New Renaissance Institute®

Technology White Paper (Preliminary)

Enhanced Floor Controllers for Music, Lighting, and Other Applications

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ABSTRACT

This whitepaper describes floor controller technologies for real-time control of signal processors, synthesizers, musical instruments, MIDI processors, lighting, video, and special effects in performance, recording, and composition environments. Various combinations of physical controllers may be utilized (including foot switches, rocking foot pedals, null/contact touch-pads, pressure sensor arrays, etc.), as well as visual displays and internal control processing. Each physical controller may include a separate visual display of assigned name, status, and/or value. Rocking foot pedals may be used to simultaneously control multiple parameters by inclusion of additional sensors. Each physical controller may be assigned specific control message functions, values, names, temporal event sequences, and invocation rules dictated by assignable state-machines. Assignments may be selected from organized structures via the physical controller elements. Physical controllers and assignments may be organized in hierarchical or other relationships rich in geometric metaphors useful for human operation. The control system accommodates MIDI and non-MIDI control signal implementations.

Introduction

This whitepaper describes a family of technologies for floor controllers useful in real-time control of signal processors, synthesizers, musical instruments, MIDI processors, lighting, video, and special effects in performance, recording, and composition environments.

After a review of existing floor controller features, each of the enhanced floor controller technologies are described. Various combinations of physical controllers may be utilized (including foot switches, rocking foot pedals, null/contact touch-pads, pressure sensor arrays, etc.), as well as visual displays and internal control processing. The control system accommodates MIDI and non-MIDI control signal implementations. The component technologies include:

- Adaptations of rocking foot pedals to include additional sensors so as to simultaneously control multiple parameters;
- Motorized positioning of rocking foot pedals to reflect positions associated with an initial value stored in memory;
- The use of multicolor LEDs for status, organizational, modality, and other indications;
- Separate dedicated visual display of assigned name, status, and/or value for multiple or all physical controller elements;
- Each physical controller is provided the capability to be assigned specific control message functions, values, names, temporal event sequences, and invocation rules as dictated by assignable state-machines;
- Assignments of functions to some physical controllers by selecting from organized structures via other physical controller elements;
- Organized physical controllers and their functional assignments according to hierarchical or other relationships rich in geometric metaphors useful for human operation;
- Modularized physical controller elements, or groups of elements, with standardized physical form factors and electrical/software interfaces, which may be mounted into one or more types of mounting frames so as to allow users to create customized floor controllers.

Applications to rich signal processing environments and some example specific musical instruments are then provided.

These technologies are protected by U.S. Patent 6,689,947 "Real-time floor controller for control of music, signal processing, mixing, video, lighting, and other systems," issued February 10, 2004. and other affiliated patents licensable from New Renaissance Institute®. New Renaissance Institute® can provide detailed hardware and software reference designs under negotiable terms. All financial or in-kind proceeds from such arrangements are used to fund pure academic research at New Renaissance Institute®.

Existing Technologies

A number of floor-operated MIDI controller products have been commercially available. Some examples, with varying degrees of features, include:

- ART “X-15”
- Beringer “FBC 1010”
- Custom Audio Electronics “RS-10”
- Digital Music “Ground Control”
- Digitech “PMC-10,” “Control 7” and “Control 8”
- Lake Butler “Mitigator RFC-1”
- Line 6 “FBV Pedal Board” and “FBV ShortBoard”
- Rockman “Midi Pedal”
- Rocktron “MIDI Mate” and “All Access”
- Roland “FC-200” and “GFC50”
- Rolls “MIDI Buddy”
- StudioLogic/Fatar “SL-MP113” and “SL-MP117”
- T-Rex “BigFoot”

(*Many of the above company and product names are or have been trademarked; the trade-marked names are property of their respective owners.*) Such products typically comprise the following elements:

- Momentary contact foot switches
- Associated on/off single-color LEDs
- A single alphanumeric display
- Connections for 1-2 external rocker pedals, or 1-2 physically integrated rocker pedals.

The foot-switches typically are used to issue MIDI program change commands, and often additionally provide internal control and programming capabilities. The now discontinued Digitech PMC-10 has among the most advanced features, which notably include issuing strings of MIDI messages comprising arbitrary numbers of MIDI note, MIDI continuous controller, MIDI system, and MIDI program change messages issued under the control of programmable foot-switches, wherein the foot switches can be user-configured to operate in momentary, toggle, or in a type of radio-button modality.

