New Renaissance Institute®
Technology White Paper

THE NRI® RICH TOUCHPAD

Music and Performance Applications

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ABSTRACT

This document describes music and performance applications for the NRI® rich touchpad, a novel touchpad controller, based on U.S. Patent 6,570,078, which can be used for a wide variety of real-time applications. The touchpad is very powerful, provides an unprecedented capability to enter large amounts of information at high speed and is extremely flexible in the kinds of input it can process, the kinds of output it can produce and in how it is configured. The touchpad creates images of the pressure exerted on it and can recognize images created by contact with different parts of the hand (e.g. a fingertip, flat finger, palm, wrist). It can process multiple areas of contact simultaneously and can extract the values of a large number (typically three to six) of continuous parameters from each area of contact. The touchpad is simple to use, and its capabilities can easily be extended. It can be favorably compared to conventional computer pointing devices, such as the mouse, trackball and conventional touchpad, which typically provide control of only two continuous parameters at any one time and can process only a single region of contact.

The general-purpose nature of the touchpad permits the same basic system to be used in a wide range of applications. They include CAD/CAE workstation control, real-time machine control, human-machine interfaces for the physically disabled and electronic musical instruments. The touchpad can also be used in intelligent machine sensing and robotics applications.

The touchpad can be implemented in a variety of ways. In one implementation, it incorporates a two-dimensional pressure-sensor array, a data acquisition and compression stage, an image processing and recognition stage, and an application interface. Special hardware and algorithms permit the data processing and image processing to be carried out in real time. The system can be modularized to support partitions of the sensor array into functionally discrete regions and aggregations of sensor arrays to form larger arrays.

This document is based on U.S. Patent 6,570,078 and related issued and pending patents, all licensable from NRI®. Detailed hardware and software reference designs can be discussed under negotiable terms. All financial or in-kind proceeds from such arrangements will be used to fund pure academic research at NRI®. Contact inquiries@newrenaissance-institute.com *for more information.*

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1 Introduction

This document, based on U.S. Patent 6,570,078 [1], describes music and performance applications for the NRI® rich touchpad, a novel controller that can be used for a wide range of data entry and real-time applications. The touchpad was originally envisioned as a human-machine interface, though it can also be used in machine sensing and robotics applications. When used by the hand, the touchpad provides an unprecedented capability to enter large amounts of information at high speed.

The touchpad incorporates a pressure-sensor array for gathering information in the form of real-time images of the pressure exerted on it [2]. When used as a human-machine interface, these images are typically produced by contact with the user's hand, though they can be produced using other parts of the body, such as the feet. The pressure images are presented to a data acquisition and compression stage, whose output is sent to an image processing and recognition stage. The image processing and recognition stage is used to identify the shape of particular types of pressure images (e.g. images of a fingertip, flat finger, thumb, palm, wrist). The touchpad can process multiple regions of contact simultaneously and can extract the values of a large number (typically three to six) of continuous parameters from each region of contact. An application interface assigns these values to control signals, which can be used to control arbitrary external systems. Special hardware and algorithms enable the data acquisition, the image processing and recognition, and the derivation of parameter values to be carried out in real time [1,3].

The rich touchpad can be favorably compared to conventional computer pointing devices, such as the mouse, trackball, stylus tablet and conventional touchpad. Conventional computer pointing devices typically provide simultaneous control of only two continuous parameters and can process only a single point of contact. In addition, the way in which the rich touchpad is operated is much more natural and intuitive than the way in which conventional pointing devices are operated.

The touchpad can be used as a human-machine interface in a wide variety of applications, including CAD/CAE workstation control, real-time machine control, human-machine interfaces for the handicapped and electronic musical instruments. In addition, as mentioned earlier, the touchpad can also be used in machine sensing and robotics applications. The touchpad naturally lends itself to metaphors useful in a wide range of user interface applications and is simple to use, and its capabilities can easily be extended. Because of the touchpad's general-purpose nature and flexible reconfiguration capabilities, one basic system can be adapted for a wide range of applications.

This rest of this document is organized as follows. Section 2 provides a brief overview of the user-level operation of the touchpad. Section 3 illustrates how the rich control the touchpad provides can be fruitfully applied to one particular music application, timbre control. Section 4 describes more music applications of the touchpad. Section 5 describes some non-music performance applications of the touchpad.

The user-level operation of the touchpad is described only briefly in this whitepaper. For detailed information, as well as some examples of applications in areas besides music and live performance, see the companion operation and applications whitepaper [2], as well as U.S. Patent 6,570,078 [1]. Additional information about the user-level operation of the touchpad, as well as some additional music and performance applications, are provided in U.S. Patent 6,689,947 [4]. For information about the touchpad technology, see the companion technology and implementations whitepaper [3] and U.S. Patent 6,570,078 [1].

2 Rich Control

As mentioned earlier, a principal difference between the rich touchpad and conventional pointing devices is that the rich touchpad provides simultaneous control of many more continuous (as well as discrete) parameters. This section briefly describes the pressure-sensor array employed by the user to operate the touchpad and the touchpad's user-level operation. For more information about the sensor array, see [1,3]. For more information about the touchpad's user-level operation, see [1,2].

Pressure-Sensor Array

An array of pressure-sensors, illustrated in Figure 1, is a central component of the touchpad. The user operates the touchpad by touching the surface of the array. The dimensions of the array range from several inches on each side to a little more than an inch or even less, depending on the application. The spatial resolution of the individual pressure sensors is 1 to 2 square millimeters, and the number of gradations in pressure the sensors can measure ranges from 16 to 256, also depending on the application. The sensors produce pressure measurements, which are passed to an image processing stage. The image processing stage extracts values of various parameters, which are then assigned to signals used to control an external device.

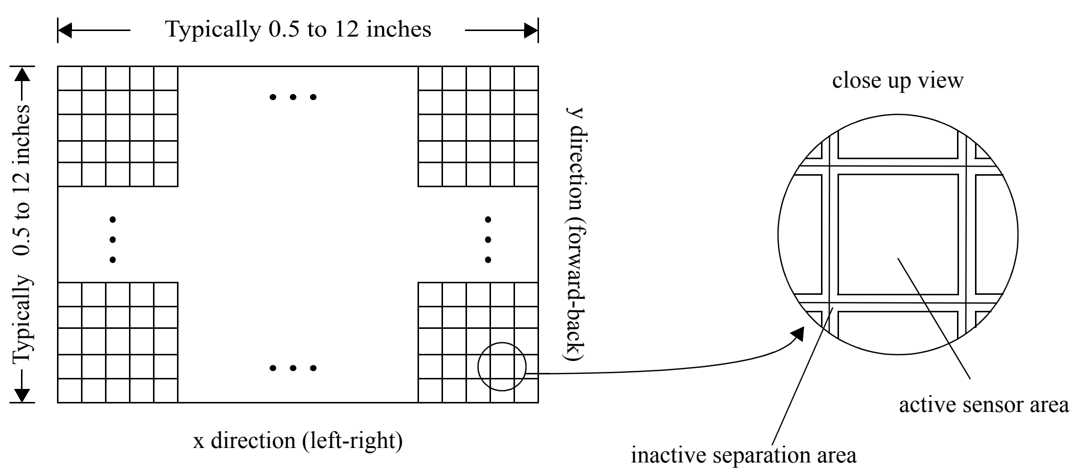


Figure 1. Pressure-Sensor Array

Single Region of Contact

Assume the sensor array is contacted by the end joint of a single finger, as suggested in Figure 2a. The pressure image produced by such contact will be similar to that shown in Figure 2b. Note that the darker the image, the higher the pressure.

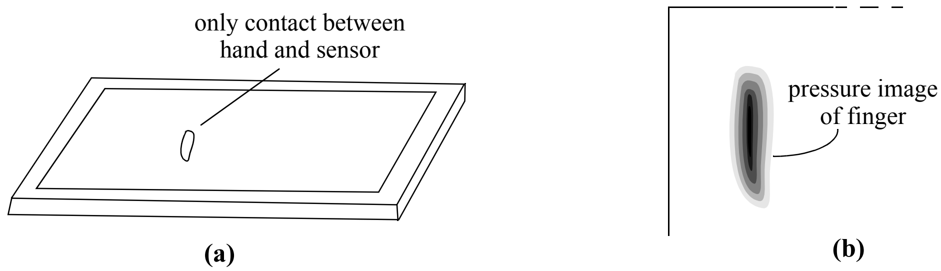


Figure 2. Contact of Finger with Pressure-Sensor Array

The finger can contact the sensor array anywhere on its surface, so the geometric center of the image determines two parameters -- the center's x and y coordinates -- that are easy to control independently of one another. The roughly elliptical form of the image has a measurable angular orientation, which the user can vary by moving her wrist so the finger pivots around its point of contact with the sensor array. It is also possible to control two dimensions of the finger's tilt, the degree to which pressure is concentrated with respect to the left-right axis and the front-back axis. Finally, the user can readily learn to keep all these parameters relatively constant while varying the average or total pressure, giving a sixth independent parameter. Thus the touchpad enables a single finger to simultaneously control six independent parameters in a way that is very easy to learn. By varying the values of the parameters, the user can vary corresponding parameters of an arbitrary external device. The parameters can be assigned to various control tasks in music synthesis, audio processing, lighting, machine control and other real-time processes. Figure 3 illustrates the six degrees of freedom just described.

