Ten Years of Tablet Musical Interfaces at CNMAT

Michael Zbyszynski
CNMAT, UC Berkeley
1750 Arch Street
Berkeley, CA 94709 USA
+1.510.643.9990
mzed@cnmat.berkeley.edu

Matthew Wright
CNMAT/UCB and CCRMA/Stanford
Stanford University
Stanford, CA 94305-8180
matt@{cnmat.Berkeley, ccrma.stanford}.edu

Ali Momeni, Daniel Cullen
CNMAT, UC Berkeley
1750 Arch Street
Berkeley, CA 94709 USA
+1.510.643.9990
batchku@gmail.com,
dcullen@berkeley.edu

ABSTRACT
We summarize a decade of musical projects and research employing Wacom digitizing tablets as musical controllers, discussing general implementation schemes using Max/MSP and OpenSoundControl, and specific implementations in musical improvisation, interactive sound installation, interactive multimedia performance, and as a compositional assistant. We examine two-handed sensing strategies and schemes for gestural mapping.

Keywords
Wacom tablet, digitizing tablet, expressivity, position sensing, gesture, mapping, algorithmic composition.

1. WHY THE WACOM TABLET?
The issue of musical control has long been a topic for research and pedagogy at UC Berkeley's Center for New Music and Audio Technologies (CNMAT). In addition to custom controllers, we advocate creative use of standard gestural controllers: joysticks, gamepads, etc. Use of standard controllers has some advantages, including low cost and availability, and the corresponding potential for redundancy and replaceability. Additionally, we look for high-resolution output data, fine temporal resolution, and multiple axes of control when evaluating the potential usefulness of any type of controller.

In 1997, CNMAT researchers [1] identified the Wacom ArtZ II 1212 [2] digitizing tablet as having strong potential as a musical controller. Cost, availability, the degree and fineness of control, and the high number of continuous controllers suggested that these devices would be useful for expressive control in a variety of musical contexts (see table 1). Different types of pointing devices (Grip Pen, Art Pen, Mouse) offer specific sets of control outputs, the Grip Pen differentiates between its tip and eraser ends, and each individual device has a unique ID number. The Wacom tablet offers multiple continuous controllers at a resolution much higher than MIDI. Earlier work with serial tablets showed high temporal resolution and mostly low latency – both desirable aspects in a musical controller. While still quite useable, newer, USB models are not as accurate or fast in the temporal dimension.

Table 1. Control Dimensions for a 9x12 Intous3 Wacom Tablet with Couturier's Wacom object v3.1ß5 for OS X.

Dimension	Output Precision (accuracy)
X-axis Y-axis	0 to 32480 (± 0.25 mm: pen; ± 0.5 mm: mouse)
Pressure	0 to 65535 (1024 discrete values)
Tilt (X and Y)	-60 to 60 (± 60 degrees)
Rotation (6D Art Pen)	0 to 23049 (1773 values, 0.2 degree resolution)
8 buttons (tablet)	Binary
2 touch strips (tablet)	Up/down[1]
2 buttons (Grip pen)	Binary
5 buttons (mouse)	Binary

Another promising aspect of the tablet, with respect to potential virtuosic performance, is its combination of tactile reference (i.e. the user touches it, and the spatial coordinates are absolute) with a gestural language that leverages human fine motor control, and years of writing experience [3]. Tactile reference is often overlooked in musical controllers, but plays a critical role in the process of learning to play [4]. Also, pen and mouse controllers leave the user's other hand free to employ a controller with a different set of affordances, such as a bank of faders or the QWERTY keyboard. HCI research comparing performance with one-handed versus two-handed control [5] indicates that there is a significant two-handed advantage, but only when the roles for the two hands are differentiated.

Although Wacom tablets are designed and marketed towards graphic artists, they share many characteristics with previous interfaces for music, including Xenakis's UPIC System [6], Buxton's SSSP [7] and the Boie/Mathews/Schloss Radio Drum [8].

[1] In conversations with Wacom Engineers, it was discovered that the strips are absolute position sensors with 13 positions. On Macintosh computers, the Wacom uses Apple's Generic Tablet description, which does not include additional position sensors. The output of these sensors is passed by the driver as keystrokes for either upwards or downwards motion.

