

Not Hyper, Not Meta, Not Cyber but Infra-Instruments

John Bowers
School of Music
University of East Anglia
Norwich, UK
+44-1603-592452
j.bowers@uea.ac.uk

Phil Archer
School of Music
University of East Anglia
Norwich, UK
+44-1603-592452
o_k_boy@hotmail.com

ABSTRACT

As a response to a number of notable contemporary aesthetic tendencies, this paper introduces the notion of an infra-instrument as a kind of 'new interface for musical expression' worthy of study and systematic design. In contrast to hyper-, meta- and virtual instruments, we propose infra-instruments as devices of restricted interactive potential, with little sensor enhancement, which engender simple musics with scarce opportunity for conventional virtuosity. After presenting numerous examples from our work, we argue that it is precisely such interactionally and sonically challenged designs that leave requisite space for computer-generated augmentations in hybrid, multi-device performance settings.

Keywords

Infra-instruments, hyperinstruments, meta-instruments, virtual instruments, design concepts and principles.

1. INTRODUCTION

Since 2001 the NIME series of conferences has seen the presentation of a wealth of interface and instrument design ideas. Uniquely at the intersection of the musical and the techno-scientific, much work reported to NIME has combined design innovation with practical playability and no little humour. Our current paper wishes to deepen this vein of playful yet practical musical design by naming an approach which we feel has been under-investigated to date: we seek to encourage the construction of what we call *infra-instruments*.

Let us introduce this concept, and connect our paper with existing literature, through a comparison with such notions as hyperinstruments, meta-instruments and cyber- (or virtual-) instruments. Although there are differences in emphasis, it is the common themes between these overlapping terms which will serve to initially ground our alternative orientation to instrument construction and musical performance issues.

Tod Machover [7] writes: "The technology we developed for this opera project [VALIS] came to be called 'hyperinstruments'. By focusing on allowing a few instrumentalists to create complex sounds, we continually improved the technology and reduced the number of actual musical instruments. The resulting opera orchestra consisted

of two performers: one keyboard player and one percussionist. They controlled all the music for the opera, and almost all of it is live... [To build effective hyperinstruments] we need the power of smart computers following the gestures and intentions of fine performers". It is clear from these passages that the hyperinstrument concept is bound up with the expansion of human capability at the musical interface. Indeed, just two musicians can serve orchestral duties in the production of something as ambitious as an opera, and do this live, before the audience's very eyes. As Machover hints at the end of the quote, initial work on "classic" hyperinstruments was to do with enhancing the capabilities of already virtuosic performers. Since the early 1990s, however, the Hyperinstruments Group at the MIT Media Lab has enlarged its remit to bring hyperinstruments to the masses through, for example, musical toys for children and devices requiring no pre-existing traditional instrumental competence. The hyperinstrument influence is a powerful one in the emerging NIME literature with, for example, [12] and [13] connecting their innovations to the concept.

Following Greek etymology, the difference between something hyper (above and beyond) and something meta (among and besides) should be quite large but, in practice, both the Machover-Ma hyper-cello [7] and Jonathan Impett's meta-trumpet [6], for example, involve enhancing a traditional instrument with various sensors to enable features of the gestural activity of performers to control augmentations of the existing instrumental sound. In Impett's meta-trumpet, amongst other sensors, Polhemus devices capture its position and orientation and enable these, suitably remapped, to serve as controllers for material derived from live sampling the trumpet. Sensor-based augmentations of instruments are common in NIME with [3] and [9] being just two examples.

Axel Mulder's [8] notion of a virtual musical instrument (VMI) arises from a comparison of acoustic (e.g. violin) through electroacoustic (e.g. electric guitar) to electronic (e.g. synthesizer) instruments. In this development, he detects a progressive decoupling of the physics of human gesture from the physics of the sound making mechanism. He also notes that attempts to model electronic instruments on the basis of acoustic instruments are often found to be inadequately expressive. From these observations, he argues for VMIs as instruments not based in any literal way on existing physical instruments but as "gestural interface[s]... to provide a greater freedom in mapping movement to sound", in particular, as interfaces to virtual physical sound-models. In an extreme case, the performer may be "empty handed" with movement tracking data, rather than any contact events, providing the means to interact with a VMI which mediates between gesture and sound synthesis. Talk of the virtual suggests a connection with Virtual Reality (VR) and numerous attempts to exploit features of 'immersive' 3D computer graphics to construct

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

Nime '05, May 26-28, 2005, Vancouver, BC, Canada.