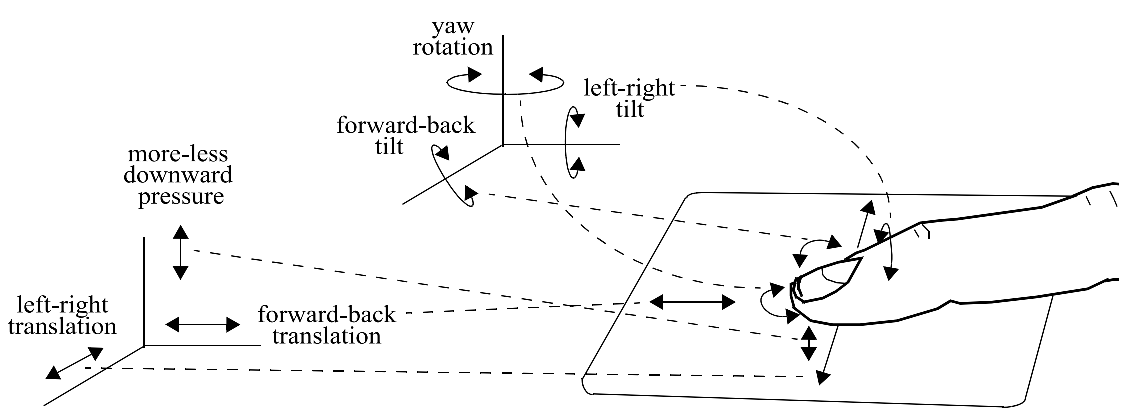


Figure 3. Six Parameters Can Be Controlled Simultaneously with One Finger

In the example just given only the finger end joint was used to operate the touchpad, but other parts of the hand can be used. Figure 4 provides some examples of various hand positions that can be used to operate the touchpad. These hand positions, or variations on them, are used to play traditional hand drums, such as the South Asian tabla/baya bols and the Persian dumbek, and the touchpad can respond to different forms of contact in ways that emulate the different sounds the drums produce in response to these hand positions. For example, the touchpad can emulate a South Indian baya (also known as a bayan or duggi), where the position and pressure of the wrist together affect the pitch of the sound produced, and the position of the wrist also affects the decay time of the amplitude and spectral-modulation envelopes.

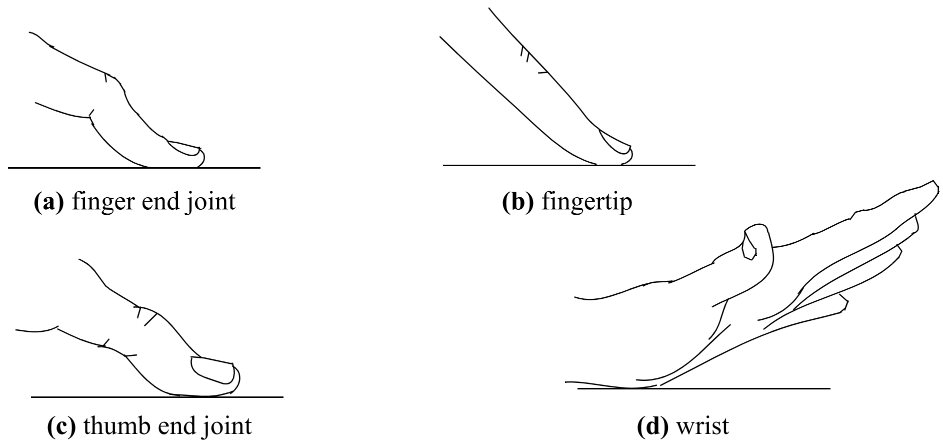


Figure 4. Examples of Hand Positions Used to Operate the Touchpad

The different hand positions shown in Figure 4 produce regions of contact with different shapes. Figure 5 illustrates the differences in the shape of the contact regions produced by the different hand positions shown in Figure 4. The touchpad's image processing stage can incorporate a real-time shape recognition capability that enables it to identify these shapes [1,3].

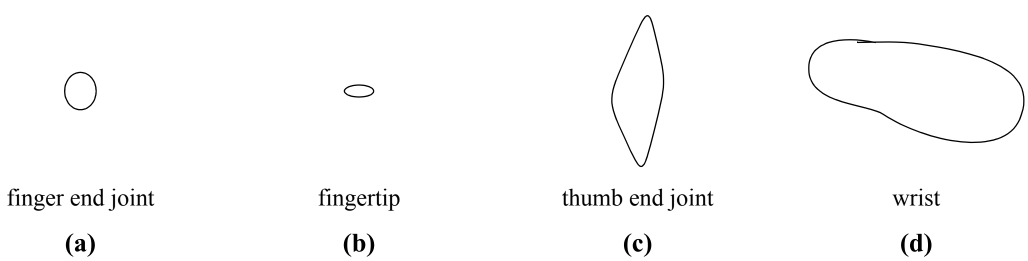


Figure 5. Shapes of Regions of Contact Produced by Various Forms of Contact

The response of the touchpad to contact with the pressure-sensor array can be made to depend on the particular way the shape of the resulting region of contact is classified. Different forms of contact can produce different kinds of sounds, vary a sound in different ways, route output signals in different ways and so on. For instance, one form of contact (such as contact with a fingertip) can be used to control variations in signals directed to one MIDI channel, for producing and controlling one kind of sound, while another form of contact (such as contact with a thumb end joint) can be used to control variations in signals directed to another MIDI channel, for producing and controlling another kind of sound.

Multiple Regions of Contact

A notable feature of the touchpad is its capability to process compound images, images comprising multiple regions of contact. Figure 6 shows a compound image created by pressing the left part of the left hand against the sensor array with the palm raised. The image consists of four non-overlapping, contiguous regions or "blobs."

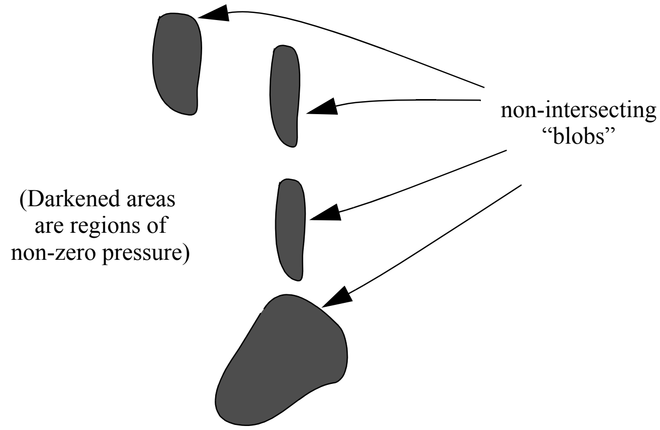


Figure 6. A Sample Compound Image

In general, contact between the pressure-sensor array and multiple parts of the hand forfeits some degrees of freedom but introduces others. For example, if the end joints of two fingers are pressed against the sensor array, as in Figure 6, it will be difficult or impossible to induce variations in the image of one of the end joints in six different dimensions (as described earlier) while keeping the image of the other one fixed. On the other hand, there are other parameters that can be varied, such as the distance between the two end joints. Compound images can provide control over many more parameters than a single contiguous image can provide. For example, by using the whole hand pressed flat against the sensor array, it is possible to vary as many as 17 parameters independently of one another [1,2].

The shape recognition capability of the touchpad, described earlier, can be used to identify particular kinds of compound images, as well as the regions of contact that are components of those images. The location of a region of contact can be used to help identify the type of contact that produced it. For instance, in the case of an image produced by laying the hand flat on the pressure-sensor array, the image of the thumb can be identified in virtue of its position relative to the image produced by the rest of the hand.

The response of the touchpad to a compound image can be made to depend on how it is classified, just as the touchpad's response can be made to depend on how a simple image, an image comprising only a single region of contact, is classified. Further, the response to a particular form of contact can be context-dependent. Consider the following example. If an image of a thumb end joint occurs by itself it generates a note in a melody. But if it occurs as part of an image that also includes a fingertip, then the image of the fingertip generates a note in a melody while the image of the thumb end joint produces a percussion effect.

Sequences of Images

Not only can the touchpad identify particular kinds of compound images, as we have just seen; it can also identify particular sequences of images. The images in the sequence can be simple or compound. And, just as the touchpad's response to a component of a compound image can be made to depend on the context created by the rest of the image, the touchpad's response to a particular image in a sequence of images can be made to depend on the context created by the images that come before and after it.

Suppose, for instance, that a fingertip is used to control variations in the absolute pitch of a sound. If an image of a thumb end joint follows an image of a fingertip, it produces a second sound with a pitch a certain interval above or below the first sound. But if the thumb image follows some other kind of image, such as an image of a wrist, then the thumb image produces a sound with a certain absolute pitch.

Image Languages

We have just seen how the response to a particular image can be sensitive to the images that come before and after it. We can build on this idea by treating sequences of images as sentences of a language. The syntactic rules of the language specify how complex linguistic structures are constructed from simpler ones, and the semantic rules specify how the linguistic structures are interpreted and assigned to control signals. Consider the following example. An image of a wrist is interpreted, according to the semantics of the language, as a specification of a particular timbre, such as the sound of a clarinet. There is a syntactic rule that requires that a wrist image be followed by images of one or more fingertips. The fingertips produce sounds whose pitch is determined by the location of the fingertips on the pressure-sensor array, and all the sounds have the timbre determined by the wrist.

In constructing a grammar for such a language it will be advantageous to take account of the biomechanics of the hand and arm, so that the syntactic rules specify sequences of movements that it is natural for a user to make. For instance, it is very easy to make a sequence of movements that begins with touching the pressure-sensor array with the tip of the little finger, then with the rest of the finger, then with the palm and then with the wrist. But it is much less natural to make a sequence of movements that begins by touching the sensor array with a flat finger, then with the wrist, then with the tip of the finger and then with the palm. Accordingly, the syntactic rules should exclude sequences like the second but might admit sequences like the first.

