and Peter Blasser's creations (e.g., the Fourses and Fyrall), and other body contact circuits emerged from a need for direct control of analog sound. David Wessel [Wessel et al. 2002] have addressed the need for intimate control and close correlation between gesture and sound, and applied it to digital instruments. There is also long fascination in art with the perceived correlation between visuals and sound, either neurophysiological (synaesthesia) or as a metaphor. One interesting example is fluxus artist Gerhard Rühm's *Bleitstiftmusik* [Rühm 1981] where the acoustic sounds of making a pencil drawing is presented together with the drawing, as a combined artwork.

The conductive and resistive properties of pencil have been explored before. Swedish musician Daniel Skoglund has developed a performance technique where pencil markings on a circular paper function as a rhythmic sequencer, read by a rotating copper brush<sup>1</sup>. The Drawdio circuit by Jay Silver uses linear resistance in pencil markings to alter pitch in an oscillator<sup>2</sup>, and Joyce Hinterding has created large graphite antennas, the properties of which can be explored by visitors in interactive installations<sup>3</sup>. But I have found no implementation that use a 2D drawing in the way

<sup>1</sup>see [http://youtu.be/PRYFn\\_JMk0A](http://youtu.be/PRYFn_JMk0A) for an example

<sup>2</sup><http://web.media.mit.edu/~silver/drawdiodio/>

<sup>3</sup>See, e.g., <http://www.breenspace.com/artists/9/exhibitions/103/joyce-hinterding-at-volta-ny-2011/>

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it is done in this project.

The Pencil Field is in essence a 2-dimensional surface controller. Other examples of surface controllers include the Korg Kaosspad series (a single point, finger control), various implementations using Wacom tablets (movable objects, pens, mice, which provide more degrees of freedom, tilt, etc.) and numerous iPad synth apps, which have started to explore the potentials of multitouch. Special interfaces such as the Haken Continuum Fingerboard [Haken et al. 1998] have been developed, with a focus on smoothness and precision.

What is different in the Pencil Field interface is that you do not only exploit location on the surface, but you define and change the field, which allows for detailed and coupled control of several parameters, on both micro and macro level. Continuous and discontinuous gestures can be produced, and a vast range of auxiliary playing techniques allowed for a variety of musical expressions and variation in performance. The particular aspect of drawing on paper, and the shuffling around of electrodes in a board game-like scenario, also brings interesting performance qualities.

## 1.2 History, and recorded performances

A primitive first prototype was tested in concert in Kyoto, Japan, in December 2010, in an improvisation together with a *Noh* flute player and a *butoh* dancer. In the spring of 2011 the current version was developed, and it has not changed since. It has been used with a variety of sound engines, all implemented in the Bugbrand analog modular, but the construction of the interface has remained constant. This is a conscious decision, and part of our evaluation method. An instrument needs to be evaluated over a long time span, in many different musical contexts, in live performances and studio sessions, with acoustic and electronic co-improvisers. Only then are we able to tell if it works as an instrument in real life, and to say something about the controllability, expressivity, dynamics and learning curve of the instrument. It takes time to develop a repertoire of playing techniques, and to find out what kind of sound engines that work well with a particular interface and the developed playing techniques.

In August, 2011, a clone of the interface was constructed and sent to electronic musician Richard Quirk, Isle of Man. He has since provided valuable feedback from his process of learning and using it in a musical context very different from mine.

There are two videos online that show typical solo performances using the Pencil Field, and how it can be played. A quick look at these will facilitate understanding of the descriptions of the construction and of the playing techniques used. Video A (<http://youtu.be/CyXByRR6I-w>) shows one of the very first performances, a headphone concert at the Gothenburg Art Sounds Festival, May 6th, 2011. It is a live recording of the whole performance (ca. 12 minutes), but the audience is not visible in the video. There are about 35 people with headphones, sitting and standing around me in a close circle. Video B (<http://vimeo.com/31173998>) shows the beginning of a performance at the opening of the Varia Improvisation Festival in Gothenburg, Sweden, Oct 26th, 2011. In addition to these performances, the interface has been used in performances in Tokyo, Kyoto and Gotheburg, both solo and together with other musicians.