Copyright remains with the author(s).

musical instruments and interactive sonic environments exist, see [10] for a review and [2] for a relevant NIME contribution.

Although the details of these proposals (and of specific projects conducted in their terms) sometimes differ, we can identify a number of recurring themes.

- *Rich interactive capability.* Hyper, meta and virtual instruments enable you to do a lot. Two players can substitute an orchestra. Meta-trumpeters can incite swarms of sound processing Alife agents (as in Impett's latest work).
- *Detailed performance measurement.* This enrichment typically requires many and varied gestural measurements through tracking or enhancing instruments with sensors.
- *Engendering of complex music.* The target, even if for just demonstration purposes, is commonly the production of complex musical textures live. Forms which are loosely symphonic, orchestral or operatic provide the asymptote.
- *Expressivity and virtuosity.* Meta-instruments and the rest are commonly made with virtuosic and highly expressive performance in mind. This is typically the case when a musician devotes attention to the augmentation of an instrument they may already have considerable competence with, or when a designer notes frustrations with traditional designs, or, if expressive participation in music is to be made more accessible. The concern for widespread participation in music and an interest in enhancing virtuosity are not necessarily exclusive and the hyperinstrument concept is often intended to cover both.

2. THE IDEA OF AN INFRA-INSTRUMENT

While the four tendencies we have just noted plot a characteristic position in the 'design space' of new instrument construction, they do not map its entirety. We feel that the research agenda of NIME includes but extends well beyond these percepts. To bring this into focus, let us note some currently influential tendencies in musical aesthetics.

There is considerable interest in lo-fi music and 'circuit-bending', to use Q. Reed Ghazala's phrase [11], or 'hardware hacking', to use Nic Collins' [4]. Sometimes such endeavours yield quite complex interfaces but more often the aesthetic pleasure and technical interest of a good hack comes from its simplicity and appositeness. Reed Ghazala may well add switches and sensors to, say, a circuit bent Casio SK-1 sampler but these will be lower in number than the count of gestural degrees of freedom typically measured in a VMI construction.

In the world of improvisation at the moment there is interest in forms of music sometimes (and controversially) named 'reductionist'. In part as a reaction to busy, dense, complex improvised musics, including the ready-to-hand complexities possible in laptop performance, some are seeking very pared-down forms. Toshimaru Nakamura's work with his 'no input mixing board' (see www.japanimprov.com/tnakamura), for example, is typically static, very calm gesturally, and sometimes outside the range of human hearing.

It is in recognition of these tendencies in musical aesthetics, and the contrary orientations towards technology and interaction that they sometimes express, that we formulate our idea of an infra-instrument. Provisionally, let us take an infra-instrument as being dedicated to the opposite of the tendencies we noted earlier. Infra-instruments support:

- *A constrained interactive repertoire* (there will not be so very much you can do)...

- Through the deployment of *few sensors* or making *few gestural measurements* (or just allowing the mechanism or circuitry to be directly engaged with or run free)...
- To *engender relatively simple musics* (or at least ones which are non-symphonic, non-orchestral, non-operatic) performed in manners that are...
- *Restricted in their virtuosity and their expressivity* (at least in terms of romantic aesthetic construals of those matters)...

but are nonetheless aesthetically engaging and technically intriguing for all that. It is infra-instruments as a design concept which the rest of this paper seeks to explore and exemplify, and give a preliminary evaluation of.

2.1 Making Infra-Instruments

To explicate our notion of an infra-instrument let us describe some of the ways one might go about constructing one.