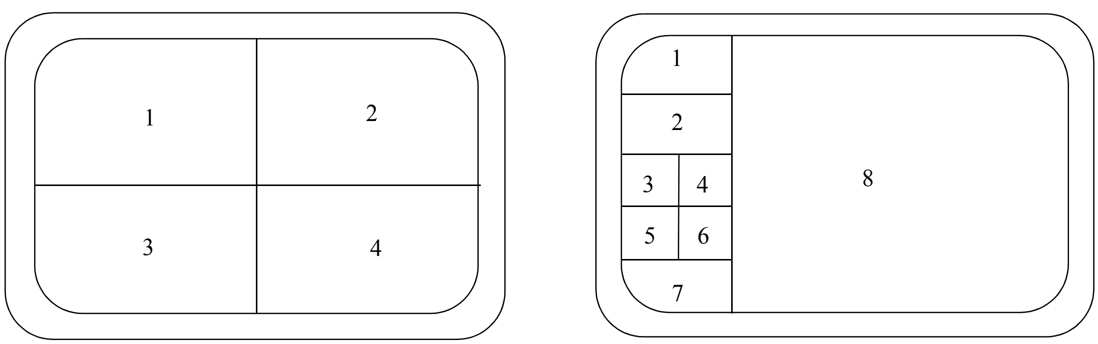
We can extend this idea by introducing the notion of a "continuous grammar." To illustrate this idea, consider the example we just gave of a natural movement that begins with the tip of the little finger touching the sensor array and ends with the wrist touching it. In this case, it is natural for the user to make the entire movement so that each part of it flows into the next, without ever breaking contact with the sensor array. It would be useful for the semantic rules to include some parameter assignments that ignore the continuity of the movement and break it up into discrete parts. For instance, contact with the fingertip, flat finger, palm and wrist might each generate chords, and the chords might be related to one another so that the sequence of movements produces a standard chord progression.

But it would also be useful to include some semantic rules in the language that exploit the continuity of the overall movement. One way to do this is to have the interpretation of the relevant parameters smoothly handed over without abrupt changes as the hand contact evolves. Abandoned parameters would either hold their last value or return to a default value using a controlled envelope. Suppose, for instance, that images of a fingertip, a flat finger, a palm and a wrist all produce distinctive kinds of sounds. Then, if the natural sequence of movements described earlier is made, the different sounds might merge into one another. For instance, if the timbres of the sounds are different, rather than having them abruptly change, they would change along continuous dimensions of abstract timbre spaces. (For examples of such spaces, see section 3 below.) And, if the sounds associated with each kind of image have different pitches, they would be gradually lowered or raised to shift from that associated with one kind of image to that associated with another kind.

In a very advanced implementation, the principles governing the operation of the touchpad would incorporate a general theory of the biomechanics of the hand and arm. The syntactic rules governing the formation of complex linguistic structures out of simple ones would be based on the general biomechanical theory. The semantics could assign various forms of hand contact to visual as well as auditory effects in meaningful ways. For instance, sequences of hand movements that are naturally made could be associated with sequences of images that have a narrative structure and sequences of sounds that contribute to the narrative, like a musical score for a movie.

Partitioned Operation

It is possible to partition the pressure-sensor array into multiple, functionally distinct regions, as illustrated in Figures 7a-b [1-3]. Each partition operates independently of the others, and different partitions can respond to the same kind of contact in different ways. For instance, different partitions can be used to produce different pitches or types of sounds, and the sensor array can even be partitioned to resemble a keyboard. Note that a pressure-sensor array can incorporate a display [3]. The display can be used to mark the partitions with lines indicating their borders or with different colors for different partitions. Text can be used to label the partitions.



(a) (b)

Figure 7. Examples of Partitions of a Pressure-Sensor Array

If different pitches are assigned to different partitions, and if the partitions are sufficiently large, it will be possible to control pitch with a great deal of accuracy. Pitches can be assigned to partitions in such a way that moving from one partition to the next generates successive notes in a scale or melody. In this way, partitioning can be used to quantize the effects of a continuous movement into discrete steps. A small "vibrato" neighborhood can be defined within each partition. Wiggling the finger within the neighborhood would produce variations of the pitch associated with the partition, just as wiggling a finger in a certain position on a violin string produces variations of the pitch produced with the finger in that position. Another application that makes use of partitioning, musical toys for children and advanced, highly expressive musical performance environments, is described at the end of section 4.

3 Timbre Control

In this section, we illustrate how three to six independently adjustable parameters derived from pressure images can be used to control musical processes and allow one to "finger paint" with sound. All the examples involve the control of timbre. We will briefly consider, in turn, vocalization synthesis, timbre-space control and model-based synthesis. Touchpads used for timbre control can be large ones, designed to be operated by most or all of the hand, or small ones affixed to musical instrument keys, designed to be operated by the fingertips.

Vocalization Synthesis

It is well known from both phonetics and vocal pedagogy that the quality of a vowel sound is largely determined by the frequencies of resonances produced by the vocal cavity [5,6]. As a result, realistic vowel sounds can be created by applying a pair of band emphasis filters to simple sawtooth or narrow-wide pulse oscillator waveforms, with variations in the filter emphasis frequencies producing variations in the vowel sounds. Figure 8, adapted from Winckel [5] and Appleman [6], illustrates how vowel sounds vary as a function of their first and second formant frequencies. By using the surface of a pressure-sensor array as a metaphor for the distribution of vowel sounds shown in Figure 8, they can be selected and varied by touching the sensor array and varying the x and y coordinates of the region of contact.

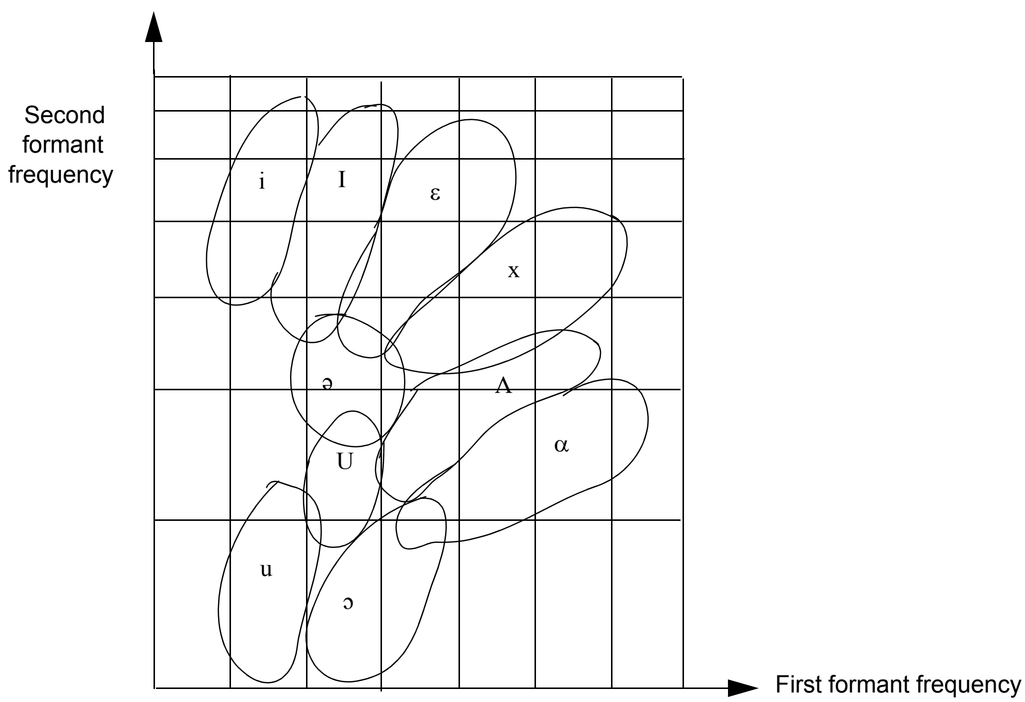


Figure 8. Two Dimensions of Vowel Sounds

Timbre-Space Control

Wessel [7], Grey [8], Krumhasl [9] and many others have shown that multi-dimensional "timbre spaces" provide a fruitful way to represent the relations among the timbres produced by different musical instruments. Such spaces are useful for analyzing the orchestration of, and for orchestrating, musical works. Even a timbre space with only two dimensions can be useful for understanding the relations among important aspects of the timbre of different instruments.

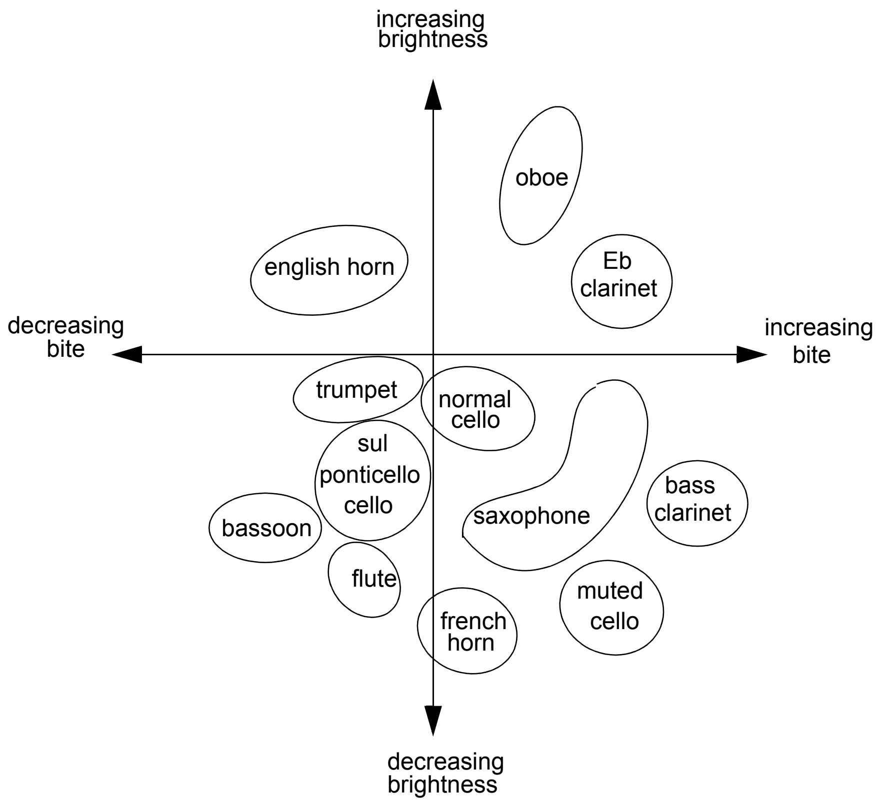


Figure 9. Relations Among the Timbre of Some Orchestral Instruments

Figure 9, adapted from Wessel [7], illustrates one such two-dimensional timbre space. This space represents differences in the brightness of various familiar orchestral instruments in one dimension and differences in their bite in the other dimension. As in the case of vocalization synthesis just described, the surface of a pressure-sensor array can be used as a metaphor for the two-dimensional timbre space, and the user can touch the sensor array in different places to produce systematic variations in the two dimensions of timbre. In realizing a timbre space representing the relationship among the sounds of acoustic instruments, as in Figure 9, volume cross-fading of sampled instruments or synthesized sounds can be used. In a more sophisticated realization, numerical model-based synthesis, which will be described next, can be used.

