Adapting the trombone: a suite of electro-acoustic interventions for the piece *Rouse*

Neal Farwell
University of Bristol
Department of Music, Victoria Rooms,
Queens Road, Clifton, Bristol BS8 1SA, UK
+44 (0)117 954 5028

neal.farwell@bristol.ac.uk

ABSTRACT

Three electro-acoustic systems were devised for a new trombone work, *Rouse*. This paper presents the technical systems and outlines their musical context and motivation. The uSlide measures trombone slide-extension by a minimal-hardware ultrasonic technique. An easy calibration procedure maps linear extension to the slide "positions" of the player. The eMouth is a driver that replaces the mouthpiece, with software emulation of trombone tone and algorithmic musical lines, allowing the trombone to appear to play itself. The eMute is built around a loudspeaker unit, driven so that it affects strongly the player's embouchure, allowing fine control of complex beat patterns. eMouth and eMute, under control of the uSlide, set up improvisatory worlds that are part of the composed architecture of *Rouse*.

Keywords

Trombone, electro-acoustic adaptation, mute, composition, improvisation, mapping, illusion, emulation, ultrasonic.

1. INTRODUCTION

Rouse for trombone, trombonist, and live electronics was the fruit of a commission from trombonist extraordinaire Hilary Jeffery. Jeffery's own "tromboscillator" is an improvisation environment controlled by a sensor-equipped trombone mute [1]. The further development of a mute, to be somehow electronically activated, was at the centre of the commission.

The final system has three interlinked components: the *uSlide*, an ultrasonic measure of trombone slide-position that is efficient in implementation and rugged under performance conditions; the *eMouth*, a transducer and excitation system that replaces the player's embouchure at the mouthpiece so that the trombone can seem to play itself; and the *eMute*, a loudspeaker-based device held and operated like a plunger mute, which changes the acoustics and playing characteristics of the trombone. *Rouse* has been performed in concerts of otherwise-acoustic music, and its hardware was used on Jeffery's regular concert instrument. The devices thus had to be easy to fit and remove with no damage to the instrument itself. A further goal was that the system should be low cost, and involve minimal application-specific hardware beyond the three named devices. Software was implemented in Max/MSP.

An obvious precursor is Nic Collins' "trombone-propelled electronics".[1] This uses an old trombone as armature for a new performance instrument, whose soundworld involves sampling external sources and reshaping them, often in collaborative improvisation. By contrast, *Rouse* aims to make the trombone more itself, in a surreal or hyper-real presentation of its acoustic world and playing styles.

This paper has a dual purpose. It will give a technical description of the suite of electro-acoustic interventions, and will also summarize aspects of the musical result with the intention of showing the motivation for the adaptations. The electro-acoustic ideas grew out of compositional goals, and the systems were optimized informally. Technical experiments and developments led to compositional ideas and vice versa. Further information about *Rouse*, sound examples, and screenshots of the operating software have been placed at the Sonic Arts Research Archive [2].

2. TROMBONE ACOUSTICS

The adaptations for *Rouse* engage with aspects of normal trombone acoustics, summarized below. A more detailed description is online at [3]. A number of older books on trombone pedagogy were found useful to relate acoustic principles to musical practice [4], [7], [9], [10], [13].

The vibrating aperture of the player's lips creates an oscillating air pressure. Buzzing on the mouthpiece alone, the frequency is a continuous variable set by embouchure shape and lip tension. The trombone acts as a resonator and radiator. The tube is effectively closed at the player's lips and is designed, through combination of the cylindrical section, mouthpiece and flared bell, to have strong resonances on an overtone series $2f$, $3f$, $4f$, etc. The pressure anti-node at the closed end interacts with the embouchure mechanism, forcing the oscillator onto the nearest preferred frequency. The fundamental f is not at a resonance but can be played as a pedal tone, the oscillator mode-locked by reinforcement of its overtones. The slide, a telescoping tube system, varies the actual length hence effective acoustic length of the trombone. With the slide closed, 1st position, the Bb trombone has notional fundamental Bb1. Each further numbered position extends the tube and lowers the fundamental by a semitone, to E1 at full-extension 7th position. The linear distance between successive positions increases because the tube length must increase in geometric progression. The slide is a precision system and the outer part is made of light-gauge tubing to be low in inertial mass, allowing considerable agility. The pitch range of the instrument is covered by slide-selection

NIME 06, June 4-8, 2006, Paris, France.