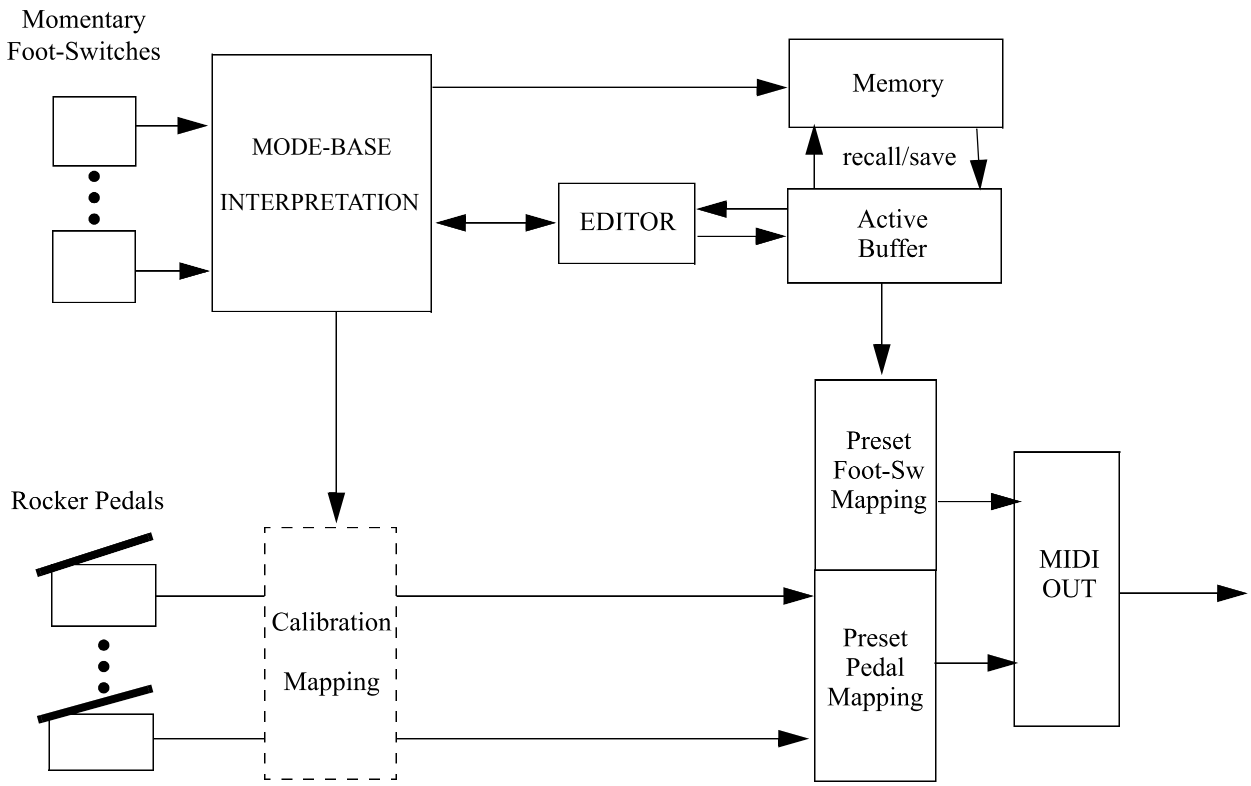


Figure 1

Figure 1 illustrates an exemplary functional sketch of such established past or currently existing foot controller technologies, with the understanding that many alternative implementations have been used. Momentary-action foot pedals are interpreted in performance, operational, and editorial contexts. In performance contexts, the foot-switches cause the recall of MIDI messages which are transmitted via a MIDI output. In operational contexts, groups of MIDI and alphanumeric display information are navigated and recalled, and editing modes may be entered. In editing contexts, MIDI message, alphanumeric display information, organizational, and utility information may be entered and edited. Some products provide built-in or remote keypads for use in editing. MIDI continuous controller messages may be created and transmitted under the control of internal or externally-connected foot-operated rocker pedals. Aspects of these MIDI continuous controller messages, as well as calibration of the range of any externally-connected foot-operated rocker pedals, is also often governed by operations made by the momentary-action foot pedals.

Enhancements Over Existing Technologies

U.S. Patent 6,689,947 offers a number of licensable enhancements to such designs. These include:

1. Various combinations of physical controllers may be utilized (including foot switches, rocking foot pedals, null/contact touch-pads, pressure sensor arrays, etc.), as well as visual displays and internal control processing.
2. Several or all physical controller elements (foot switch, rocker pedal, etc.) may include separate dedicated enhanced visual indication of assigned name, status, and/or value. The enhanced visual indication may include the use of multicolor LEDs, alphanumeric displays, LCDs with graphic capabilities, etc.
3. Rocking foot pedals may be used to simultaneously control multiple parameters by inclusion of additional sensors.
4. Each physical controller may be assigned specific control message functions, values, names, and temporal event sequences.
5. Each physical controller may be assigned specific invocation rules dictated by assignable state-machines.
6. Control signal assignment to the physical controller elements may be made utilizing organized structures such as page and group arrangements.
7. Physical controllers and assignments may be organized in hierarchical or other relationships rich in geometric metaphors useful for human operation.
8. The control system accommodates MIDI and non-MIDI control signal implementations.
9. Real-time event play-back capabilities, which can include specific pause/resume breakpoints, can also be included.
10. Internal control signal processing functions to provide scaling, translation, complementary value, and other operations on internally generated control signals for modified output or several types of simultaneous output.
11. Floor controller elements may be separated into modules with standardized physical form factors and electrical/software interfaces that may be inserted into one or more types of mounting frames so as to allow users to create customized floor controllers.