Since the timbre space just described has only two dimensions and a single finger can provide control over six parameters, variations in other parameters can be used to produce additional variations in the generated sounds. For instance, the total or average pressure can be used for volume control, and the other three parameters can be used to navigate through higher-dimensional timbre spaces, such as ones described by Grey [8] and Krumhansl [9].

Extended Control of Model-Based Synthesis

Model-based synthesis provides a way to recreate the sounds of traditional musical instruments and to control the timbres of the sounds in real time. Model-based synthesis is typically used to produce variations in the sound of a single instrument rather than across instruments, as in the timbre spaces just described. The qualities of the sounds are based on the acoustical physics of the instrument whose sounds are recreated.

Available model-based synthesis products, such as the Yamaha VL1, typically provide control over a large number of parameters but no good way to do so. The interfaces of the products, such as wheels, joysticks and breath controllers, afford control over only a limited number of parameters for each note. Moreover, they can control the sound of only one note at a time. As a result, even the best model-based synthesis products are monophonic -- that is, they generate only one note at a time.

One possible implementation of the touchpad provides an effective way to control the generated sounds. In this implementation, a small touchpad is affixed to the top surface of each key of a musical instrument keyboard. Pressing each key generates a different sound, and the touchpads enable the user to control three to six parameters of the sounds. Since each key can be operated independently of the others and multiple keys can be played simultaneously, a model-based synthesis engine that uses a touchpad keyboard as an interface provides a natural way to implement a polyphonic, model-based synthesis instrument.

To get a sense of how such an instrument might be played, consider the following examples. The first example provides one possible assignment of parameters a finger controls directly to prominent features of a single synthesizer voice:

- left-right position: pitch
- forward-back position: volume
- side-to-side tilt: waveform morphing dimension 1 (e.g. duty cycle, even-harmonic content)
- forward-back tilt: waveform morphing dimension 2 (e.g. waveform curvature, odd-harmonic content)
- left-right rotation: stereo pan
- total pressure: filter opening

In the second example, the same parameters are assigned to features of two synthesizer voices:

- left-right position: pitch of voice 1
- forward-back position: pitch of voice 2
- side-to-side tilt: pan or filter opening of voice 1
- forward-back tilt: pan or filter opening of voice 2

- left-right rotation: relative volume of voices
- total pressure: total volume of voices

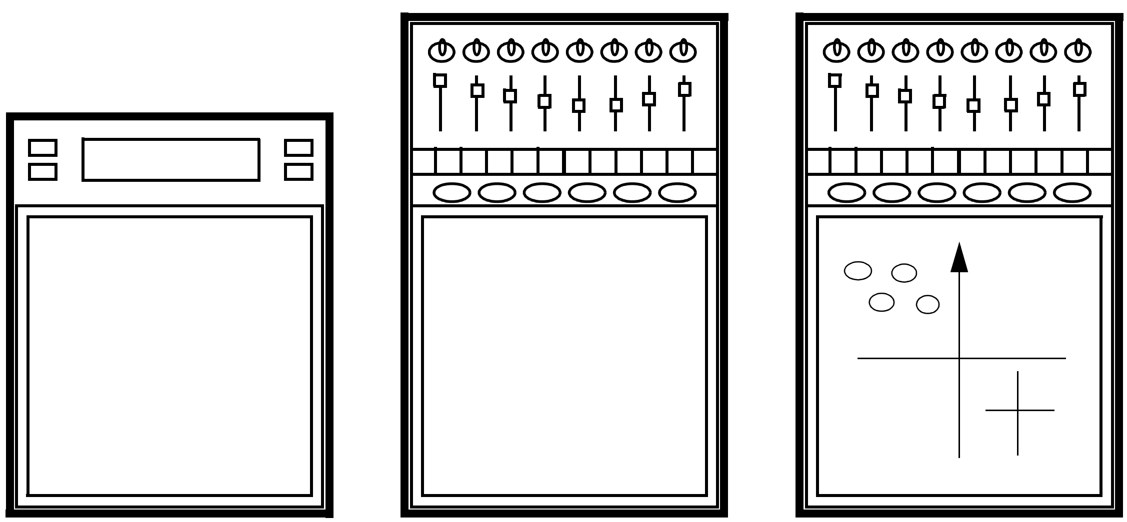
For more information about touchpad keyboards, see the next section as well as [1,10].

4 Musical Instruments

This section provides some examples of touchpad implementations that can be used as stand-alone musical instruments or as components of musical instruments. Such implementations will typically output MIDI messages. They may also receive MIDI messages as input to configure them, and have a computer interface. For more examples of musical instrument implementations of the touchpad see [1,4,10-15].

"Performance Canvases" and General-Purpose Music Controllers

Touchpads of various sizes can be used as stand-alone electronic instruments or as devices for controlling musical sounds. Figure 10a shows a touchpad with a small alphanumeric display and a limited number of panel controls. The panel controls can be used for programming, configuration, operating mode selection and so on. Figure 10b shows an example of an implementation with more panel controls, as well as LEDs. The panel controls include switches, sliders and push buttons. An implementation like this can provide an enhanced version of currently available, general-purpose music controllers, pioneered by products like the Peavey PC-1600. Figure 10c shows a transparent pressure-sensor array positioned over a display. In this case, the display provides graphical cues for the user. An alphanumeric display, which performs the function of the display in Figure 10a, or a video display can also be incorporated. The touchpads can be supplemented with impact sensors for velocity-controlled triggering of notes or percussion effects.

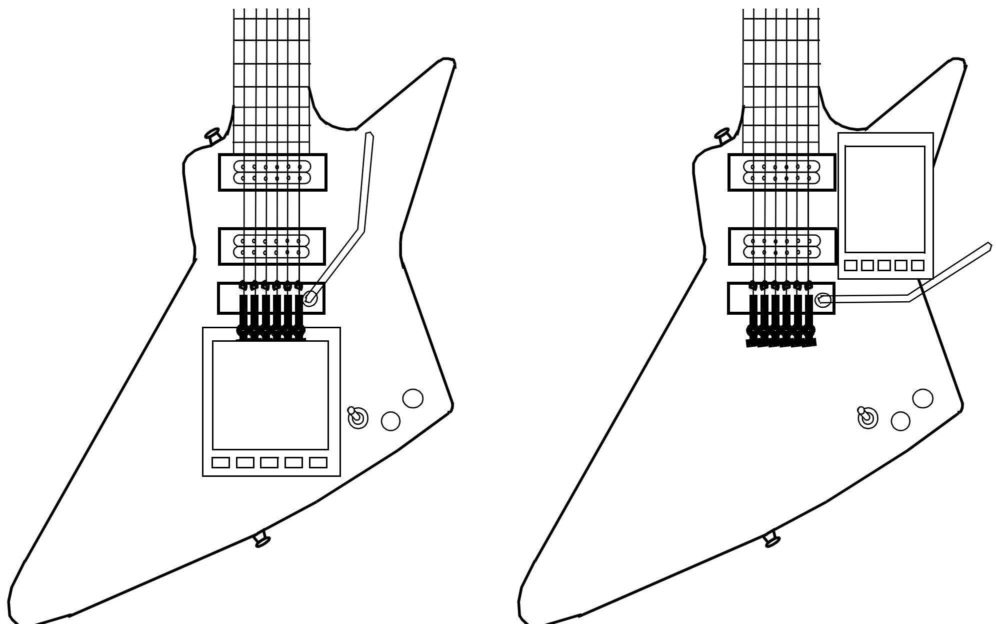


(a) **(b)** **(c)**

Figure 10. Touchpads for Performance Canvases or Music Controllers

General-Purpose Touchpad Attachments

Figures 11a-b show two possible implementations of a removable touchpad module for an electric guitar. In Figure 11a the touchpad is positioned so it can be played by moving the fingers beyond the bridge. In Figure 11b the touchpad is positioned so it can be played by extending the fingers below the strings. A touchpad module like this is self-contained and can include wireless MIDI support. It can be mounted on many different kinds of instruments and supports, including bass guitars, keyboards, drum kits and microphone stands. More discussion of modular touchpad implementations is provided below.