---

[1] Seen in concert, and described in [5].

of series and embouchure-selection of overtone. The radiation characteristics of the bell vary with frequency. A mute reshapes this frequency dependence.

3. THE uSLIDE

Slide extension is measured by a time-of-flight ultrasound method using a 40KHz transmit-receive ceramic transducer pair. There are many existing implementations of ultrasonic distance measurement. The version here offered particular advantages for the trombone and in conjunction with the other hardware for *Rouse*. Mapped to slide position, the uSlide provides control information to the eMouth and eMute.

3.1 Hardware

The computer audio interface (a Hammerfall DSP Multiface) hosts the ultrasound transducers directly, at a system sample rate of 96kHz. The ultrasound transmitter is driven by the headphone output, and the receiver is wired to an analogue input – there is no hardware amplification or signal conditioning. This further simplifies an approach described by Johannes Taelman [12]. The transducers are mounted on buffers shaped from pencil erasers, and bound to the trombone tubes with double-sided eye-and-hook tape (see Figure 1). This makes a lightweight non-slip and non-abrasive mount, possibly with a shock-decoupling effect, and is very quick to attach and remove from the instrument.

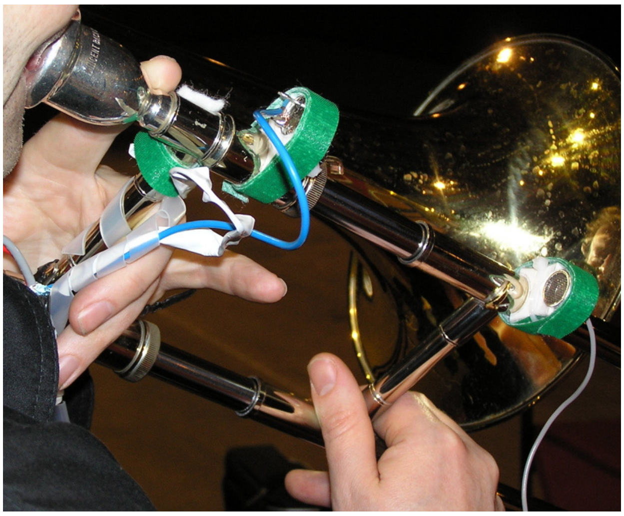

Figure 1. The uSlide transmitter (right of photo) and receiver (upper middle). The player's left forefinger is resting on the mouthpiece, next to the Trombone push-button (hidden). The nylon coil-wrap (centre left) is an easily released tether for the umbilical cable.

Measurements of the trombone spectrum (see below) suggest the trombone can produce significant energy in the 40KHz region. The transducer mounted on the outer slide will pass in front of and behind the bell edge as the slide moves. To minimise interference, the receiver is mounted on the static inner slide, where its acoustic environment is more stable, and the transmitter is fitted to the outer. An umbilical cable connects both signals to the computer, extended by a fly-lead of miniature coax in the case of the moving transmitter. The umbilical is tethered to the cross piece of the inner slide and falls loose in front of the player's body. This proves very workable in practice, the main inconvenience being that the fly-lead sometimes tangles when the instrument is first picked up. Early experiments with a miniature powered satellite, optical in one direction, ultrasonic in the other, were abandoned. Future development may revisit this idea, or explore the mechanically simpler option of a reflector mounted on the slide.

3.2 Drive and Conditioning

The uSlide uses continuous-wave (CW) transmission, with phase inversion acting as the change-of-state to be detected. The ultrasound system runs in a software shell at 96KHz – see [2] for Max/MSP patches.[2] The nominal measurement accuracy is one sample, or 3.5mm, at a refresh rate of 200Hz.