- *Take an Instrument and Make it Less.* Break an existing instrument (irreversible procedures) or restrict its operation and/or how one interacts with it (reversible procedures).
- *Take Materials Partway to Instrumenthood.* Instruments are typically assemblies of multiple components and different materials. Do not go all the way in making a complete integrated, rigid construction. Investigate temporary assemblies of stuff. Leave the case off.
- *Build an Instrument but Include Obvious Mistakes.* Like selecting fresh vegetables as the material for construction (see The Vegetable Orchestra, www.gemueseorchester.org), encouraging fret-buzz or loosely winding pickups to enhance microphony. Hopkin's books on instrument construction [e.g. 5] are excellent resources for infra-instruments if properly misread.
- *Take Something Non-Instrumental and Find the Instrument Within.* A DTMF phone dialer can be regarded as an infra-synthesizer, a Geiger counter as infra-percussion, and so forth. The percept here is that the instrument you find within something conventionally non-instrumental is likely to be an infra-instrument.
- *Find Infra-Instruments Readymade.* In contrast to the above, here we have in mind instruments which already are infra in status, at least in the minds of aesthetic snobs. This would include many musical toys or musical boxes and other 'amusements'. One might also want to argue that historical 'rejects' fit here, the antecedent forms of modern instruments which have fallen by the wayside. Bits and pieces of stuff which sound nice just as they are might be readymade infra-instruments awaiting recognition as such.

3. SPECIMEN INFRA-INSTRUMENTS

Having introduced our concept by way of contrast with other notions, and sketched the ways design might go with this concept in mind, let us now provide some examples of infra-instruments from our own work. We proceed by looking at, to use the jargon, infra-chordophones, followed by infra-electrophones, then infra-idiophones before discussing how to put it all together (infra-mixers). Our intention in selecting these examples is to illustrate our concept of an infra-instrument. We do not necessarily select them because they are the best things we have built. Nor, *singly*, do they manifest much in technical innovation. The research value we hope to offer you is by means of the interest of our overall design concept of infra-instruments and the consequences for the NIME research agenda that this concept might have.

3.1 Broken and Re-Built Violins



Figure 1. The bow-stab infra-violin.

Atonement for Violin Quartet (by John Bowers, first realisation at the Norwich Gallery, UK, 2004) is a combined installation-performance-webcast work which revisits the instrument destruction preoccupations of the Fluxus artists. *Atonement* specifically builds upon Nam June Paik's 1962 work *One for Violin Solo*. In *One*, a violin is slowly raised above the performer's head and then brought down suddenly upon a table-top. *Atonement* continues the action by re-building the broken violin and, indeed, over four days, repeats this ritual four times to create a quartet of refashioned instruments. The performance of a quartet composition completes the work. *Atonement*, in our terms, involves the transformation of violins into infra-violins. The broken bodies of the violins are difficult to use for good string tension. Other sonic possibilities have to be sought in the strings: lengthwise scrapings and low-tension thunks for instance. The broken shards present percussive opportunities with perhaps violin bows becoming beaters or scrapers. Figures 1 and 2 depict two different styles of infra-instrument building from fragments of broken violins.



Figure 2. The splinters-on-a-string infra-violin .

3.2 Monochords, Zithers, Guitars

The Strandline guitar (see Figures 3 and 4) has a pickup, a whammy arm, and steel strings. All of its other components are objects found at the strandline, the area of a beach at the high tide marking where sea-borne detritus gets deposited. Notably string tension is achieved using pebbles which have eroded to have a hole in the middle, the string being knotted around the

pebble, and the pebbles left to hang over the edge of a table. Of course, the pebbles provide inadequate weight for a coherent pitch to be heard on plucking. Indeed, furious one handed use of the whammy arm is commonly preferred to plucking, the swinging of the pebbles leading to string tangles, slippages and scrapings against the pickup, all contributing to a characteristic sound when amplified. Spring reverberation can be added to underline the surf guitar inspiration of the design.



Figure 3. The Strandline guitar (front), The Tone Arm Bandit (record deck tone arm and processing, left and middle, not discussed here).



Figure 4. The Strandline guitar (detail).

In contrast to the Strandline and the infra-violins, we have built string instruments with a string tension adequate for coherent pitch. However, other features of the design suggest the infra status of the instruments. In many respects a monochord can be thought of as one of the earliest infra-instruments, the infra-instrument of choice for Pythagoras certainly. The purity of the monochord can be nicely corrupted by the use of a movable bridge pickup to divide the string length in two. While positions for the bridge pickup can be found where Pythagorean ratios obtain between the string segment lengths, we prefer dissonant relationships when a little more 'fuel' is required for live processing and sound transformation. Our four string zither design also has a movable centre bridge but this time we employ pickups at either end. This means we can conventionally amplify the vibrating string segment over the pickup or obtain 'behind the bridge effects' like those associated with Hans Reichel and Glenn Branca's guitar constructions [see 5]. A rewired stereo volume pedal serves as a foot-operated cross-fader to mix

these effects. In terms of pitch selection, the zither has just eight notes at most. However, this constraint enables other (spectral) possibilities to become the focus of exploration.