2. GENERAL IMPLEMENTATION

2.1 Wacom object for Max/MSP

Except for the earliest works mentioned, the pieces described in this paper use the "wacom" object, a third-party extension to Cycling '74's Max software [9]. It was originally written by Richard Dudas [10, 11] for Classic Macintosh OS, and subsequently ported to Windows XP and OS X by Jean-Michel Couturier [12], who currently maintains it. Treating the tablet as a mouse yields only buttons, X, and Y data, while an external object can read all of the control data coming in from the driver. The current object also offers data scaling features and control over the rate at which data is reported. Ronald J. Kuivila and Shuichi Chino independently made similar extensions at different times.

2.2 OSC Wrapper

The earliest Wacom performances at CNMAT relied on Open Sound Control [13] by necessity; at that time a Macintosh running Max managed control data (e.g., mapping incoming MIDI data to sound control) and a Silicon Graphics workstation running Softcast [14] performed additive synthesis. The OSC messages therefore represented synthesis control messages such as "set the odd/even harmonic balance of voice 6 to 0.72."

Subsequent experience with OSC taught us that it is a good programming practice to use an OSC namespace to represent both the input and the output of the software processes that translates sensed gestures to musical control. In other words, we represent the output from the Wacom tablet as an OSC namespace, these tablet-specific OSC messages are the input to our gestural mapping software, and the output is a second OSC namespace representing the capabilities of our sound synthesis. Even now that it is possible for a single laptop to do both synthesis and control processing, we use OSC as an abstraction mechanism to provide clean interfaces between modules of the software in our instruments [15].

With a well-designed OSC namespace, the resulting software becomes much more readable, and self-documenting. Also, switching to new control and synthesis technologies, or changing control mappings, becomes fairly simple. CNMAT now has a library of OSC wrappers (soon to be released) for all of the promising controllers in the building, from joysticks to P5 Gloves. We have updated our original Wacom-OSC patch [16] to work with the current generation of Wacom hardware and software.

3. SPECIFIC IMPLEMENTATIONS

3.1 Matthew Wright's Instruments

Matthew Wright has used a Wacom tablet as the central element of every one of his interactive computer-based instruments for the last 10 years. All of these instruments use rectangular regions of the tablet each with different musical behaviors. The pen activates a region each time it touches the tablet surface, according to the X-Y coordinates of the point where contact is first made. Subsequent motion of the pen then controls continuous parameters of the sonic process associated with that region for as long as the pen contacts the tablet, even if the pen goes outside the bounds of the region. In other words, the gestural input is chunked into a series of "strokes," and the effect during each stroke depends modally on the region in which the stroke began. An advantage of this method is that the tablet surface can be densely packed with many small regions, but the continuous motion of the pen can cover the entire tablet surface instead of being restricted to the area of a small region.

A pre-drawn paper "template" fits underneath the tablet's clear plastic overlay to show the performer the locations and contents of the regions. One disadvantage of this use of a template is the constant need to look down at the tablet to select a region; the visual aspect of performance is therefore dangerously close to "office work" rather than "musical performance" [15]. This effect is somewhat mitigated by the stroke-based interface described above: after the pen touches the tablet the performer can look away from the tablet.