## 2. CONSTRUCTION AND THEORY

The main idea behind this interface is to use the resistive properties of a 2-dimensional conductive surface of pencil markings on a paper to produce various levels of analog control voltages (CVs). The main difference from other surface-

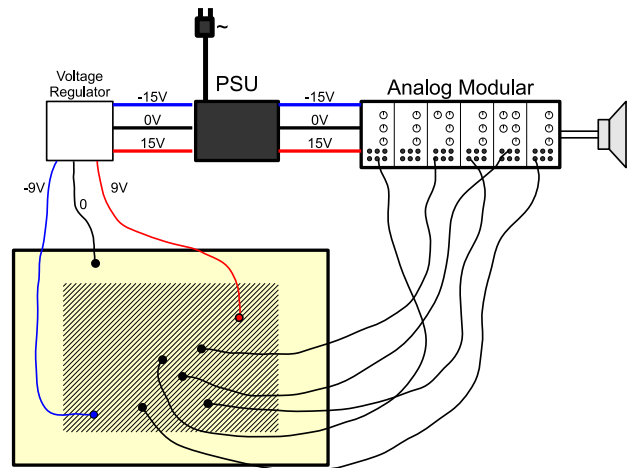


Figure 1: An overview of the connections within the Pencil Field system.

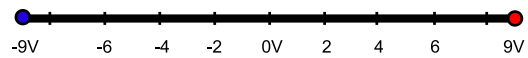
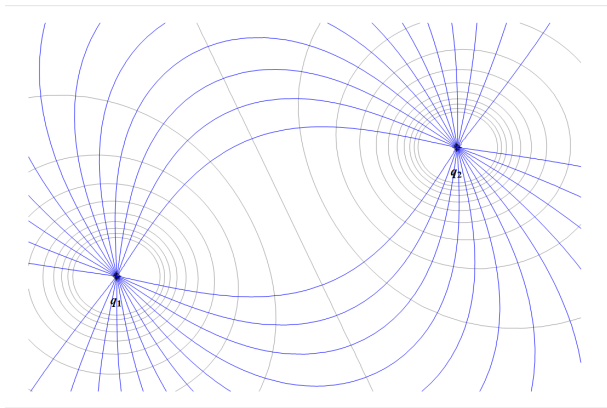


Figure 2: Pencil markings in the shape of a line equals a 1-dimensional voltage divider. Intermediate voltages are distributed linearly between the supply electrodes.

based interfaces is that there is no fixed coordinate system – the voltage field is created by the same kind of electrodes that are used to tap specific potentials from it. Hence it is flexible, and playing with the field itself while keeping the tap electrodes still is one of the key techniques, allowing simultaneous partially coupled control of a large number of control parameters. Also, the analog nature of the interface allows for a number of additional playing techniques, 'abusing' the design of the electrodes and the resistive properties of the human skin and body. Also, the 2-dimensional resistive surface is drawn by hand before or during the performance, and can take any shape, and can be of variable density. Many different topologies are imaginable, from a simple dense rectangle with uniform resistance, to complex patterns and figurative shapes, which combined with physical movement of the electrodes can be used to create continuous or jumping parameter sequences and rhythms.

A couple of early prototypes were tested in performance and studio sessions to prove the concept, but were clumsy and difficult to control. Since then, I have settled on a more thought-out hardware design that works very well. This is the version described here.

The system consists of four parts parts (see Fig. 1). A custom voltage regulator provides +9V, -9V and ground (0V), from the +15V power supply of the analog synth. These lower voltages are connected to three supply electrodes, and the placement of these electrodes on the pencil marks on the paper determines the current potential field on the paper. A 1D resistor functions like a simple voltage divider (Fig. 2), but for a resistive surface, the pattern is more complex. In case of an ideal surface with perfectly uniform resistance, the field looks like in Fig. 3. Here only the positive and negative supply electrodes are used. Additionally, the ground electrode can be placed anywhere on the pencil markings to distort this field. For example, if the ground electrode is placed near the negative supply electrode, this will push the equidistant lines closer between the negative and the ground electrodes. Typically, only the



**Figure 3:** If the resistive A 2D dipole electric field.  $q_1$  and  $q_2$  are two equal charges of opposite polarity. The gray lines show equipotential, i.e., constant voltage. The straight line in the middle shows 0V.

positive and negative electrodes are used, with the ground electrode used sporadically to distort the field.