At 96KHz sampling, one cycle of 40KHz occupies 2.4 samples. An exactly repeating pattern of 12 samples generates 5 complete cycles. As far as the audio hardware is concerned, this is an ordinary signal at less than the Nyquist frequency and so is reconstructed by the DAC as a smooth 40kHz sinewave for the transmitter.

Pulsed transmission was rejected for this application. If the pulse amplitude is high, it can be audible as a click or buzz. The drive level available from the interface headphone jack was in any case limited. If the pulse amplitude is smaller, the receiver is susceptible to mis-triggering from air-born interference and from mechanical impact pinging the transducer. Both are likely in the case of the trombone, mechanical noise arising for instance from the proximity of the F-valve trigger. Time-based averaging or reasonableness-measures introduce latency. Simple pulse systems can also suffer from a "cogging" effect, when the detection threshold interacts with the received pulse envelope and distance-dependent amplitude: depending which cycle of the received waveform is registered, the measured distance can show abrupt jumps of around 8mm.[3]

For the uSlide CW implementation, a buffer is pre-filled with cycles of the 12-sample pattern, and played in a continuous loop. The buffer index provides both a trigger for synchronous inversion of the carrier at the loop start, and a measure of elapsed time since that inversion. The loop period is 5ms, more than enough for the <2ms time-of-flight at full slide extension, but short enough for acceptable latency.

The buffer is in fact two-channel, the second channel filled with a quadrature version of the first. These sine and cosine signals (without the periodic inversion) are used for synchronous demodulation of the receiver signal. The cutoff frequency of the filters in the demod chain (8-pole lowpass) can be adjusted to trade off selectivity against response time. The received signal must pass through an amplitude null at the notional phase inversion. The null is detected by thresholding the demodulated amplitude against a fraction (set empirically at 0.7) of its locally-smoothed value. This also implements AGC on the received signal, with controllable parameters.[4] When the null is detected, the buffer index is captured in a sample-and-hold, rescaled as slide position, and passed from the shell to the main software body running at 48kHz.

---

[2] The CW technique here was originated for *Rouse*, and I have not seen other examples in NIME applications. A later search suggests that related techniques are documented in the engineering and instrumentation literatures.

[3] $340\text{ms}^{-1} \times 1/(40\text{kHz})$. I encountered this effect during work on my "funny fiddle" (1996), described in [8].

[4] Continuous-wave reception also allows (though not used in *Rouse*) the continuous direct measurement of movement velocity via Doppler shift. For the "funny fiddle", a self-zeroing digital hardware implementation was devised for bow velocity [8]. For Doppler sonar, see also [12].

In use, the AGC seems to prevent the cogging phenomenon, and the system copes readily with the unamplified transducer signal some tens of dB below full-scale. Resilience to air-borne and mechanical interference has not been systematically tested, but the uSlide has so far proved reliable in concert use.

3.3 Scaling

The ultrasonic system generates a raw linear measure of slide extension. For most purposes in *Rouse*, a measure of slide position – the musical measure natural to the player – is needed, which at integer values corresponds one-to-one to a chromatic scale of pitches identifying the overtone series. If the ultrasonic measure is x and the effective length of the trombone tube is L, then $L = L_0 + kx$ for some L_0 and k. The notional fundamental frequency $F_x = cs/L$, where s is the speed of sound in the tube, and c depends on the geometry.

For the player, it is much easier to deal in pitches than frequencies. For calibration, we select two pitches in a register that is easy to play accurately, both on the third overtone. Using the MIDI-note ←→ frequency conversion functions in Max and simplifying fractions:

$$\text{note\#} = \text{ftom}\ (F_x) = \text{ftom}\ (\ 1 / (a + bx))$$

Once the uSlide sensors are fitted, and the acoustic instrument tuned and warmed up, we play F3 (1st position, note# =53) and C3 (6th position, note# =48), register the two x values and solve the pair of equations for the variables a and b. A simple user interface hides the math. The slide position, floating-point for continuously-variable control, is then

$$\text{POS}_x = 54 - \text{ftom}\ (\ 1 / (a + bx))$$

A higher order function was considered, but this was found to be as accurate as needed. The transducers need not be precisely positioned when fitted, because variations are calibrated out.