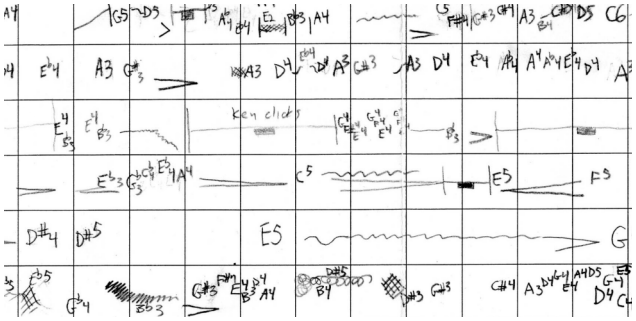

Figure 1. One of Wright's Templates

Another feature that Wright's Wacom interfaces share is the use of the "scrubbing" metaphor [17, 18]. A vertical array of half-inch-tall by 12-inch-wide regions represents a collection of sinusoidal models created by analysis of musically expressive prerecorded phrases. The horizontal position of the pen continuously determines the time index into the corresponding sinusoidal model; the extremely high spatial resolution of the tablet therefore translates into extremely fine temporal control in the selection of musical material from the sinusoidal models. The templates contain notation of the musical material in each of these phrases, as shown in Figure 1. The process of drawing one of these templates is very much like transcription in that it visually depicts important musical aspects of the phrases, and is an essential step in the performer's exploration of the musical material and learning to be expressive with the instrument. Pressure always maps to loudness in scrub regions and tilt is never used in these regions, because control of tilt interferes with extremely accurate control of position. Faders under the left hand[2] control additional synthesis parameters such as transposition and inharmonicity.

Wright often brings improvising acoustic musicians into the studio to record some expressive phrases on his or her instrument, and then to selects some of these phrases and prepares them for scrubbing as described above. The resulting instruments are then used in performance with that musician, and sometimes re-used in the future in different performance situations. Wright has made instruments from:

[2] All of Wright's interfaces use faders in the left hand because faders have complementary affordances to the Wacom tablet: they maintain state (slider position) when not being manipulated, and it is easy to manipulate multiple parameters at the same time.

- Shafqat Ali Khan: Khyal (Indo-Pakistani classical) singing in various ragas. [18]
- Abbie Conant: Trombone phrases as part of the Conant/Wright composition "Garden of Earthly Delights"
- Rova Saxophone Quartet samples from the *Rovamatic* sample CD (see figure 1).
- Ornette Coleman samples from the sax solo in his original 1959 recording of his piece *Tears Inside*, which Wright uses when *That Situated Trio* [19] performs their deconstructive rendition of that piece. This instrument also contains two scrubbable sinusoidal models of John Schott playing the "head" (main melody) of the tune on guitar.
- Samples of Roberto Morales playing some of his replicas of pre-Columbian Mexican flutes.

What these have in common is that they are drawn from the same musical world (timbre as well as expressive use of pitch, phrasing, and articulation) of the fellow improvisers in a performance. Wacom-based scrubbing of sinusoidal resynthesis allows for much finer control and greater expressivity than simply playing back prerecorded samples of these musicians.

3.2 Ali Momeni

Ali Momeni has extensively used Wacom tablets as gesture instruments for live electro-acoustic performance. Two particular techniques are noteworthy in his usage of the instrument: first, use of parameter interpolation spaces as the primary mapping model for the tablet and second, mixed sensing of tablets as a way to enrich this controller with audio input.

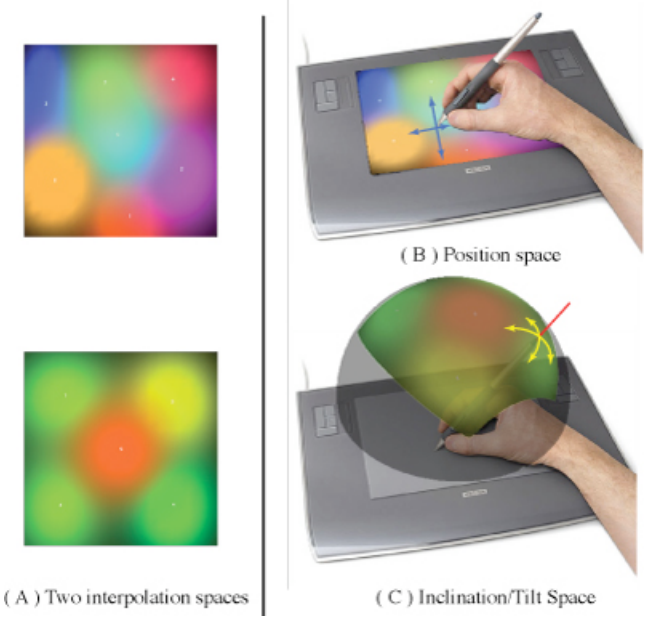

Figure 2. (A) Two parameter interpolation spaces; each colored region represents a Gaussian function whose height at any point in the space defines the influence that point has over the interpolated mix. (B) The X-Y position of the stylus tip performs interpolations in the first space. (C) The X-Y inclination of the stylus performs interpolations in another parameter space, for a different software synthesis engine.