(a) (b)

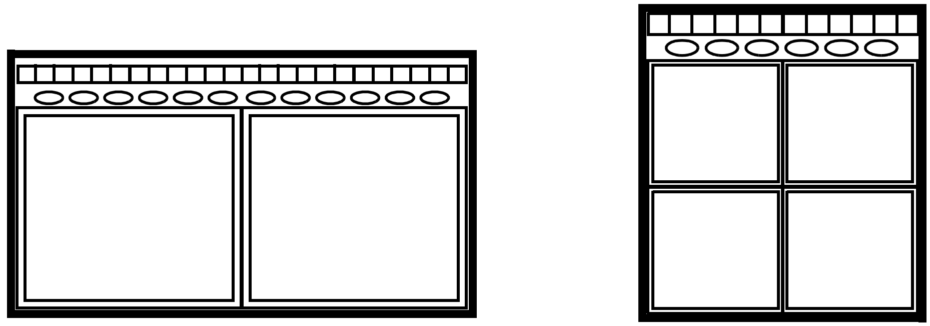
Figure 11. Modular Touchpad Attachments

Ganged Pressure-Sensor Arrays

It is possible to gang two or more pressure-sensor arrays to create more elaborate electronic instruments or controllers than can be created using a single sensor array. Like implementations described earlier, ganged assemblages of sensor arrays can incorporate panel controls, impact sensors and displays. Figures 12a-b show two examples of such assemblages. Figure 12a shows one with two arrays, and Figure 12b one with four arrays.

Many instruments, such as the tabla, baya and congas, consist of two drums connected side-by-side, one for each hand. A touchpad assemblage with two pressure-sensor arrays, like the one in Figure 12a, can emulate such instruments. A touchpad like this can be constructed so that the relative sizes of the two sensor arrays, and their orientation relative to the floor, match those of the specific kind of instrument it emulates.

An implementation of the touchpad with twin sensor arrays, one for each hand, is likely to have many uses besides as a percussion instrument. One possible use is as a general-purpose, two-handed music controller. When used in this way, it may be advantageous to use large sensor arrays, with an area of eight to twelve square inches, for enhanced control. In



(a) **(b)**

Figure 12. Ganged Pressure-Sensor Arrays

touchpad assemblages with more sensor arrays, like the two-by-two assemblage shown in Figure 12b, it may be advantageous to make the individual sensor arrays small enough so that the fingers of one hand can operate two or more of the arrays simultaneously.

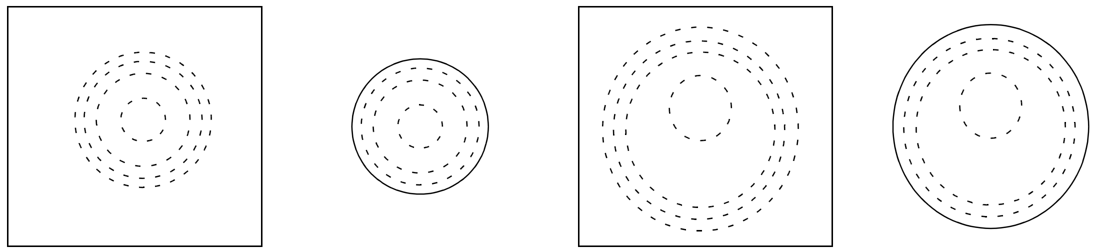
More examples of implementations that include large numbers of sensor arrays, like that in Figure 12b, will be given below. For more information about ganging sensor arrays, see [1,3].

Hand Drum Emulation

The techniques used for playing many kinds of hand drums require that specific hand positions be used. This is true of Persian and South Asian hand drums, such as the tabla, baya bols and the dumbek. As mentioned earlier, the image processing facility of the touchpad can distinguish and identify these various hand positions. It is possible to derive parameters from the resulting pressure images that enable the touchpad to simulate the effects of the different hand positions on the sounds the drums produce. And the touchpad can even provide an enhanced response to the different kinds of hand contact.

Figures 13a-d show examples of formats for the touchpad that are attractive for hand drum applications. Figure 13a shows a rectangular pressure-sensor array that includes a circular region. Hand contact within that region produces the same sounds produced by hand contact with the corresponding part of the surface of the emulated drum. The part of the sensor array outside the circular region can be used to extend the capabilities of the emulated drum. However, having the sensor array extend outside the circular region may be problematic if the player is accustomed to resting her hand on the edge or body of the drum. If so, a circular pressure-sensor array can be used, as shown in Figure 13b.

Dashed circles, as shown in the figures, can be used to indicate the boundaries of different partitions of the sensor array. Different partitions can be configured to respond to the same kind of hand contact by producing different sounds, in a way that emulates certain hand drums. As an alternative, the sensor arrays can have raised areas to mark the boundaries of partitions, like the rim and "gob" of South Asian hand drums such as the North Indian tabla and South Indian mridangam. Figures 13c-d show adaptations of the sensor arrays of Figures 13a-b. In these adaptations, the circular area is larger, and the gob area is displaced from the center, to emulate the North Indian baya (bayan). In cases where a support is desired, a sensor array can be mounted on a stand, as shown in Figure 14.



(a) **(b)** **(c)** **(d)**

Figure 13. Touchpad Hand Drum Implementations

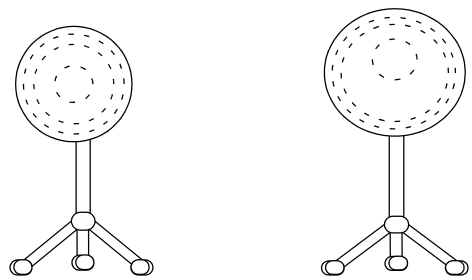
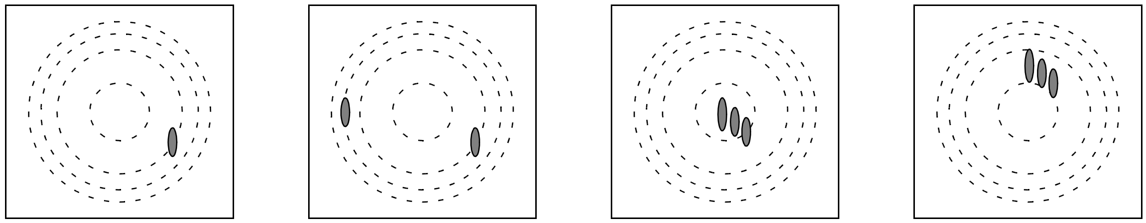


Figure 14. Hand Drum Touchpads with Floor Supports

Figures 15a-d and 16a-d provide examples of pressure images created when a sensor array is played like a hand drum. The first set of figures illustrates a case where a sensor array is played like a tabla, and the second set a case where a sensor array is played like a baya. The traditional bols are recognized and used to control the generation of synthesized or sampled sounds.

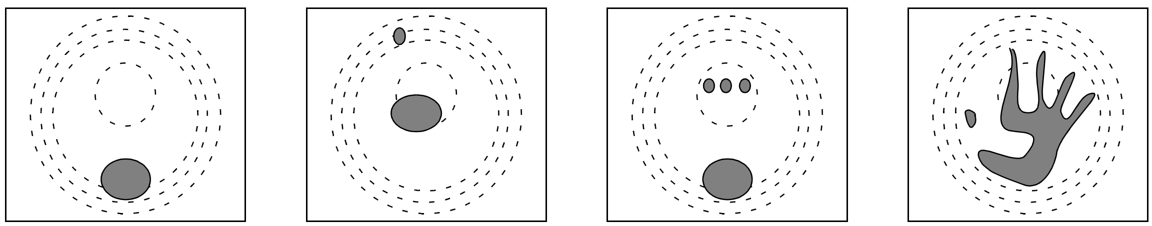
A touchpad can provide a fully authentic replica of a hand drum, or it can be used to extend the drum's capabilities. When used in the second way, striking the touchpad in the same ways used in playing the emulated drums produces the same sounds. But other kinds of hand contact can be used to elicit different kinds of responses. As Figures 15b-d and 16c-d illustrate, it is common in many traditions of hand drum playing to sometimes slap the drum head with multiple fingers at once or with the entire hand. Varying the distance between the fingers in the slap or during the after-touch has no discernible effect on the sound produced. As a result, by taking account of the distance between the fingers that contact the surface of the sensor array, the control the user has over the sounds produced can be extended beyond the control the emulated drum provides.

One possibility is to use the distance between the fingers to control variations in the timbre of the sound. By varying the distance between each finger and the finger next to it, the user can control four different parameters. Other features of the contact between the hand and the sensor array that have no discernible effect when playing the emulated drum can be exploited in a similar fashion. In this way it is possible, for instance, to control the signal processing of the touchpad to expand the range of available sounds by applying such effects as location modulation, muffling or peaking filtering, reverb, sustain or note pitch.



(a) (b) (c) (d)

Figure 15. Baya Pressure Images



(a) (b) (c) (d)

Figure 16. Tabla Pressure Images

Touchpad Keys for Keyboards

The idea of keyboards whose keys allow the user to control multiple parameters is a familiar one. By pressing a key of a piano, the user produces a sound whose pitch is determined by the particular key pressed, and whose volume is determined by the amount of force used to press the key. Like the piano, the multiple tape-loop Melletron, used in many famous recordings, has keys that control the same two parameters. In contrast, by pressing a key of an organ, the user can control only the pitch of the generated sound.

In recent years, keyboards have been developed with keys that enable the user to control more than two parameters. Moog [16] and Snell [17] have created keyboards whose keys enable the user to control three parameters. This is accomplished by incorporating a two-dimensional null/contact touch sensor on each key. A null/contact touch sensor, unlike a pressure-sensor array, does not measure variations in pressure. Instead, it determines only whether it has been touched with an amount of force that exceeds a low-level noise threshold [3]. A similar keyboard, whose keys also allow the user to control three parameters, can be created by combining a null/contact pressure sensor and a key displacement sensor [10]. The keys of such a keyboard, which is polyphonic, can be used to navigate the timbre spaces described in the last section.