4. THE eMOUTH

For the opening of *Rouse*, I wanted the trombone to appear to play itself. The illusion should be strong, yet also be easy to blur, and the trombonist would gradually be allowed to participate in the trombone's dream. The eMouth system provides an acoustic drive to the trombone in place of the usual mouthpiece, with constrained control from the uSlide.

4.1 Driver

In his "trombone-propelled electronics", Collins used a compression driver of the kind designed for use with an HF radiator horn in loudspeaker arrays. I concluded that available models were too bulky and massive for *Rouse*. With the eMouth fitted, it had to be possible to handle the trombone as normal; and the physical loading could not risk damage to the mouthpiece socket. I wanted also to use a wide audio spectrum.

Jeffery provided a typical mouthpiece that fitted his instrument, of 26mm inner diameter at the embouchure opening. The driver selected is a small-diameter metal diaphragm, rubber surround type. This type allows a long-throw pistonic movement of the diaphragm, producing a high sound level for the small size. Despite their widespread use inside computers and in miniature satellite loudspeakers, these drivers seemed to be unavailable for one-off purchase in the UK. I sought a model closely matching the mouthpiece in diameter: for the eMute prototype, this was a 24mm-diaphragm device cannibalized from an Apple computer. The driver is mounted to the mouthpiece using a plastic gasket, and the assembly held together by a web of cable ties. This is readily adjustable, and easy to dismantle for transport or storage. See Figure 2 and Figure 3. The connection must be airtight and somewhat rigid for all the sound to appear to come through the instrument, since this might not otherwise be the path of least resistance.

This arrangement places the diaphragm of the driver as close as possible to where the player's lips would normally be, and with minimal alteration of the mouthpiece enclosed volume. This gives a close match to the instrument's normal closed-tube acoustics, so that the tuning of the slide positions feels normal to the player and the transducer approximates the pressure drive of the buzzed lips. The transducer is powered by one channel of a small hi-fi amplifier.

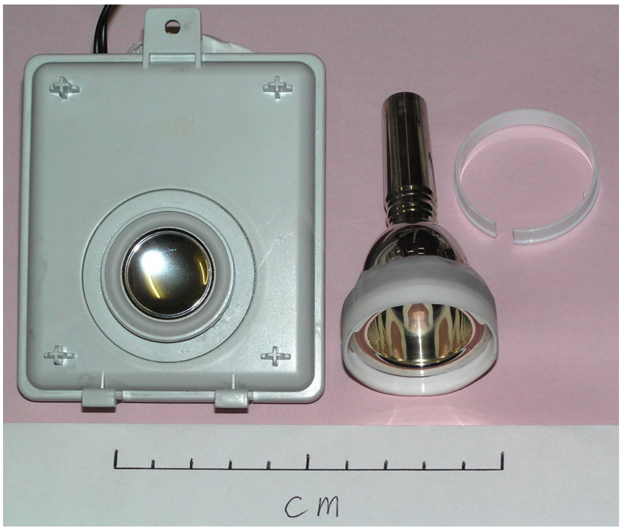

Figure 2. eMouth components. The plastic enclosure has a small port on the rear, which is here sealed closed.