Figure 2 is an exemplary functional sketch of how enhancements 1-10 above, provided for in U.S. Patent 6,689,947 may be implemented in conjunction with established past, or currently existing, foot controller technologies, with the understanding that many alternative implementations may be used.

These licensable patented technologies may be used for a wide variety of real-time applications in performance, staging, recording and composing environments in music and performance arts. Additional issued and pending patents provide for modular implementations, adaptations to pedal steel guitar, and additional tonality control to South Asian instruments. Outside of applications in music and performance arts, the licensable technologies may be applied to machine control, computer interfaces, medical equipment control, and may find uses as tools for the physically disabled.

Additional details of the individual enhancements are now provided. These are organized in the following sections:

- Enhanced Foot-Operated Rocker Pedals
- Foot-Operated Multiple-Parameter Touchpads
- Impact Sensors
- Paged and Hierarchical Assignment Structures
- Display and Status Indication
- Assignable State Machines

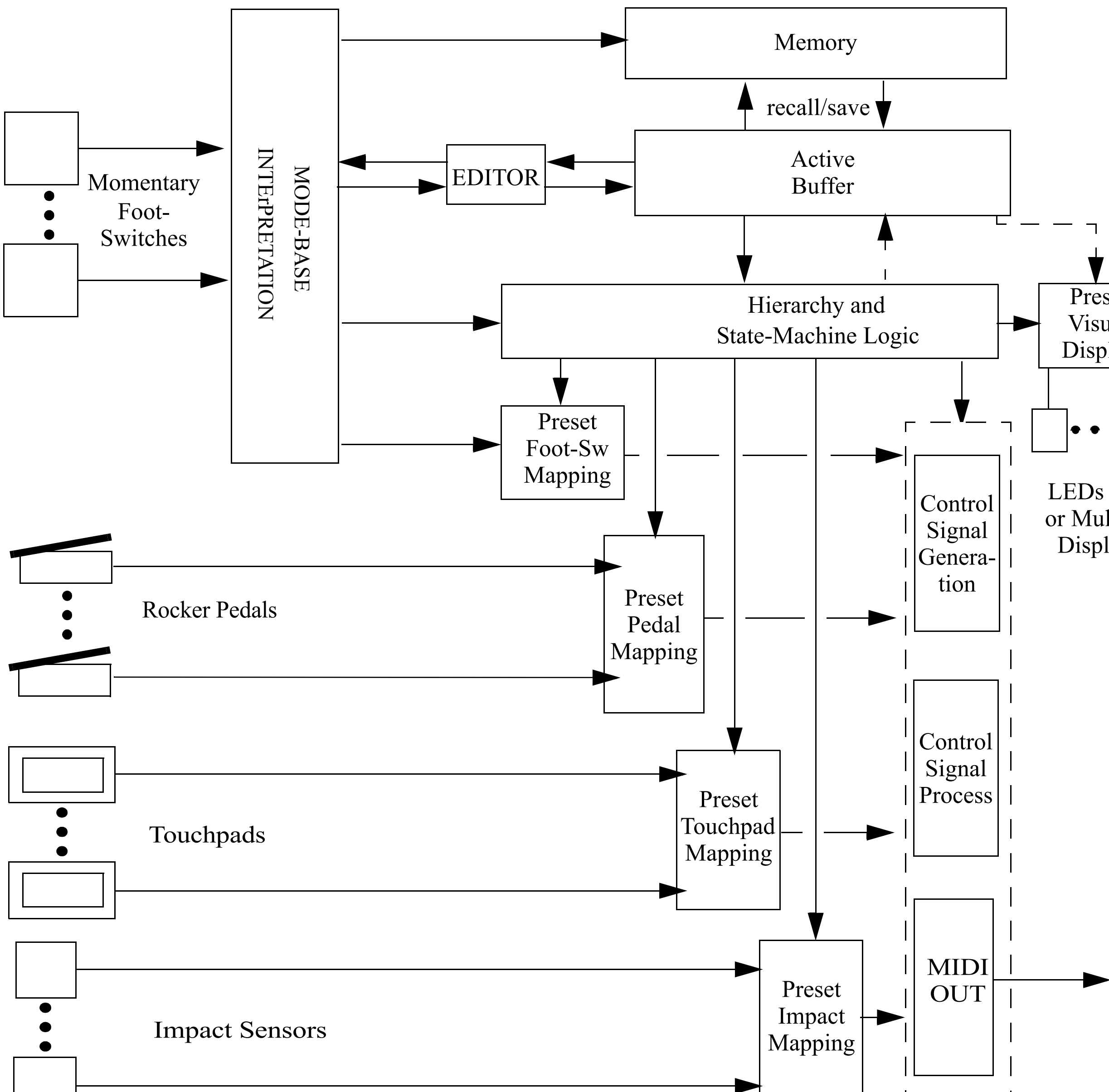


Figure 2

- Internal Control Signal Processing
- Temporally-Sequenced Control Message Generation
- Geometric Control-Element Layout for Larger Scale Control Metaphors
- Modular Field-Configurable Assemblies

Enhanced Foot-Operated Rocker Pedals

The traditional way to control volume on an electronic keyboard instrument is by means of a rocking floor-level foot-pedal. More recently, such pedals are often used to generate continuous-range control signals such as MIDI messages, though allowing the control of only one continuous-range parameter at a time. This section addresses several enhancements to foot-operated rocker pedals.

Multi-Parameter Foot-Operated Rocker Pedals