But the number of parameters each key controls can be increased beyond three by incorporating a small pressure-sensor array touchpad on each key [1,10]. Such keys would enable the user to control as many as six parameters with a single finger and could also process multiple regions of contact. As a result, the keys would allow the user to control more than two dimensions of timbre. This would be useful for notes of great significance or long duration.

The reason it is useful to control more than two dimensions of timbre for longer notes is that the longer the duration of a sound, the more information the ear gathers about its timbre. A long note without timbral richness or timbral variation will sound bland. Thus the timbre of a note is less important if it is short than if it is long. The keyboard just described is well suited to accommodate this phenomenon. For notes played quickly, it will be difficult to control the precise location of the contact with the key and other parameters needed for precise control of the timbre of the generated sound. But for notes of long duration, it will be easy to control those parameters and to have more precise control over timbre. Thus the keyboard will provide the user with greater control of timbre where it is needed; but when such control is not possible, it will not be needed.

Using Touchpad Chips on Keyboard Keys

One possible implementation of the touchpad is of particular interest in connection with keyboards. It is possible to package a small pressure-sensor array with data acquisition hardware and a small processor to create a low-profile chip [1,3]. The chips can be laid as tiles in arrays. Advanced seating and connector technologies, as used in laptops and other high-performance miniature electronic devices, can be used to minimize the distance between adjacent chips and to make the surface of the tiled array smooth.

There are many possible uses for touchpad chips, but one very natural one is to affix them to the surface of keyboard keys. Although keys incorporating small, dedicated touchpads can be created [1,10], tiled arrays of touchpad chips are likely to prove preferable. For one thing, if dedicated touchpads are used, they would need to have several different shapes. But if arrays of chips are used, all the chips can have the same dimensions, with the dimensions selected so that when tiled the chips will cover the surface of the keys.

Figures 17a-d illustrate how this can be done. Figure 17a shows the various shapes of keys used in conventional musical instrument keyboards. White keys have one of five different shapes. Black keys have one shape, but may be tapered so they are narrower at the top than the bottom. The top surface of the white keys can be decomposed into two contiguous rectangles. The dimensions of the rectangles vary somewhat depending on the style of the keys, but typical dimensions are 0.75” wide by 1.75” deep for the front rectangle and 0.375” wide by 2” deep for the rear. The depth of the top surface of the black keys is typically around 2”. The width will depend on the degree to which they are tapered; two possible widths are 0.25” and 0.3125”. Figures 17b-d illustrate how chips of various dimension can be tiled on the keys. In Figure 17b the chips are 0.25” wide by 0.58” deep. In Figure 17c they are 0.25” wide by 0.75” deep. Figure 17d illustrates a third possibility.

Keyboard-Modulated String Arrays and Electronic Autoharps

Figure 18 shows an array of strings, suitable for strumming, with an integrated 12-note keyboard. In most contemporary autoharps, chord buttons with a damper bar are used to select the chord played. Here, as in the earliest autoharps [18,19], a keyboard is used in place of chord buttons.

The chord buttons and the keyboard keys of early autoharps control mechanical vibration dampers. The dampers inhibit the vibration of some strings and allow others to vibrate, so that only notes of the chord selected with the buttons, or the notes selected by pressing keys,

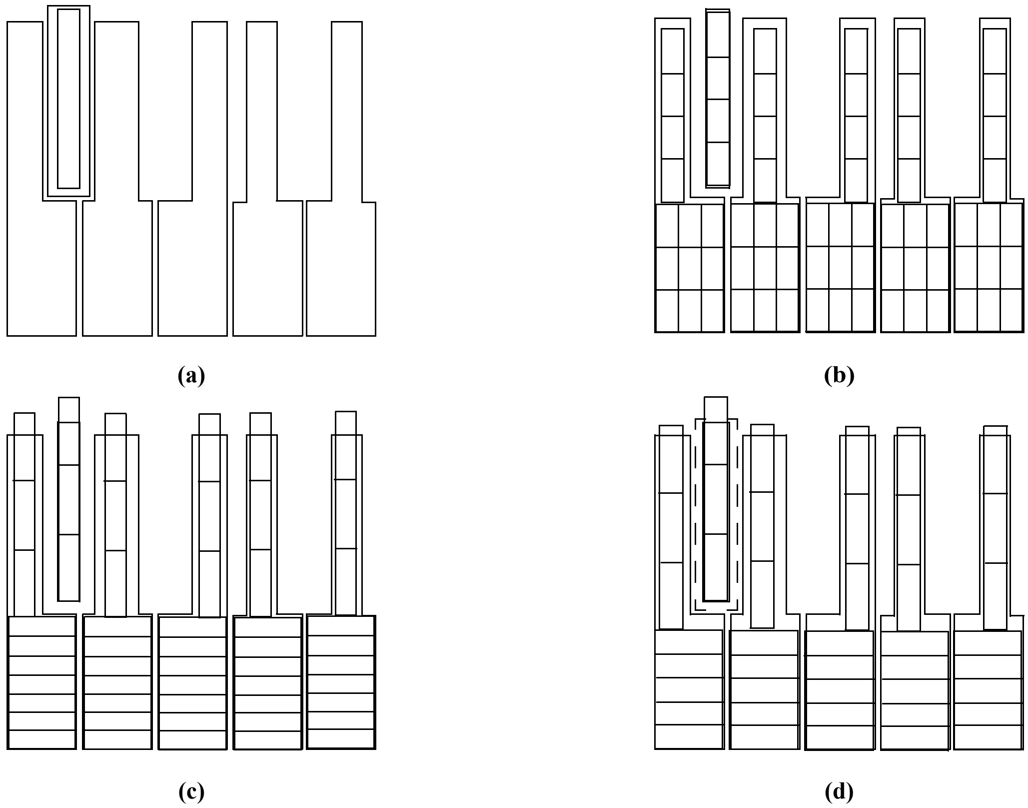


Figure 17. Touchpad Chips on Keyboard Keys

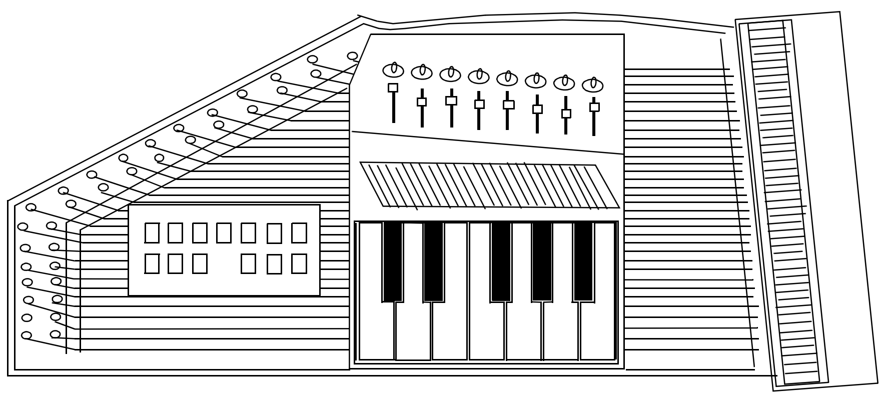


Figure 18. Electronic Autoharp with Touchpad Keyboard

are allowed to sound. But in the electronic autoharp, the mechanical damping apparatus is replaced with electronic amplitude control [18,19]. To implement it, an array of pickups is provided, one for each string. When a key is pressed, a group of notes is gated on. For instance, if a C is pressed all the C's of the instrument are gated on, and if a D is pressed all the D's are gated on. When a note is gated on, the sound produced by the vibration of the appropriate string is amplified by the associated pickup. The total pressure on a key, or the depth to which it is depressed, can be used to control the volume of the group of notes associated with the key.

It is possible to provide each key with a two-dimensional touch sensor. This can be done, for instance, by fitting each key with a null/contact touchpad. One possible use for the touch sensors is to control the relative volume of the individual notes in each selected group. For example, the left-right position on the key can control the relative volume of octaves one and two, and the forward-back position the relative volume of octaves three and four. Or the additional parameters can be used to control signal processing. If each key incorporates a pressure-sensor array touchpad instead of a null/contact touchpad, even more parameters can be controlled.

There are other ways in which an electronic autoharp can be implemented. For instance, instead of generating sounds by amplifying vibrating strings, the vibrations can be used to trigger synthesized sounds, or synthesized sounds can be generated by operating an integrated strumpad. Or the sounds that are amplified can include ones induced by sympathetic vibrations.

Advanced Hybrid Instruments with Multiple Touchpads

It is possible to create an electronic instrument that incorporates multiple touchpads used in various different ways. Figure 19 depicts a full-tilt version of such an instrument, a "transcendental," guitar-based hybrid. One touchpad, used for sound "finger painting," is located next to the bridge. There is a pair of keyboards whose keys incorporate touchpads [10], and, to the right, a touchpad implementation of a long strumpad [14,20]. There are also several small, circular touchpads, which can be used for triggering and controlling percussion effects. In addition, the instrument includes a string array, which can be operated in three different modes: harp, arpeggiation and sympathetic vibration. When used in the sympathetic vibration mode, the keyboards can be used to control which strings are allowed to sound, the volume of the sounds they make and additional signal processing [18,19].