3.2.1 Parameter Interpolation

Wacom tablets' ability to simultaneously report position and inclination of the pen allows the performer to move in two separate two-dimensional spaces with one hand, making these tablets uniquely strong controllers for use with parameter interpolation spaces [20]. This gesture mapping technique relies on using a two-dimensional space as a map containing multiple points, each of which represents a particular state, or preset, of a multi-parametric software synthesis engine. Moving around in this two-dimensional space performs a weighted interpolation among the different presets; the weight of each preset is determined by the height of a Gaussian function associated with that preset. In the case of the Wacom, the X-Y position of the stylus tip moves within one interpolation space, while the X-Y inclination/tilt moves within another interpolation space (Figure 2). For example, tip position might interpolate parameters for a physical modeling audio engine, while tilt interpolates parameters for a reverb engine.

Figure 3. Mixed sensing of the tablet by way of audio input from a contact microphone placed on the tablet's body. The performer plays the tablet like a percussion instrument with one hand while he manipulates the pen with the other hand in order to modulate synthesized sounds.

3.2.2 Mixed Sensing

One deficiency of Wacom tablets is their lack of the high-sampling-rate/low-latency control streams that are quite desirable in many applications [21]. By placing a contact microphone on the body of the tablet, it can be used as a percussion instrument whose audio signal can be used in software, either as an excitation audio signal or as control stream by way of audio analysis. This *mixed sensing* technique was put to use in the performance of the opera *Takemitsu: My Way of Life* [22]. For example, during the performance of "Munari by Munari," a software instrument allowed Momeni to make harmonic analysis of sounds made by a solo percussionist, and to generate in real-time resonance models of the these sounds. These models were excited by the audio signal from the contact microphone. The result was a two-handed manner of playing the tablet, where one hand used the tablet like a drum, while the other manipulated the pen in order to change parameters (Figure 3). This arrangement offered a tactile and very low-latency mode of playing software instruments, while the stylus's position, tilt, and pressure controlled real-time modulation of the synthesized sound; the stylus's buttons were used to capture new analyses, and place them in particular spots in the interpolation space.

3.2.3 *Frelia*

Frelia (Figure 4, [23]) is a multi-user kinetic sculpture that translates bodily gestures into computer-generated sound, made by Ali Momeni and Robin Mandel [24]. The instrument works by reducing the movements of a 5-foot long metal pole to parallel movements of the stylus. Two pantograph arms work together to proportionally reduce the movements of the metal bar by a factor of 6 (Figure 5). This translation allows the players to make music with a tablet by making larger gestures than the usual miniscule-scale of the tablet and stylus.

Figure 4. *Frelia*: an interactive kinetic sculpture; up to three users play *Frelia* by moving a 5-foot metal bar, whose movements are translated mechanically to the movements of a Wacom stylus on a tablet.

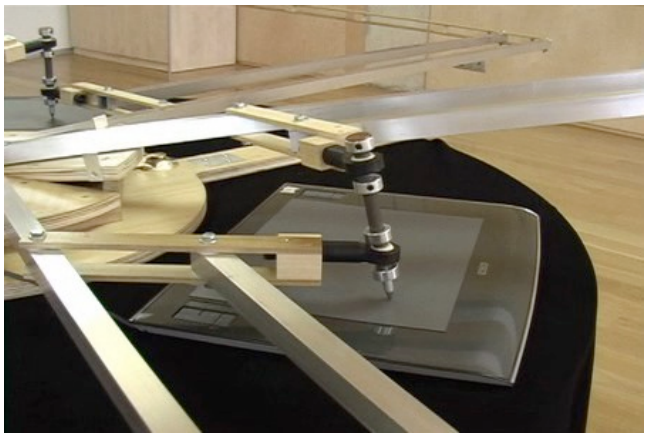

Figure 5. Two pantograph arms work in conjunction to one another to mechanically reduce the movements of a metal bar to those of the Wacom stylus.