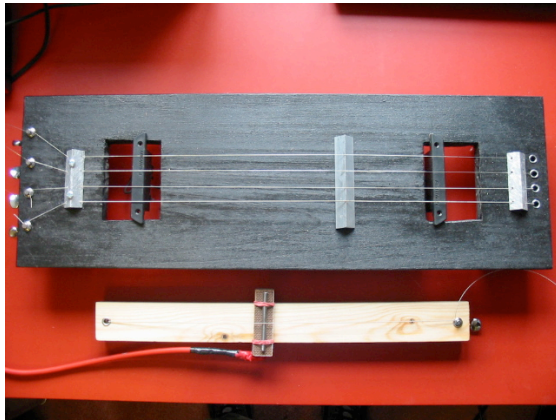


Figure 5. Monochord below a double-ended electric zither .

3.3 The CD Player Slide Guitar

Various essential elements from a CD player and an electric guitar are combined to create an instrument with the rich tonal and expressive possibilities of neither. The motor-driven sled, which would typically determine the playback position of a CD, has its laser replaced with a metal 'slide' which governs the pitch of a single guitar string plucked by an electric motor.

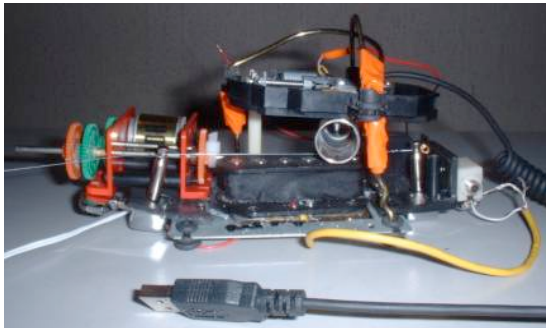


Figure 6. The CD Player Slide Guitar.

The CD player sled motor is connected to that of a second, fully functional CD player set on 'random play', while the plucking arm motor is powered by a hacked USB cable. In this way the position of the slide on the guitar string is directly related to the playback position of the accompanying CD. We have found that the actual voltage delivered over USB on some computers is sensitive to the machine's CPU load. Accordingly, we can influence the plucking motor's speed by forcing bogus computations at the other end of the USB cable.

Sonic interest arises from the interconnections of these simple devices, as the various motors and power sources are mutually influential with unpredictable interactions and interferences. The physical surface of the CD is also prepared with clear tape and ink [cf. 4] to cause further irregularities in playback (and hence slide position), the resultant musical structure deriving from the (ir)regular functioning of the devices themselves.

3.4 The Victorian Synthesizer

The Victorian Synthesizer is an ongoing project to construct a synthesizer using methods known to the Victorians but which,

nevertheless, has some of the features and sound generation and shaping units associated with more modern instruments. It is this collision of contemporary concepts and aspirations with outmoded means that creates the Victorian infra-synthesizer as an imagined historical reject.

Generally, the Victorian synthesizer needs to be electro-mechanical rather than electronic, manual rather than voltage control is typically required, and some synthesis units will present especial challenges. Oscillators constructed through feeding back the output from amplifiers are, for example, post-Victorian inventions (c.1920 by Barkhausen and Kurz). Accordingly, we make the most of electro-magnetism (an 18th century discovery much celebrated by the Victorians) and the minimum of circuitry.

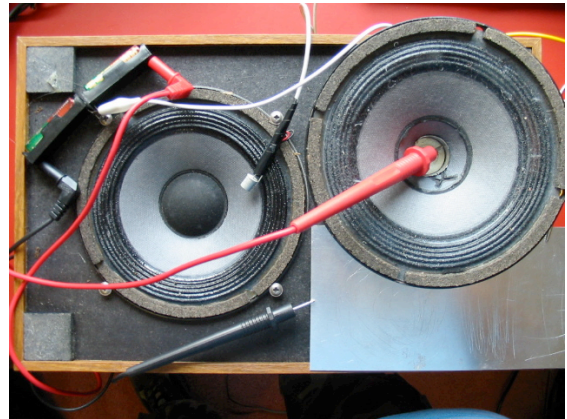


Figure 7. Battery-driven loudspeakers.