The custom regulator is a simple design utilizing a couple of standard semiconductor DC-to-DC converters and some stabilizing capacitors. It shares a ground connection with the synthesizer. The + and - supply electrodes each have a current-limiting resistor, to allow for accidental or intentional short-circuits without overloading the supply. They also help preventing too large currents going through the skin of the performer.

The design and construction of the electrodes is crucial, because they are the primary movable parts of the instrument. They need to be heavy so they stay in place when not touched. The weight also ensures good contact with the pencil markings underneath. In the current system they are made from soldered stacks of six copper coins, of 20mm diameter. A soft cable extends from the side. The electrodes can be oriented either way, and the flat surfaces have been cleaned and brushed for good contact. The heat-shrink tubing on the cable connection is red, black and blue on the supply electrodes, and white on the tap electrodes. In the current setup, 7-8 tap electrodes have been used.

In addition, sometimes paperclips soldered to cables have been used for fixed connections to a specific point on the paper (see for example the upper left corner of the paper in Fig. 4).

The cables going from the electrodes to the voltage regulator and to the synth need to be very soft, not to interfere with the playing. Also, you want to avoid tangling them.

The tap electrodes are directly connected to various modulation inputs on the modular synthesizer. There is no electrical buffering between the pencil field and CV inputs. The electrical coupling and co-dependence that can appear is musically interesting, and makes the interface more organic and interesting to play. Since the synthesizer CV inputs on the system currently used have high impedance (100k $\Omega$ ), these effect are small, but noticeable. Buffer stages between the taps and the synth may be included in future versions, to make the system more robust and compatible with different makes of analog modulars and other voltage-controlled devices.

So far, the Pencil Field interface has only been used together with various configurations of the Bugbrand modular synthesizer, designed and built by Tom Bugs in Bristol, UK<sup>4</sup>. The sound engines have varied between performances,

as they are improvised just before each performance. However, based on extensive experience designing sound engines for explorational sound design using interactive evolution [Dahlstedt 2007], I apply the same ideas to these sound engines. They are designed as potential parameter spaces, made for exploration. They are often chaotic, using feedback and cross-modulation to allow for complexity to emerge from simple configurations. Also, such circuits often exhibit interesting phase transitions, providing an interesting parameter space for an improvising musician. I have sometimes used generative gestural configurations, where periodic or chaotic rhythms and patterns are controlled by the interface, in parallel to timbral control. Two or three sound engines are often run simultaneously, and the control parameters are then mapped to various parameters of all of these, at the same time. So any movement of an electrode will affect parameters in all sound engines.

### 3. PLAYING TECHNIQUES

An instrument designer may have certain ways of playing in mind during the design process, but specific details of the design and implementation often lead to unforeseen ways to play it, e.g., the extended techniques of contemporary instrumental music, or circuit bending of existing instruments. In this section I describe the primary playing techniques, and a number of auxiliary techniques that have emerged from extensive practice and performance. What each playing technique actually does depends on the current sound engine and how the tapped voltages are applied to modulate it, i.e., the current mapping. Since this can be very different, even within one performance, as several sound engines often are played at once or alternated, I try to describe the playing techniques in terms of abstract parameter changes, and not in terms of sonic changes. Also, since this is an instrument primarily for improvisation, it is good to have an understanding of what different techniques do on an abstract level. They can then be applied at will, depending on musical context and configurations on the playing surface.

The primary design idea of the Pencil Field interface is to be able to produce a number of voltages, affected both by the positions of the supply electrodes, which define the electric field, and the positions of the tap electrodes, which “read” the voltage at a certain position. This sounds simple, but can be done in many different ways, producing various kinds of gestures, involving just one voltage, or a few, or all of them.