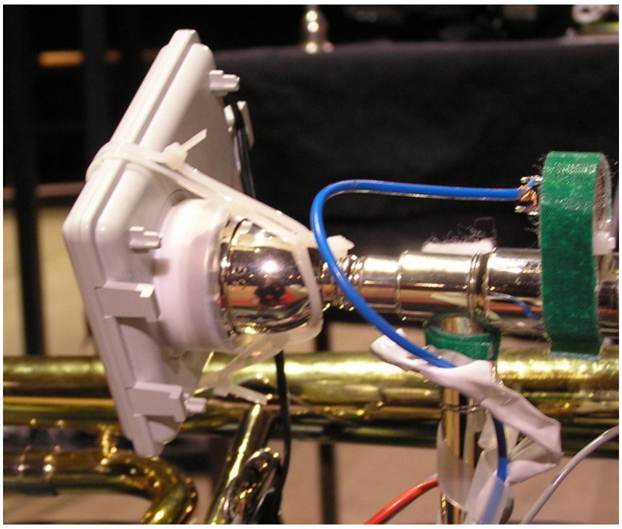

Figure 3. The eMouth assembled and fitted to the trombone.

4.2 Excitation Function

The excitation signal for the eMouth transducer is from a simple synthetic model of the trombone. Test recordings were made of the trombone played normally. An omnidirectional microphone was placed on-axis in front of the bell at around 50cm, in a dry acoustic. Spectral analysis of the recordings yielded some heuristic conclusions:

1. At a given pitch and sustained dynamic, there is an approximately straight-line relationship between partial-amplitude in dB and frequency on a linear scale.
2. The slope varies with dynamic level, flatter at *forte* hence more energy in high partials, steeper at *piano* with the high partials lost below the measurement floor.
3. The overall spectrum is subtly modulated by a formant shape, and the fundamental is typically a few dB weaker than the 2nd or 3rd harmonics. The fundamental, however varies relatively little with playing dynamic.
4. Short notes confirm this behaviour, with the spectral envelope tilting from steep to flat and back during the attack and release of the note.

A surprisingly simple model approximates the measured spectrum. An anti-aliased sawtooth passes through a two pole low-pass filter, a state-variable implementation at low Q. A further high-pass filter rolls off the lowest partials (and protects the driver from exaggerated cone excursions). The interaction of the 1/f amplitude-spectrum of the sawtooth and the LPF slope approximates the measured variable dB/frequency slope by varying the filter cutoff relative to the oscillator frequency.

In steady state, the timbre is plausible for the trombone, but very clearly synthetic. A much more “real” effect, reflecting the common psychoacoustic observation that instrumental timbres are characterised strongly by their transients, is gained by modulating the LPF cutoff with an envelope, linear in frequency/time but matching the timing of staccato notes. Figure 4 shows a test version of the model.

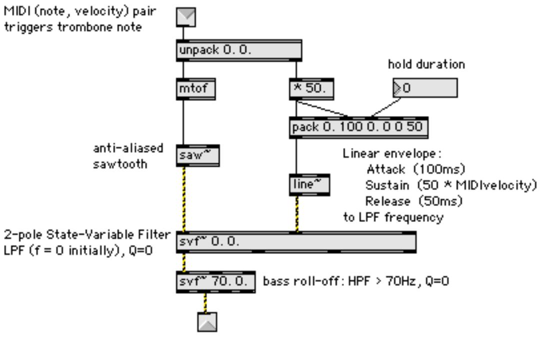

Figure 4. Simple trombone model.

5. THE eMOUTH IN CONTEXT

5.1 Illusion and Transformation

When the eMouth is fitted to the trombone body and driven with passages of notes synthesized by the basic trombone model, the effect is disconcerting. The resonances of the physical instrument overlay and enrich the synthetic timbre, and all the sound is heard to come from the bell. The instrument seems indeed to play itself. However, the sound is “not quite right”. In part this is because the dynamic level available from the eMute is quieter than would be expected for the heard tone-colour – I was not prepared to destruct-test the transducer to establish a maximum level(!) – and the frequency of the eMute drive is not precisely matched to the acoustic response of the resonant system.[5]

The ambiguity and incompleteness of the illusion was retained because it was what I sought compositionally: an image of the not-quite trombone. To manipulate further the illusion, a “noisy trombone” extension was made to the basic model. Pink noise is fed through a comb resonator, implemented as a bank of individual resonators, whose Q can be varied to give a tone from nearly-unpitched to strongly focused in pitch, with a spectral envelope close to that of the sawtooth. When the tone is most focused, the noise source is crossfaded to the pure sawtooth. Parameters are mapped to give subjectively smooth transformation from noisy to pure in a single control variable.