Our initial, most primitive, most infra, constructions involve directly driving a loudspeaker with a battery. We make and break the circuit with a switch or two bare wires to create impulses and square waves as the speaker cone jumps around. This basic design can be enhanced by introducing a textured metal plate (see bottom right of Figure 7) over which a probe (of the sort used in test equipment) can be scraped to make the circuit. As the probe varies in its contact with the plate, an uncannily good rendering of the surface texture can be heard from the speaker, regular textures producing regular 'waves'. The use of two probes and two batteries (wired to associate the probes with opposite polarities) enables the speaker cone to flex both in and out. While drawing the probes across textured conductive surfaces creates manually controlled infra-oscillators, we have had success with various methods requiring less intervention. For example, a mercury switch can be introduced into the circuit and rested on the speaker cone (see the speaker on the left of Figure 7). As the cone moves in and out, the switch makes and breaks creating a feedback loop which will give a form of self-oscillation, at least for a while. Under certain circumstances, feedback and self-oscillation can also be created by touching the moving metal band attached to the speaker cone directly with a probe (see right of Figure 7).

3.5 Home Keyboard, De-Housed

Here, a Yamaha Portasound keyboard, perhaps already an infra-instrument to some, is opened up and played with 'restricted technique'. The device's lower casing is removed to expose the circuit-board, then the inverted instrument is placed on the performer's lap and played by making connections between components on the board with a stripped piece of wire.

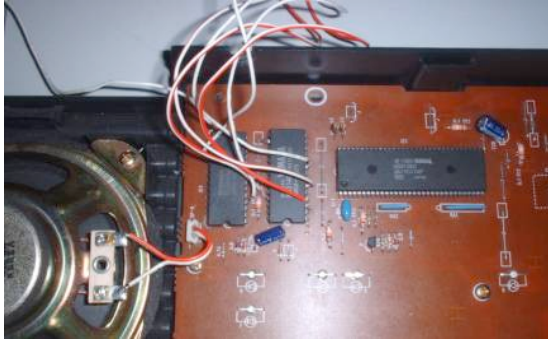


Figure 8. A De-Housed Home Keyboard.

These connections induce tones, bursts of noise and corrupted 'auto-accompaniment' sequences which are unpredictable in their details but generally 'steerable' with practice. The precision afforded by the standard keyboard interface is eschewed in favour of direct contact with the circuit, and the performer is continually forced to rethink and re-evaluate their engagement with the instrument in light of the sonic results.

3.6 Percussive Printer

In this example the two primary motors essential to the operation of an inkjet printer (paper feed and print head position) are extracted from the housing and repurposed for musical goals. Divorced from their initial functionality, the motors are built into small mechanical percussion instruments constructed from other writing implements.

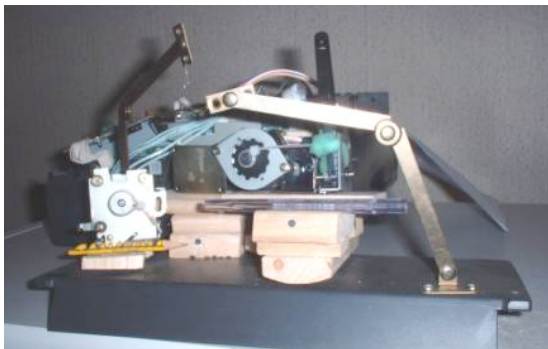


Figure 9. Percussive Printer.

The first motor causes a ball-point pen to strike a piece of wood, bouncing until it comes to rest, while the second drives a guiro-like device constructed from a pencil and a cable-tie. The instrument, an infra-percussion kit, is played as it would be utilised in its everyday incarnation: a text file is sent from a computer causing the motors to move as if printing the document. Instead of a page of text, this 'score' produces rhythmic material relating to the horizontal and vertical position of the characters as well as the density of the text.