**Tapping from the field.** The simplest case is to place the - and + electrodes on each side of a uniform pencil field, and move the taps with the fingers (a clear example in video B, at 1’00”). If a tap is closer to +, it will give a higher voltage, and naturally, proximity to - will give a lower voltage. The resolution is not uniform in a 2D field, as shown in Fig. 3. The voltage change increase close to the supply electrodes. Musically, this is convenient, since small expressive changes can be performed with great precision in the middle, while sudden wild gestures can be played by quickly moving the tap closer to one of the electrodes. A number of taps can be moved easily with one hand, since they are designed to fit nicely under the tip of the fingers.

**Scaling and shifting the field.** A group of parameters can be *scaled* by moving the + and - closer or further apart. In the same way, they can be *shifted* by moving both + and - in the same direction. These two actions can be combined – and simplified – by moving just one supply electrode away from or towards the taps. Then they will be simultaneously

Bugbrand modular.

<sup>4</sup>See <http://bugbrand.co.uk> for more information on the

shifted and scaled. An extreme example of this is when one supply electrode is moved very far away on a thin stretch of pencil, a tail, as the one to the left in Fig. 4. The narrow shape makes it work more like a linear voltage divider, and moving the - electrode out to the end of this tail pushes all the other voltages up towards their maximum value (video A, 2'50", video B, 3'25").

**Rotating the field.** By moving + and - around the taps in a circular motion, the whole field can be rotated, causing out-of-phase wave-like changes in all taps. A simpler version is to just move for example + around a group of taps, with - in a distance. This causes a sequential series of peaks in the taps, usable for swirly musical gestures.

**Warping the field.** The field can also be *warped*, in various ways. By warping I mean changing the distribution of voltage potential away from the standard dipole field, as shown in Fig. 2. This can be done by placing the 0V electrode somewhere on the playing field. Then this point is forced to ground (0V), and the field around it adjusts to this. Taps near to the 0 electrode will be scaled towards 0V, and by moving it around on the field, different taps can be affected. Electrodes placed close to - or + are affected the least.

**Jumping the field.** So far we have dealt with continuous changes. But since the field relies on steady contact with the supply electrodes, it can be abruptly changed in a number of ways. Easiest is to lift either + or - from the paper (video B, 3'55"), or slide them quickly out of the pencil field, to an empty part of the paper. Lifting gives a very sudden change in the field, and all voltages are suddenly shifted towards the remaining pole. Sliding off gives a fast but smooth transition. Single taps can also be lifted to create a jump in the specific parameters controlled by it.

**Ladders.** Rhythmic and periodic gestures can be created by drawing a ladder pattern on the side of the field, basically a series of tails, as can be seen to the right in Fig. 4. If a group of taps are placed just to the left of the ladder and the + is moved back and forth over the ladder, rhythmic changes are created (video A, 7'00", video B, 7'10"). A single tap can also be moved over the ladder, to induce a rhythm in only one tap.

**Shorting.** Another way to jump values is to create short-circuit connections between different electrodes, by making them touch each other. This can be done by lifting one of them and placing it on top of the other, or by sliding them towards each other on the surface. A particular tap can instantly be brought to its maximum or minimum value by shorting it with one of the supply electrodes. This has often been used to create sudden timbral changes and "events" in the music (video B, 1'30", 7'35"), or to mute sounds. The ground electrode can in a similar way be used to bring any tap to 0V. Any of these actions will also change the field, since the tap electrode being shorted is connected to the field. Hence, nearby electrodes will also be shifted by the shorting. A number of electrodes can also be bunched together on the playing surface, shorting them to each other. When several electrodes are shorted to each other, the metal electrodes bypass the underlying pencil resistor, so that the field is collapsed underneath, affecting nearby taps. This is also an example of *warping*. It is also possible to collapse the field partially, by shorting + to 0, or - to 0. Then all taps will be shifted to one half of the range. Finally, the whole field can be totally collapsed by shorting + and -.

**Body contact and pressure.** As is well known from many circuit bending instruments, the human body conducts electricity, but the skin resistance is quite high. It is greatly reduced by moistening of the skin. In the Pencil Field interface, this effect is often noticeable, and can

be used to the advantage of the musician. For example, I can touch the + electrode with one hand, and lightly touch other electrodes in a rhythmic pattern. Their voltage will increase a little when I touch them, and this often is clearly audible. Also, the contact between the electrodes and the pencil markings can be improved by applying pressure to the electrodes. In this way, electrodes can be played as keys, while keeping them stationary on the field. This effect is subtle, just like the skin touch, but both can be used musically (video B, 5'33").