Table 1. The five phases of "Dream".

P	Mapping of slide position to pitch behaviour.	Automation
1	Slide locked in 1st position. *Trombone solo.* *Trombonist joins for Phase 2.*	Emergence from noise to resonance to trombone-tone. Bb horn-call figures, initially three low notes, expanding to five. The tone returns gradually to noise.
2	Fundamental moves in discrete semitone steps. New pitch takes effect at the start of the next note to be sounded.	Tone re-focuses. Range gradually expands to seven notes of the series.
3	Fundamental moves in discrete semitone steps, but pitch changes straight away, in the middle of any note already sounding.	Tone abruptly changes to noise. Tempo becomes more brisk.
4	Pitch-control becomes continuous: slide to any fundamental in the Bb – E range, and not just tempered semitones.	Noise becomes abruptly darker, then re-forms into trombone-tone.
5	Tessitura also responds to the slide position. If the slide spends more time in positions 1–3, the tessitura drifts towards upper overtones. If the slide spends more time in positions 4–6 (–7), the tessitura drifts down towards the pedal range. The **Trombone** button has an effect: while pressed, the pitch moves rapidly down towards the pedals; only shorter notes are played; and there are no rests in the eMouth phrases. Intended for the end of Phase 5, but may be used earlier if desired.	Note-speed accelerates. A continuous rushing noise gradually fades in.

5.2 Music and Mappings

The opening section of *Rouse* is called “Dream” and has five phases. At the start, the trombone is set on stage, bell facing the audience, and the player sits unobtrusively upstage. The player takes up the instrument for Phase 2. Throughout, the “note” information to the eMouth is an algorithmically generated cadenza exploring horn-call figures. The trombone automatically plays notes up and down an overtone series (including the pedal tone), and the uSlide determines which series is used. For slide positions 1 – 7, the fundamental is Bb – E (descending), just as in normal playing. Position 7 also acts as trigger for the transition to the next dream-phase. The visual component of reaching full extension may be theatricalized or underplayed. The effective resolution of the uSlide control evolves through successive phases, as do the note-speed and range of the algorithmic cadenza, and trajectories automated

---

[5] I made early experiments in matching the eMute pitch automatically to the actual trombone response; but I chose instead to use defined drive pitches, enjoying the timbral inflection created by uncorrelated movement of the slide.

between noisy and pure tone. Table 1 summarizes the behaviours. The score guides the trombonist through “an improvisation within the strange dreamworld of the not-quite-trombone”, moving from calm to frenetic.

5.3 Player and Audience

The sensory feedback loop from the trombonist’s action – the uSlide selection of pitch-series – is incompletely closed because a heard pitch may arise from different series. The player can draw on practised knowledge, (pre-)setting the slide intuitively for a desired pitch-set. However, the controlled-random detail of pitch and rhythm, the progression of the slide mapping from under- to over-determined, and the programmed trajectories in texture, tend to undermine this security. The player has to balance the attempt at fine control with the management of larger-scale momentum. For the audience, the fact of the player’s control is apparent, but its limits and frustrations are also suggested. The ambiguity and the partial redundancy of the player help set the dramatic intent of the dreamworld.

6. THE eMUTE

My initial idea for a new mute was to create a device with electronically-variable frequency dependence in its muting effect. Experiments with small loudspeakers in the trombone bell led to a different discovery, which became the core of the eMute. The eMute is a hand-held device build around a loudspeaker driver and fed by a variant of the simple synthetic trombone model. Because the driver has no housing, the sound heard from the mute is quiet compared to that from the trombone yet, with the trombone acting in reverse as an “ear trumpet”, exerts a strong effect on the player’s embouchure. If the played and eMute pitches differ, strong pulsation is heard in the played tone corresponding to the beat frequency, and this beat is closely felt through the embouchure.