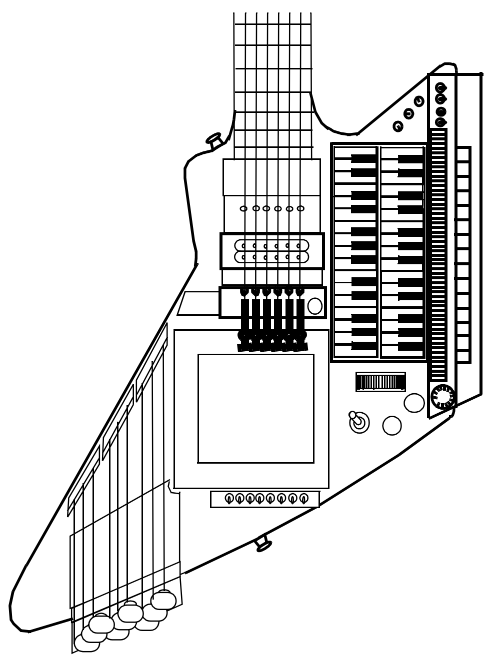


Figure 19. Advanced Hybrid Instrument with Multiple Touchpads

The hybrid instrument can also incorporate electromagnetic or piezo vibration-drive transducers, used for electronically stimulating the vibration of the strings. A simple on/off feedback loop can be used for vibration stimulation. The dynamic and timbral nuances of the sounds generated by the feedback loop can be manipulated by including level control and signal processing facilities [21,22], which can be controlled with the keyboards or with the touchpad next to the bridge.

Touchpad Modules for Modular Instruments

Electronic instruments are typically unitary entities; that is, they consist of built-in, integrated components that are not easily removed or replaced. An important alternative to a unitary instrument is a modular instrument, an instrument built out of interchangeable components that are easy to add and remove [12,13,15,23]. The modules are inserted in various types of mounting frames and instrument bodies, and the modules themselves can be built from various types of submodules. When the modules are inserted in the mounting frame or instrument bodies, or modules are constructed out of submodules, the appropriate mechanical and electrical connections are made. Modular instruments are particularly useful for building customized or hybrid instruments.

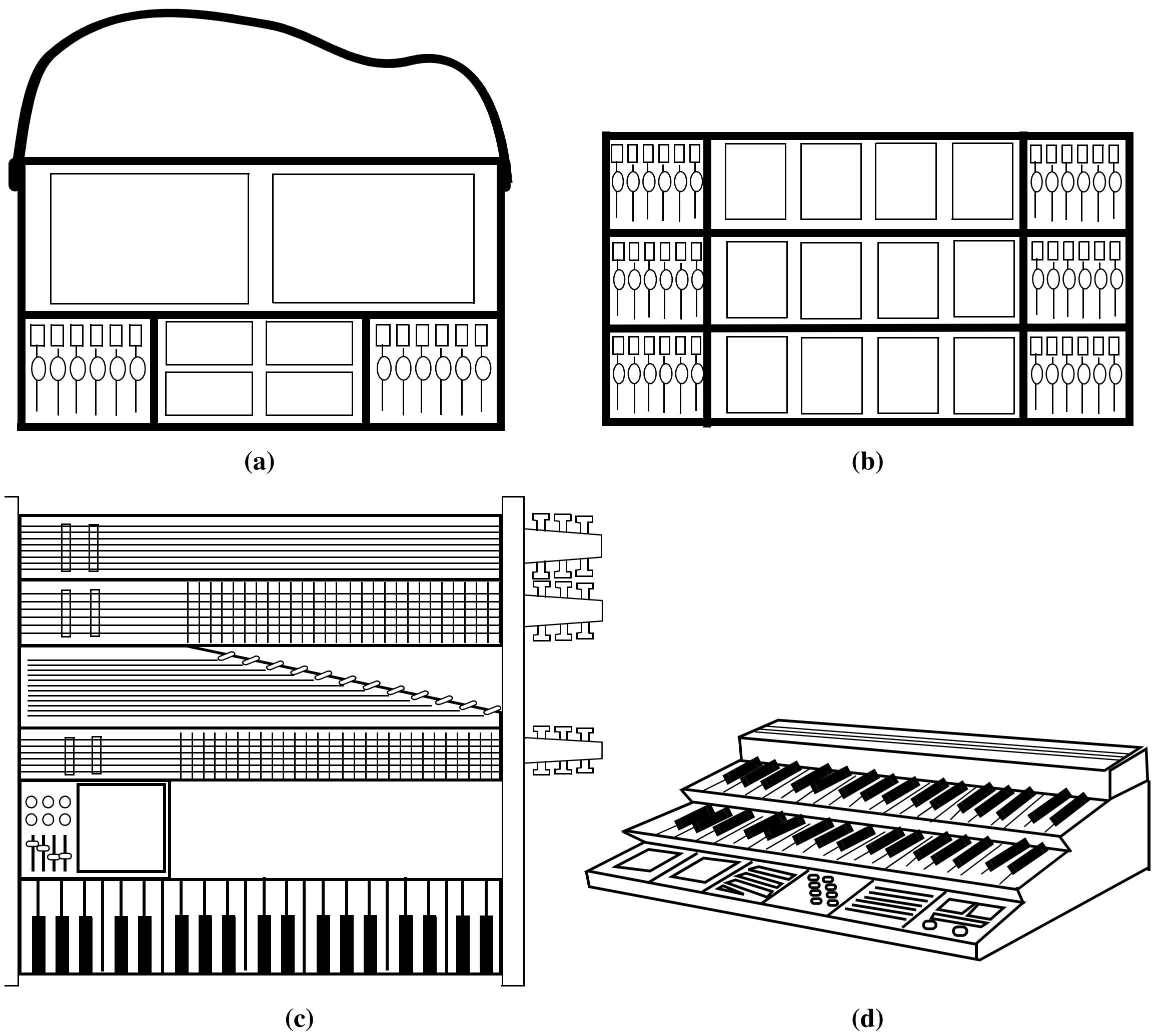


Figure 20. Modular Instruments with Touchpad Modules

As mentioned earlier, instrument modules and submodules can include modular implementations of touchpads. Figures 20a-d show some examples of modular instruments that include touchpad modules. Figure 20a shows a modular instrument that comprises a mounting frame, two control panels and three touchpad modules. A neckstrap is attached to the frame. One of the touchpad modules consists of four touchpad submodules.

Figure 20b shows a modular instrument intended to be supported by a floor-stand or table. The mounting frame is itself constructed out of three smaller mounting frames. Each of the smaller mounting frames has three slots, two small ones and one large one. The small slots are populated with panel controls, and the large ones with touchpad modules. Each of the touchpad modules is constructed from four touchpad submodules, resulting in a modular instrument with a total of twelve touchpads, enough to generate and modulate the sounds of an entire orchestra.

Figure 20c shows a modular instrument consisting of three string instruments, a string array, a keyboard, a small panel control and a small touchpad. Figure 20d shows a modular instrument constructed using a stair-step mounting frame. The instrument consists of two keyboards, a string array and, on the bottom step, an assortment of controller submodules, including a touchpad submodule.

Floor Controllers

Foot-operated controllers, or floor controllers, are an increasingly important part of a musician's performance environment. They can include touchpads operated with the feet [2,4]. The touchpads can be included alongside various foot switches and rocking foot pedals typically found in floor controllers, and can also be attached to the surface of various kinds of rocking foot pedals, as shown in Figure 21.

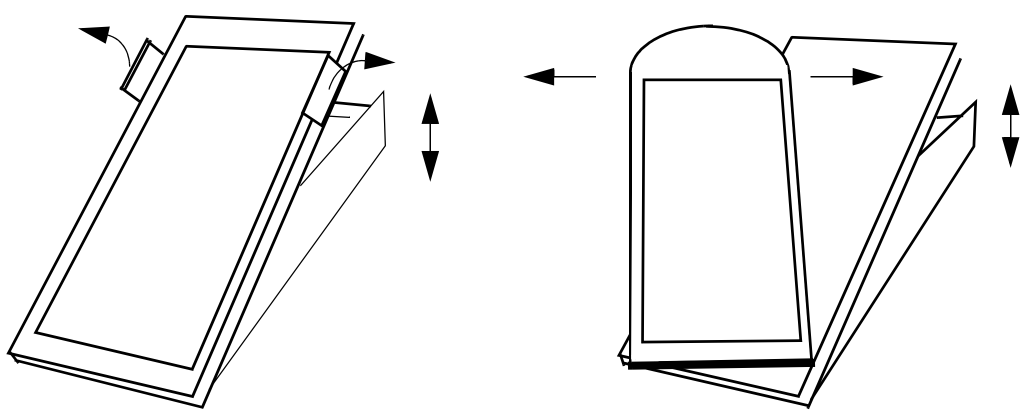
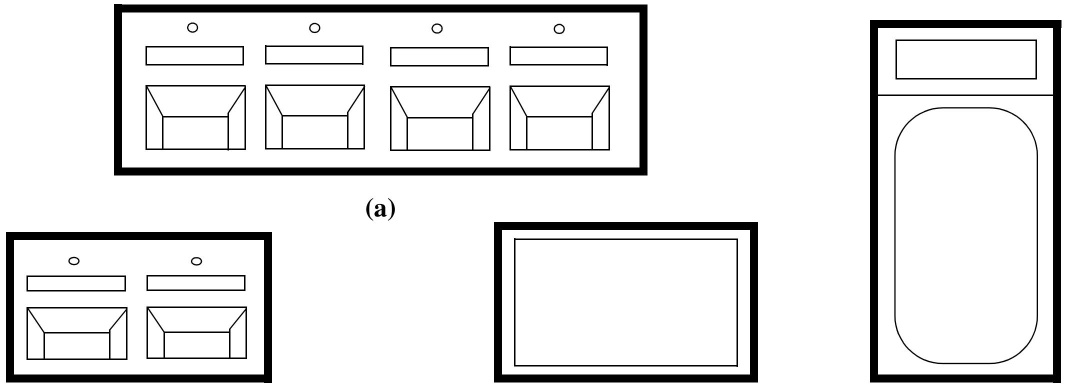


Figure 21. Rocking Foot Pedals with Touchpads

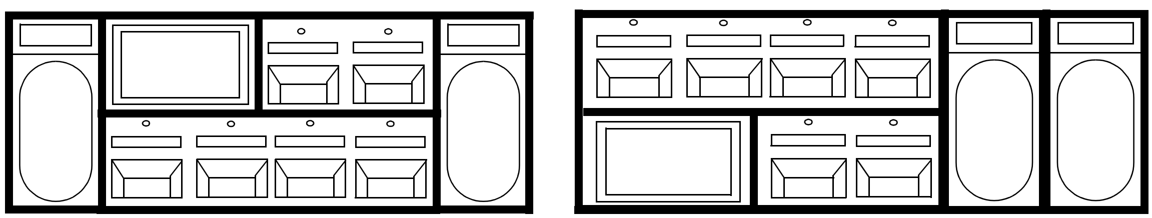
Like the hand-operated instruments described in the last section, floor controllers can have a modular design and incorporate touchpad modules [12]. Figures 22a-d illustrate the form factors and relative sizes of various modules that can be inserted in a floor-controller mounting frame. They include a module consisting of four foot-switches (a), one consisting of two foot-switches (b), a touchpad module (c), and a rocker pedal with a surface-mounted touchpad and alphanumeric display (d). There can be different types of touchpad modules, which are operated in different ways or carry out different kinds of functions.