**Electrical disturbance of the field.** It is possible to induce fluctuations in the voltage field by, e.g., adding a supply electrode directly from a gestural generator such as an LFO (low frequency oscillator). This has been used, e.g., to add flutter and graininess on top of steady drones. Different effects are achieved if the active disturbance is induced directly to different electrodes, or to an empty spot on the pencil field.

**Theatrical/conceptual playing techniques.** A few more performance-oriented techniques have emerged while preparing for performances, and sometimes during the performances, as part of the improvisation. This kind of playing techniques could be dismissed as mere gimmicks, but they work very well in a live situation, especially an intimate one with the audience near the performer. I have often left all the electrodes on the surface and tilted, hit or shaken the pad, to randomize the positions of all electrodes. Repeatedly doing this on a continuous sound structure becomes like a series of mutations, each time changing the sound a little bit. I also often shuffle around all electrodes with my hands, and see where they end up, to inject radical indeterminacy into the improvisation (video B, 2'55").

Picking up and dropping electrodes is visually and sonically rewarding. It is a very clear gesture, and causes large sudden jumps in parameter values. They might even bounce on the paper, with a corresponding bouncing effect in the sound. An example can be seen in video A (11'35").

The springiness of the electrode cables sometimes prevent them from staying in place where I want them. This creates an audible and visible "self-playing" gesture as the electrode slides on the pencil field. This is difficult to prepare, but can be picked up and used to great effect when it happens spontaneously (video A, 6'05").

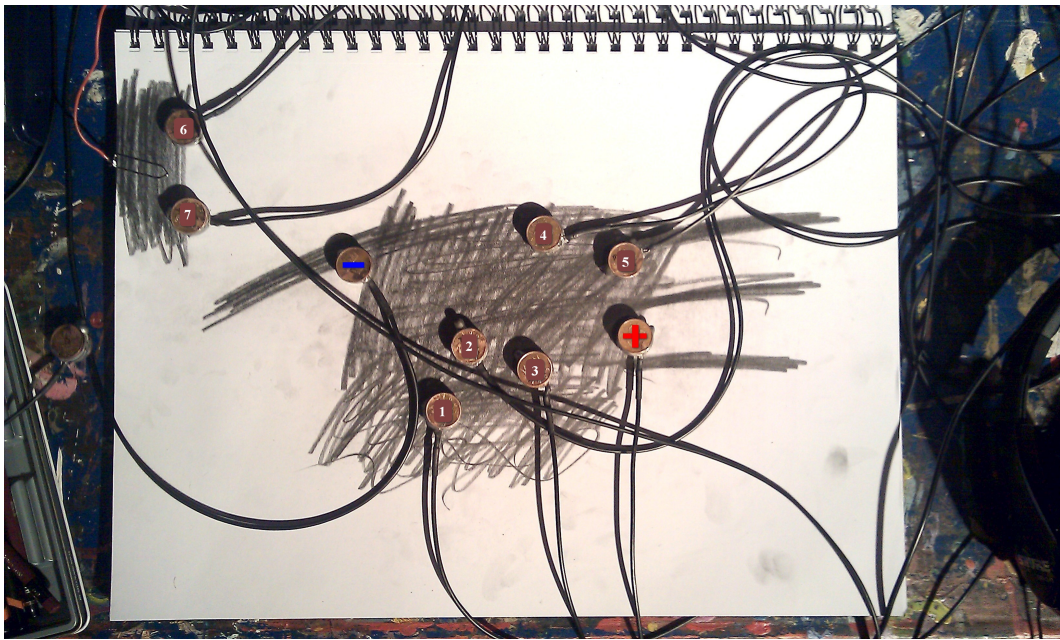
Finally, I try to build little towers with the electrodes. This might seem far-fetched, but is physically encouraged by the cylindrical shape of the electrodes. When doing this, the electrodes short each other as I pile them, creating lots of clear jumps in the voltages, with audible result and an interesting connection to what is seen. But the tower always falls because of the heavy cables, and I immediately try to build it up again. This struggle can go on for a while, and works very well with the audience, is rewarding to perform, and is sonically interesting (video A, 4'50", video B, 4'55").