3.7 Max Plank and The Mixing Bowl

We have created a number of infra-mixers designed to combine sound sources (perhaps other infra-instruments) and/or variably distribute sources to destinations. Our approach has involved creating a circumscribed 'micro-environment' in which sound makers (including loudspeakers) and sound transducers (microphones, contact elements, pickups) can come together and be directly manipulated. A crude example instantiating a culinary pun is The Mixing Bowl (Figure 10) in which vibrating devices (including two wiggly pen-toys)

bump up against piezo-elements and microphones of varied quality, or electro-magnetically interact with guitar pickups.



Figure 10. The Mixing Bowl.

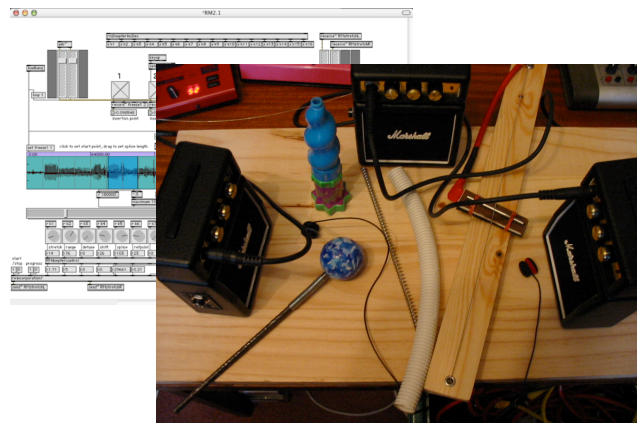


Figure 11. Max and Plank. Max Plank!

A more sophisticated design is Max Plank, a plank of wood designed as a physical mix surface as well as a controller for patches running under Max/MSP (™Cycling74). Small amplifier-loudspeakers (here three half-watt Marshall MS-2 combos) can be directly manipulated and positioned on or near the wooden surface. On top of the surface are also two small omnidirectional microphone capsules and the monochord described earlier, as well as various beaters, scrapers and vibrators. Beneath the wood are two strips of piezo film which act as contact microphones for any surface-contact activity. A Max/MSP patch analyses the relative amplitudes from these two piezos to gain an impression of the distribution of sonic activity across the surface. Statistics describing this distribution are mapped as controllers for patches which process the sound picked up by the small capsules and the piezo films. In this context, we have successfully used Max/MSP patches for pitch shifting, brassage, granularisation, and other processing techniques.

This all creates an extremely flexible and lively performance environment. Sounds can be mixed through the surface (and filtered through the wood) by placing loudspeakers. Moving the loudspeakers affects the distribution of sound on the table and hence how the processing is controlled. Sound from the loudspeakers can be mixed through the wood or, by holding a loudspeaker above the surface, only routed to the small omni-capsules. The wood surface itself can be struck or scraped to

yield percussion sounds or to influence how the processing takes place. Figure 11 shows the monochord resting on top of the plank. This creates a greater acoustic resonator for its string and a larger responsive surface for its bridge piezo. This can be most spectacularly exploited by amplifying the bridge piezo through one of the mini-loudspeakers. Feedback can be controlled by placing or removing the loudspeaker and, on a good day, its pitch varied by adjusting the area of contact between monochord base and plank.

4. DISCUSSION

We have presented our notion of an infra-instrument through contrast with hyper-, meta- and (to keep consistency of Greek prefixes) cyber-instruments (though we know full well that cyber should not be equated with virtual on etymological grounds). Infra-instruments come from beneath and are below the standards we would want of well-constructed instruments. However, we believe that infra-instruments are a valuable addition to the NIME research agenda with its concern for technology, musical practice and playful aesthetics.

Infra-instruments have strongly featured in performance and composition work by ourselves and others. For example, based on the work described here, Nic Collins has composed a piece *The Bowerbird* in which several individuals each armed with a loudspeaker and battery make ‘Victorian synthetic’ sounds from all around a concert hall. The first author typically improvises with an ‘assembly’ of infra-instruments, synthesizers and computer-based transformations. The second author is concerned to use infra-instruments to explore the hinterlands between improvisation and composition, performance and sound sculpture, the digital and the electro-mechanical. On the basis of this experience, we would like to make some preliminary evaluative claims.