3.3 *News Cycle #2*, Michael Zbyszynski

In 2006, video artist Anthony Discenza [25] approached Michael Zbyszynski to create a collaborative performance piece in the style of Discenza's earlier video installations, which involve overlaying, compressing, and distorting huge amounts of footage. (*News Cycle #2 (Excerpts from a Long Day*) used 36 hours of news footage, 12 hours from MSNBC, Fox News, and CNN from one day.) That installation work used sound from the original footage, distorted as an artifact of the video processes. For this performance piece, it seemed antithetical to write a "score" to this material, which instead offered the bountiful opportunity for very direct interaction.

Dealing with a video stream which is already densely macerated, the performer uses the tablet to select specific scan lines from the piece, generating changing buffers that are subsequently convolved with either the audio content of the video, pink noise (in silent sections), or a mixture of the two. Originally this procedure was developed using a mouse as the controller, but this was unsatisfactory due to difficulty of immediately pinpointing an exact spot on the video, and also the limited dynamic range of the sonic output. Because of its absolute position sensing, introduction of the tablet immediately solved the first problem[3], while mapping pressure to overall loudness added crucial dynamic sensitivity. Additional axes then became available for further expressive control, as shown in table 2.

Table 2. Control Mappings for *News Cycle #2*

Dimension	Mapping
Y-axis	Vertical position of line from video
X-axis	Luminosity "noise gate"
Pressure (either pen)	Overall gain
Grip pen: Button 1	Turn on/off flange effect
Grip pen: tilt	Depth of flange effect
Grip pen: button 2	Change to color selection mode
Grip pen: Eraser end tilt	Rotate scan line
6D Art Pen: Rotation	Rotate scan line
Left bank of buttons	Trigger recording and playback in red, green, or blue slots
Left Touch Strip	Control noise/video signal balance
Right buttons	Movie start/stop

It is always important to account for the theatrical dimension of musical performance [26], especially of a multimedia piece that already has a visual dimension. Given the complexity of this video, and resulting sound, the audience needed to have a sense that the sounds were the result of gestures being performed live. The performer is placed on stage, slightly to the side of the projected image and dimly lit, with the tablet on a horizontal music stand at about waist height. Much effort was put into the control mappings and performance to ensure that a broader physicality would be manifested. The gestures required to draw shapes and change pressure on the tablet could translate into clear motions, not only of the hand but through the shoulder and into the body, telegraphing the musical content of the piece. Pen

[3] We also considered using a combination display and tablet, such as Wacom's Cintiq, because it would allow the performer to place the pen directly on the moving image. This was not done because these tablets have fewer control dimensions, are more expensive, and would have directed the performer's focus downwards, towards the desk. We found it better to direct audience attention forwards by looking at the projected image. Furthermore, coordinating hand placement on the tablet with coordinates on the image turned out to be an easily acquired skill.

changes also became a dramatic gesture. Unlike watching a performer behind a laptop, the viewers see the larger motion of the performer, and empathize with the fact that they are “making music.”

Figure 6. Still from *News Cycle #2*

Although this instrument was developed in the context of one specific performance, it was designed to interact with many different kinds of video. It is notable that the sonic result from pulling scan lines from more traditional cinematography, or animation, are quite different that the sound world of *News Cycle #2*. Also, we are exploring the possibility of feedback into the video dimension, cases where the sounds that result from the video influence the future of the video in a linked chain of trans-media interactivity.

3.4 Daniel Cullen: harp composition space

Daniel Cullen uses the Wacom tablet as tool to explore compositional ideas, designing a space in which to improvise and develop material for use in written composition. In the interest of exploring a specific harmonic space, Cullen’s harp patch models the desired compositional content by laying out materials in a way that can be explored with the tablet.