(a) (b) (c) (d)

Figure 22. Modules for Floor Controllers

Figures 23a-b illustrate two different ways in which the same mounting frame can be populated with instances of the modules shown in Figures 22a-d. If desired, the modules can be removed and inserted in mounting frames of other sizes or with other layouts, or modules can be removed and replaced with others. For instance, the two rocker pedals shown in Figure 23b can be replaced with a small foot-switch module (Figure 22b) and a touchpad module (Figure 22c).



(a) (b)

Figure 23. Floor Controller Modules Inserted in Mounting Frames

Wind Instruments

By crafting pressure-sensors or pressure-sensor arrays out of special types of materials, it is possible to create small touchpads that are convex or concave. Such touchpads can be incorporated in electronic and amplified acoustic wind instruments. The touchpads can be affixed to instrument bodies or keys, or positioned where there would normally be holes in the instrument bodies.

Wind instruments have a variety of forms. Many Western orchestral flutes have several open holes and one or more holes with a covering operated by a levered key, as do some recorders. Many folk and non-Western flutes have only open holes. Although there are electronic wind controllers manufactured by Akia and Yamaha that are based on reed instruments, there are to date no wind controllers with flute- or recorder-like formats. But the techniques that will be described for incorporating touchpads in instruments with those formats can be used as a basis for implementing wind controllers with all types of wind-instrument formats.

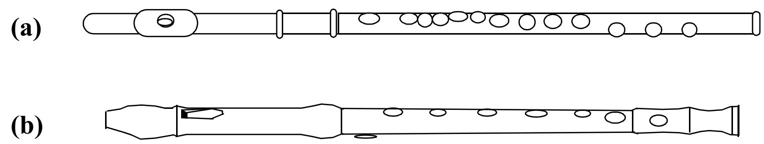


Figure 24. Wind Instruments Incorporating Touchpads

Figure 24a shows an adaptation of a Western flute with closed holes, and Figure 24b an adaptation of a recorder with open holes. Pressure sensors or small touchpads are affixed to the keys (24a) or positioned where the holes would normally be (24b). The instruments also incorporate mechanisms for measuring air turbulence and the average air pressure. The adaptations shown are amplified acoustic instruments, but can serve as a basis for all-electric versions. Transducers located inside the instrument or attached to its body can generate both audio signals, which are subjected to further processing, and control signals (for instance, by mapping pitches to control messages).

String Instrument Bows

As mentioned in the last subsection, special types of materials can be used to create pressure sensors or small pressure-sensor array touchpads that are concave or convex. Convex pressure sensors or pressure-sensor array touchpads can be affixed to bows for string instruments. Figure 25 shows some possible locations for such pressure sensors or touchpads. Control signals and power can be carried over an attached cable, or, to eliminate the cable, the control signals can be transmitted using wireless links, and power can be provided by a lightweight, rechargeable battery. In either case, the bow would be constructed to incorporate the necessary hardware without affecting the weight distribution and balance.

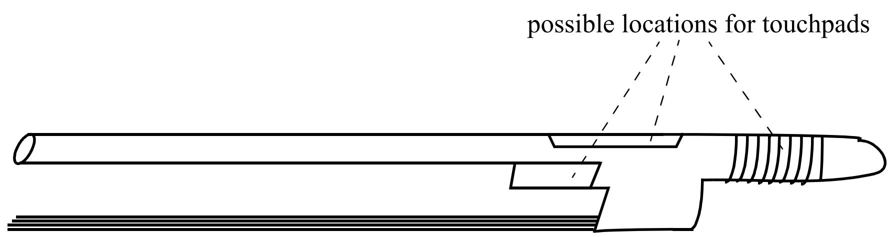


Figure 25. String Instrument Bow

Mallet Grips

Pressure sensors or small pressure-sensor array touchpads can be affixed to the grips of mallets used to play amplified acoustic or electronic percussion instruments. Figure 26 shows a square mallet grip covered with tiles of touchpad chips. Control signals and power can be transmitted using the techniques described in the previous subsection for string instrument bows.

Touchpads for Musical Finger Painting in Toys and Advanced Instruments

There is a growing market for musical toys for children and non-musicians. A natural way to implement a toy like this is to use a touchpad with a row or rows of partitions. Each par-

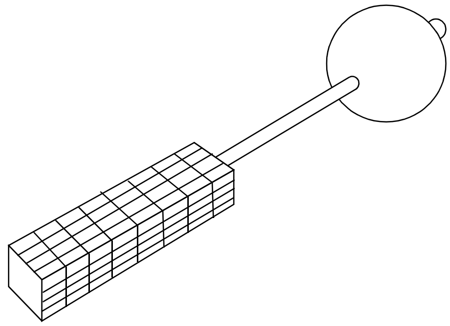


Figure 26. Mallet Grip with Touchpad Chips

tition can be assigned to a different note of a phrase or melody so that, as one moves from each partition to the next, successive notes in the phrase or melody are generated. The note assignments of the partitions can be paged so that when one reaches the last partition a new assignment is recalled from memory. To continue playing the phrase or melody, one returns to the first partition.

A touchpad configured in this way would enable a user to avoid having to worry about the accuracy of the pitches of the notes she plays, as is the case for traditional keyboard instruments. Instead, she could devote all her attention to other aspects of the sounds she produces, like timbre and timing -- aspects that can make the difference between a performance that is run-of-the-mill and one that is spellbinding.

Purists may scoff, but a touchpad used in this way can be much more than a toy; indeed, it has the potential to provide a degree of expressive control that can make it an instrument of choice for the serious musician. Students of instruments like the violin and cello expend considerable effort learning to play notes with the correct pitch, and much time is required to make the accurate control of pitch automatic. With the touchpad, the time and effort needed to develop the ability to accurately control pitch can be devoted instead to developing the ability to control other aspects of musical expression. As a result, in the hands of a dedicated musician, and with further development of the technology described in this whitepaper and elsewhere [1-3], the touchpad could become a vehicle of musical expression enabling the performer to attain a degree of musicianship far exceeding what she could attain in a normal life span with traditional musical instruments.

5 Non-Musical Performance Applications

In this section, we briefly consider some applications of the touchpad to the control of non-musical processes that may be of interest to the performer. Although the touchpad can be used for the control of musical processes by themselves or non-musical processes by themselves, its potential to control both kinds of processes simultaneously in a performance context is of particular interest, especially when the non-musical processes involve lighting. Simultaneous control over musical and non-musical processes can be achieved by using MIDI interfaces. Such interfaces would make it possible to use MIDI messages as a common control signal format shared by both musical and non-musical devices.

When used to control both musical and non-musical processes simultaneously, some kinds of contact, sequences of contact and partitions of the pressure-sensor array can be used to control either musical or non-musical processes exclusively, while others are used to control both. For those that control both, the parameters the user directly controls can be assigned to aspects of the musical and non-musical processes in such a way that they reinforce one another; for instance, if increases in pressure produce increases in the volume of the generated sounds, increases in pressure might also increase the brightness of any lights that are controlled.

Lighting Control

As mentioned, the touchpad can be used for lighting control. It is particularly well suited to the control of multi-channel and motor-controlled lighting. Aspects of the lighting that can be controlled include pan, tilt, zoom, gel and gel-pattern orientation. When used to control multiple lights, the pressure-sensor array can be partitioned into cells, with each cell controlling a different light. The touchpad can be used to control not only traditional stage lighting, but also performance light sculptures. For more information, see [1,2,26,27].

Robot Control

The touchpad can be used to control robots and other motor- and actuator-driven structures used in performances. For more information about the use of the touchpad for robot control in general, see [1,2].

Video Control

The touchpad can be used to control video processes used in performances. Video signal generation, video signal processing and camera image capture are examples of aspects of video processes that can be controlled. As suggested earlier, by using a MIDI interface, it is possible to integrate video control with the control of musical processes, as described in [24].

Control of Self-Organizing Processes

The touchpad can be used to control self-organizing processes used in performance contexts. For instance, the touchpad can be used to determine how an incoming signal influences a self-organizing process that, in turn, controls sound production or the production of visual effects. For more information, see [25].

6 Further Information

The purpose of this document has been to describe various music and other performance applications of the NRI® rich touchpad. This document is based on U.S. Patent 6,570,078 [1] and related issued and pending patents, all licensable from New Renaissances Institute®. Detailed hardware and software reference designs can be discussed under negotiable terms. All financial or in-kind proceeds from such arrangements will be used to fund pure academic research at New Renaissance Institute®. Contact *inquiries@newrenaissanceinstitute.com* for more information.

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