### 3.1 Visualization of output gestures

An example of the actual voltage contours that are produced from the system is shown in Fig. 5. The graph shows a very brief performance (15 seconds) with only 5 tap electrodes, but still shows the different kinds of gestures that can be produced. A video of the playing that produced the graph is available online.

## 4. DISCUSSION

The pencil field is essentially a 2D interface, but because of its design, it differs a lot from other 2D interfaces. For example, most multitouch surfaces cannot distinguish between the fingers that touch them. Hence, it is difficult to



**Figure 4:** A typical setup of the Pencil Field playing surface in a concert situation. The + and - electrodes create a potential field in the pencil carbon surface, and electrodes 1-5 tap voltages from this field. E.g., electrode 5 would give a positive voltage because it is closer to the + electrode. Electrode 6 and 7 are placed on a separate pencil patch directly connected to +9V through a paper clip. This is a technique sometimes used to control volume parameters, separate from timbral parameters. Electrodes 1-5 can be freely moving around, while keeping the volume of two sounding structures steady in this corner (see video A, 5'40" and onwards for an example).

create a digital model of the pencil field. You can grab and move around graphical symbols, but the tactile feel of moving around real objects is hard to beat. The mapping of the field is dynamic, i.e., dependent on the current placement of the supply electrodes. Also, the physical design of the interface allows for a number of auxiliary playing techniques, as outlined in the previous section. This makes it very rewarding to play.

The directness and complete lack of lag is rewarding, and makes it feel like interacting with a physical object. This resonates with the need for intimacy between gestural controller and sound generation, as emphasized by Wessel et al [Wessel et al. 2002]. Also, everything you do with the electrodes and on the pencil field has consequences, just like when playing an acoustic instrument. There are no neutral gestures, and there is strong inter-dependence between the elements of the interface, which makes it feel like a whole. Like in acoustic instruments, it is not a one-to-one mapping [Hunt and Wanderley 2002], but many-to-many. Any combination of parameter values can in theory be achieved, but it is not a matter of adjusting them one by one. You do not control a number of independent parameters. You play an instrument, using your fingers and your ears. These physical inter-dependencies between the parameters force you to find simple and elegant solutions, and to respond directly to what you play. You have to play with big ears, and be ready for the unexpected. It is a challenge, also for the experienced improviser.

The whole construction is dirty (literally) and involves very basic materials, such as carbon, copper and paper, which is also a welcome change to the sometimes sterile world of electronic music.

The interface has some weaknesses. The control signals from the tap electrodes are sometimes noisy, and sometimes there is bad contact to the pencil markings. Also, the pen-