- *Usability.* In many respects, it is not hard to use an infra-instrument as they do not do very much and what they do is usually simple. Some merely require starting up and a little maintenance. Also we have often preferred methods of direct physical interaction with our infra-instruments and, in one of the cases where we have discussed interfacing to software processes, we have noted the value of having a direct manipulation method for sound mixing (this isn’t really an interaction ‘metaphor’ here as one really is moving sound makers around). None of this means, of course, that practice doesn’t improve things. Indeed, intuition acquired over the years has been especially useful for homing in on...
- *Emergent interactions between components and devices.* The possibilities for feedback between the amplified monochord and Max Plank were discovered in the course of an improvised performance. Looking out for interactions between things can readily become part of the business of performance because components are more accessible in the ad hoc or half-built construction that is an infra-instrument.
- *Infra-instruments, technique and virtuosity.* Rather than a virtuosity based on ‘extended technique’, infra-instruments are concerned with supporting a more mundane, prosaic yet honest practice. It is a virtuosity of restricted technique, or bricolage, if you will.
- *Infra-instruments and sonic augmentation.* The live computer-based transformation of instrumental sound is a common format for contemporary electro-acoustic music. Much work on meta-instruments and the rest falls naturally within this interest. However, improvisations and compositions in this format can run into problems of

spectral-temporal complexity. Traditional instruments are often already timbrally very rich, so the computer-based multiplication of this richness can sometimes be excessive, especially if a virtuoso instrumentalist is having a good workout. Infra-instruments, precisely by virtue of their producing degenerate or simplistic tonalities, can work very well with live processing or computer-derived parts – more spectral-temporal latitude is available for augmentation.

- *Infra-instruments, interaction and ‘assemblies’ of performance technology.* If you have a bunch of stuff before you in performance, it makes sense if some of those devices are dumbed-down-reduced-restricted in the demands they make on you. The restricted techniques involved in interaction with infra-instruments often enables a hand to be kept free for other purposes – more interactional latitude is available for engaging with other devices. Important to both authors’ performance aesthetics is the juxtaposition of devices which vary in technical idiom (acoustic, mechanical, electric, electronic, digital) [1]. Handling an assembly of stuff is often facilitated by an infra-instrument design philosophy, where each device plays its part in a manageable hybrid environment. Indeed, this is where infra-instruments come into their own and, ultimately, where we would wish our design notions to be evaluated: to the extent that they engender playable and engaging *performance settings* [1]. The whole performance setting becomes the unit of analysis, design and evaluation, not just a single ‘new interface for musical expression’. Our positing of infra-instruments is a rhetorical move in a general argument for that position.

5. ACKNOWLEDGMENTS

We thank the UK’s Engineering and Physical Sciences Research Council for granting a Research Fellowship to the first author, and Nic Collins for divine inspiration.

6. REFERENCES

- [1] Bowers, J. *Improvising Machines*. ARIADA 4. Available at: <http://www.ariada.uea.ac.uk/ariadatexts/ariada4/>.
- [2] Burtner, M. Composing for the (dis)embodied ensemble. *Proceedings of NIME 03*, Montreal, Canada 2003.
- [3] Burtner, M. Noisegate 67 for metasaxophone. *Proceedings of NIME 02*, Limerick, Ireland 2002.
- [4] Collins, N. *Handmade Electronic Music: The Art of Hardware Hacking*, London, Routledge, expected 2006.
- [5] Hopkin, B. *Musical Instrument Design*. See Sharp Press, Tucson, Arizona, 1996.
- [6] Impett, J. A Meta-Trumpet(er). *Proceedings International Computer Music Conference*. Aarhus, Denmark, 1994.
- [7] Machover, T. ‘Classic’ Hyperinstruments. Available at: <http://brainop.media.mit.edu/Archie/Hyperinstruments/classichyper.html>.
- [8] Mulder, A. Design of virtual instruments for sound control. *PhD Thesis*, Simon Fraser University, 1998.
- [9] Palacio-Quintin, C. The hyper-flute. *Proceedings of NIME 03*, Montreal, Canada 2003.
- [10] Pressing, J. Some perspectives on performed sound and music in virtual environments. *Presence*, 6, 1-22, 1997.
- [11] Reed Ghazala, Q. Circuit-bending and living instruments. *Experimental Musical Instruments*, 9, 21-23, 1993.
- [12] Weinberg, G., Aimi, R. and Jennings, K. The beatbug network. *Proceedings of NIME 02*, Limerick, Ireland 2002.
- [13] Young, D. The hyperbow controller. *Proceedings of NIME 02*, Limerick, Ireland 2002.