Embouchure tracking has been investigated as a means of electronic control [6], and breath control has appeared in several commercial products. With the eMute, the effect is rather reversed. The embouchure provides haptic sensitivity to the electroacoustic intervention, while continuing its normal purpose of acoustic control. This facilitates, with a nearly normal playing technique, fine control of the beat-interval from unison through microtonal to large. Coupled with a quasi-intuitive manipulation of the eMute pitch, this proved a rich space for contemplative improvisation; and, with the eMute driven programmatically, for scored materials.

6.1 Hardware

A large driver is preferred for a strong acoustic effect, and the driver must also withstand induced vibrations from the blown trombone. However, the assembly must be light enough to be held in the hand and operated like a plunger mute, without fatigue, because this player-adjustment is essential to the improvisatory control. The driver model chosen for the prototype is a mid-range/woofer with a 12cm diaphragm and compact magnet assembly. The paper diaphragm is not ideal, because water droplets can be propelled out of the trombone bell; but it has so far withstood extended sessions without harm. A glued surround cut from 5mm foamboard matches the outer diameter (18cm) to that of a metal plunger mute favoured by Jeffery, and provides non-abrasive and circular contact with the instrument bell. The assembly balances in the hand, and a push switch (labelled eMute) is mounted at a convenient position for the player’s fingers. A tethered cable connects the driver to the spare channel of the hi-fi amplifier, and the switch to a hacked USB game controller serving as computer interface. The eMute prototype is shown in Figure 5 and Figure 6.

Figure 5. eMute. The white foamboard surround has a circular cutout matching the inner diameter of the frame.

Figure 6. eMute in use.

6.2 Control mapping

Real-time change of the eMute pitch is by manipulation of slide position and the eMute button, using a click-drag metaphor modelled on the computer mouse. Table 2 summarizes the actions. eMute pitch changes, though quiet, are sometimes audible to the audience, but this is absorbed into the improvisation.

6.3 An eMute context: “respiration”

The second section of *Rouse* is called “Deep Sleep”, an extended improvisation with the eMute. For the first time, sound is heard from two playback monitors, placed discreetly in the near stage-space of the player. Within the imagined world of the piece, these create a “respiration field” extending the body. In this section, the monitors quietly play a shifting overtone field related to the eMute pitch.

A synthesis engine periodically triggers overlapping sine-tone voices each with a slow attack-release envelope. The frequency of each tone is a controlled-random exact multiple of the current eMute frequency, whether or not the eMute is currently sounding. At the start, the eMute pitch is preset but the device itself is silent. Overtones sound while the player changes from eMouth to mouthpiece and takes up the eMute. As the eMute pitch subsequently changes, new overtone triggers relate always to the current pitch. The result is a disembodied sound-bed with no abrupt transitions. Yet the overtone field always suggests, probably unconsciously for the audience,[6] the eMute pitch and hence anchors the blown pitch: there is a "rightness" to the played pitches.

There are three further influences on the overtone field. Patterns of rapid slide movement (whether or not they are changing the eMute pitch, and whether or not the instrument or eMute are sounding) accelerate the synthesis retriggering to produce flurries in the overtones. Over time, the tessitura of the field migrates. Lastly, once the trombone begins playing, a small random frequency deviation is added to each sine voice, less than or equal to a maximum that gradually increases from zero. This gradually increases the likelihood and intensity of beats perceived in the respiration field, a mirror of those created by the trombone and eMute.

Table 2. eMute control mappings.

single-click
Toggle the eMute on/off (i.e. sounding / non-sounding). *If the eMute is "off", the actions below still change the (silent) pitch. If "on", the change is heard immediately.*
single-click-drag
Slide moves the eMute pitch up/down the present overtone series (as performed by *embouchure* in normal playing). Motion is relative to the initial pitch when eMute is pressed. ***Example:*** *the eMute pitch is currently in the pedal range. Move the slide to 7th position; click and hold eMute while bringing the slide into 1st position; release eMute. The eMute pitch will ripple up to the 7th harmonic. To raise it further, repeat (go to 7th, click-drag upwards, release).*
double-click-drag
Change the fundamental pitch for the eMute, according to the slide position when the second click on eMute is released. Slide positions 1 – 7 give fundamentals Bb – E, "as normal". *A quick double-click gives near-immediate pitch change.* If the button is held – *click-release-press-hold-release* – the pitch makes a glissando. The duration of the gliss is equal to the *hold* time, and begins at the final button release.
You can play normally at the same time as changing the eMute pitch.