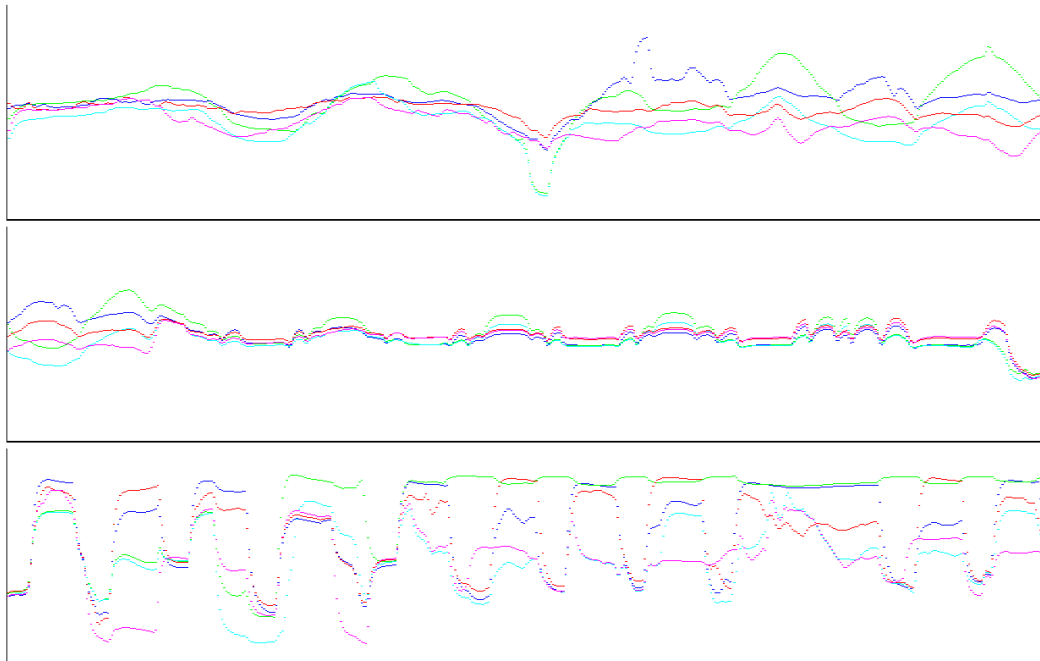
cil markings wear out pretty quickly, since I'm using very soft pencils, for better conductivity (lower resistance). The playing surface has to be redrawn for each performance or rehearsal. But these weaknesses can also be regarded as strengths, and are essential to the kind of performance that has developed around this interface. Noise and minute variations make the sounds animated and less predictable. Bad contact forces you to be careful and make the sound engine robust. In a solo improvisation, sudden unexpected changes can be regarded as creative input from the instrument, just like the input from a fellow player injects new material into a duo improvisation. The redrawing of the pencil field has become part of the performance, and is visually and theatrically rewarding. Features, such as ladders and tails, are added as the improvisation calls for them, and even the sharpening of the pencil becomes a performance act, with contact miked and amplified sharpener providing interesting sounds to the mix.

Further performance elements include contact microphones under the paper, used to amplify the sounds of drawing. Also, if the electrodes are left on the pencil field while drawing, the slight movements of the paper are transferred into the synthesized sound.

Obviously, the audience should see all this clearly. For some concerts in intimate spaces, people have been so close so that they clearly see what is happening, even if they do not understand the inner mechanics of it (just like most people do not know the inner workings of, e.g., a trumpet). In other cases, a camera and projector have been used, showing the performance area on a big screen behind the performer.

#### 4.1 Future development

There are a number of things with this interface that can be improved, and a number of possible applications of these ideas that have not yet been tested. For example, it is tech-



**Figure 5:** The voltage outputs of a short session on the pencil fields interface. In this example, the + and - electrodes were used together with 5 tap electrodes. The graph shows 15 seconds and is captured from the session shown in this short video: <http://vimeo.com/36385389>. The first row shows some simple movement of the taps between the + and - electrodes. In the end of the first row, the + and - are rotated back and forth around the group of taps, visible as alternating simultaneous up and down gestures. In the middle row, a ladder and a tail is used to create fast rhythmic patterns. The third row shows some short-circuit playing.

nically possible to use the pencil field to scale and treat sound signals instead of DC currents. The resistive properties of the graphite can be used as part of a summing mixer, where distance would regulate relative volume.

And maybe most interesting, the full potential of the drawing medium has not yet been explored. Figurative drawing combined with the pencil field interface could allow for a new mix of story-telling and musical performance.

## 5. CONCLUSIONS

While I have concentrated on live improvisations using the Pencil Field, musician Richard Quirk at Isle of Man, was given access to the same interface, and he has developed his own way of using it, only aided by a brief introduction by me. I want to conclude with a quote from him:

*“The pencil-field provides a linked source of voltages that encourage fluidity. The process of drawing the roadmap for the coins is in itself a stretching exercise that helps the mindspace to be ready to create. I was not expecting this focus point, as one of the problems I have frequently had with modulars is where to start with something that can be as open-ended as your imagination allows it to be. My mind was free to seek pathways within the modular as the graphite pencil etched out a framework. .. The coins can be stacked with increasing random results as the pos/neg coins are added, touched together momentarily for staccato voltage spikes or rubbed slowly for vibrato when controlling oscillators. Collected in separate clusters like constellations till fingers collide. Moving the coins in a looped pattern, the equivalent of a blues riff. “*

## 6. ACKNOWLEDGMENTS

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