The patch processes tablet data through musical and gestural mappings and passes the result via MIDI to Vsamp [27], a VST sampler, with a bank of harp samples. All aspects of musical content are in the mapping section, where the space is designed to access specific notes according to the pen's gestures. Mapping the harp (in this case a lever harp) to the tablet is fairly direct: drawing across the space corresponds to strumming across the strings. What makes this control space different from a MIDI keyboard is the ability to draw crude "brushstrokes" which are refined by the constraints defined in the patch.

The surface design of the tablet (figure 7) maps out the harp strings in various modal subsets. This diagram is physically attached to the surface of the tablet during use. Placement of the pen tip determines harmonic content and subsets while gestures using the pen's tilt and buttons play chords or execute various figurations of interest to the composition. Additionally, the sampler includes harmonics and other timbres available on the harp, accessed by the tablet's buttons**.**

With the harp patch, the tablet becomes an instrument that abstractly resembles both the harmonic material of the composition and the instrument itself. We intend to explore the potential for other uses of the pen interface as a compositional aid.

While algorithmic compositional methods are appealing, navigating their complexity can be arduous and uninspiring. By combining carefully designed musical spaces with viscerally effective gestural interfaces, we hope to achieve the deliberate quality of algorithmic composition combined with the spontaneity of improvisation.

C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C
C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B
C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C
C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C
C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B
C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C
C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C
C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B
C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C
C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C
C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B
C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C
C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C	D	F	A♭	B♭	C♯	E	F♯	A	C
C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B	D	F	G	B♭	C♯	D♯	F♯	A	B
C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C	E♭	F	A♭	B♮	C♯	E	G	A	C

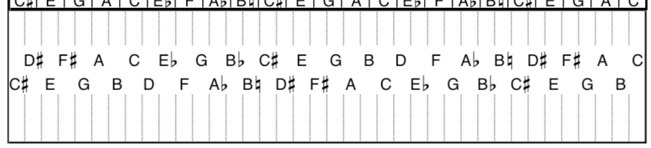

Figure 7. Pitch Mapping for Daniel Cullen's Harp Patch

4. FUTURE RESEARCH

All of the users in this paper have taken advantage of their non-writing hand to manipulate controllers with a different set of affordances: bank of faders (Wright), contact microphone (Momeni), and buttons and touch strips on the tablet (Cullen and Zbyszynski). Formal study of two-handed, “mixed sensing” setups would be of great interest, both in understanding the way we learn to play new musical instruments, and in identifying optimal combinations of controllers for specific expressive situations.

While it is very important that the tablet allows for a very precise, low-level interaction with music sound, it would also be possible to simultaneously employ gesture recognition strategies to extract higher-level control data from tablet performances. Matt Wright is already working in this mode, with his use of “strokes” (see above). Exploration into extracting gestures, ranging from plucking or beating to Graffiti-like handwriting analysis, would be another fruitful area of tablet research. [28]

It has also been suggested that acquisition of performance skill could be improved by adding haptic feedback [4] in addition to the existing tactile reference. This might be accomplished by attaching an audio or vibration transducer to the tablet.

5. CONCLUSIONS

Ten years of musical work with Wacom tablets has confirmed our initial intuitions. They have proven to be expressive and robust controllers, adaptable to disparate situations including musical improvisation, interactive sound installation, interactive multimedia performance, and as a compositional assistant. Furthermore they have been used by many different musicans inside and outside of CNMAT [29] and in a diverse spectrum of musical styles and cultures.

In addition to the Wacom’s quantitative merits as a controller, the tablet offers a gestural language whose affective characteristics

are deeply ingrained, both for the performer and the viewer. We can all imagine pen-based gestures such as an angry scribble or delicate tracing. In an electronic world, where any sound can be triggered by any action, it is of great value to be able, if the aesthetic demands, to perform in a physical language that communicates meaning to the audience. Additionally, we have used pen gestures to imitate gestures common to acoustic instruments, such as plucking or strumming, adding another layer of semantic reference. In the case of interactive installations, it is desirable (and often difficult) for participants to understand the type of interaction the installation invites. The familiarity of the pen (even if it is five feet tall) solves this problem by immediately communicating the kinds of actions that are likely to lead to an expressive result. Participants do not need to "read the manual."

6. ACKNOWLEDGMENTS

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