7. CONCLUSION AND FUTURE PLANS

The systems described above were developed for a particular composition, *Rouse*. Control mappings here have an important role in specifying the musical intent and result, by defining an improvisatory space. Choices within this space are further conditioned by composed indications in the score. The network of interactions in the trombone-trombonist-electronics system involves various different pathways. The electro-acoustic interventions set up the dramatic shape of *Rouse*, which moves from a disembodied, electronically mediated and improvisatory starting point in "Dream" and "Deep Sleep" to an acoustic and fully-scored ending via (not described here) three further sections, "Half World", "Snooze", and "Rouse". I welcome enquiries from interested performers!

The electro-acoustic systems have the potential for other applications and for evolution. The uSlide system offers another option in the range of techniques for ultrasonic distance measurement. The eMouth may be strongly bound to *Rouse* by its visual theatre, but future plans include a higher sound level, matching of excitation to acoustic-system spectrum, and many possibilities for emulation and dissolution of the trombone tone; hence, perhaps, setting new allusive contexts. The eMute/uSlide system can be made self-standing as a tool purely for improvisation. A line of exploration for the eMute is to use the transducer simultaneously as driver and as microphone, to investigate muting and synthesis behaviours steered by the trombone's acoustic output. eMouth and eMute may be readily adapted to other brass instruments, perhaps in ensemble.

8. ACKNOWLEDGMENTS

My thanks to Hilary Jeffery for the invitation to make this piece, for supplying the mouthpiece used for the prototype eMouth, and for his patience, skill and musical insights in our experiments and rehearsal.

9. REFERENCES

[1] http://www.mti.dmu.ac.uk/~jrich/kreepa/tromb.html

[2] http://www.sara.uea.ac.uk/?work&id=2450

[3] http://www.phys.unsw.edu.au/~jw/brassacoustics.html

[4] Bate, P. *The trumpet and trombone : an outline of their history, development and construction*, 2nd ed. E. Benn, London, 1978.

[5] Collins, N. Low Brass: The Evolution of Trombone-Propelled Electronics. In *Leonardo Music Journal*, 1 (1991), 41-44.

[6] da Silva, A., Wanderley, M., and Scavone, G. On the Use of Flute Air Jet as A Musical Control Variable. In *Proceedings of the 2005 International Conference on New Interfaces for Musical Expression (NIME05)*, Vancouver, BC, Canada, 105-108.

[7] Dempster, S. *The modern trombone: a definition of its idioms*. UC Press, Berkeley/London, 1979.

[8] Farwell, N. J. *being what I am, doing what I do: manifesto of a composer*. PhD Thesis, University of East Anglia, Norwich, UK, 2001, 131-133.

[9] Gregory, R. *The Trombone. The Instrument and its Music.* Faber, London, 1973.

[10] Kleinhammer, E. *The Art of Trombone Playing*. Summy-Birchard, Evanston, IL, 1963.

[11] Pierce, J. Introduction to Pitch Perception. In Cook, P.R. *Music, Cognition, and Computerized Sound*, MIT Press, MA, 2001, 58-63.

[12] Taelman, J. A low-cost sonar for unobtrusive man-machine interfacing. In *Proceedings of the 2002 International Conference on New Interfaces for Musical Expression (NIME02)*, Dublin, 92-95.

[13] Wick, D. *Trombone Technique*, 2nd ed. OUP, Oxford, 1984.

---

[6] The perceptual mechanism infers a fundamental pitch [11], though the effect is subtle here.