Figure 3 illustrates some enhanced foot-pedal arrangements which permit simultaneous single-foot adjustment of a plurality of continuous range parameters for use with floor controllers. These may be used as components of a larger foot controller system, as optional modules of a larger foot controller system, or as stand-alone controller devices. In stand-alone configurations, these may provide outgoing MIDI signals, analog control-voltage signals, or both.

Many years ago, several rocking and pivotingly "volume/tone" foot pedal products were available, though none appear to be commercial, produced at this writing. These products offered a foot-operated rocker capability devoted to controlling instrument volume, supplemented with a clockwise/counterclockwise pivoting capability devoted to the control of instrument tone. Figure 3a shows an exemplary pivoting foot-plate rocker pedal of this sort providing independent control motions of up-down and clockwise/counterclockwise twisting of the top surface foot-plate. Such arrangements may be used to double the number of

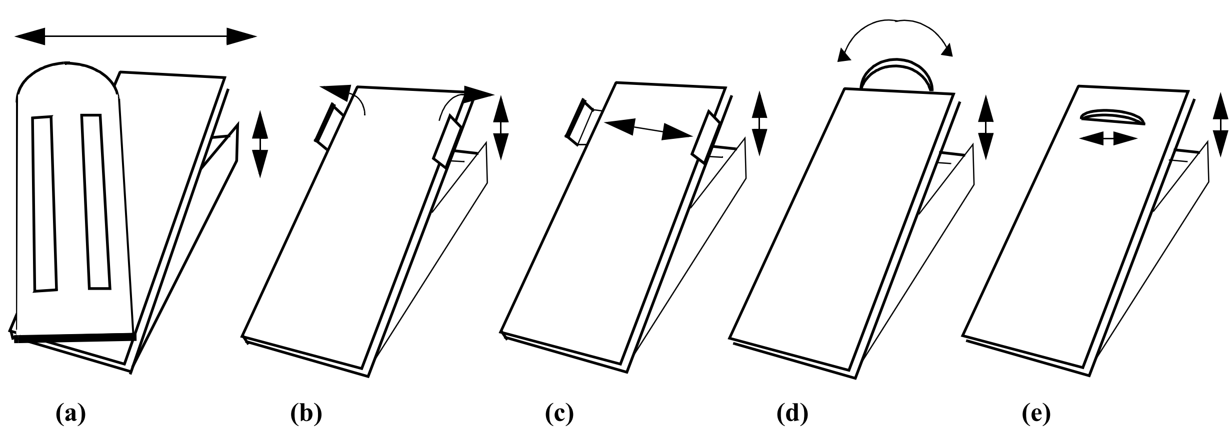


Figure 3

foot controllable parameters that can be reworded in a roughly comparable physical layout area, together with the bonus of allowing a foot to control two continuous-range parameters at once.

An adaptation of the arrangement of Figure 3a is to substitute the pivoting foot-plate with one that can slide forward and back. This could also be combined with the pivoting capability to provide three independent continuous-range parameters.

Conventional rocking foot-pedal arrangements (without any such pivoting and/or forward-back sliding capabilities) can be adapted in other ways to control two or more continuous-range parameters at once. One method for such an enhancement is through the use of one or more side-mounted spring-levers. Momentary-action and push/push toggle switches have been mounted on one or both sides of rocker foot-pedals for mode control (as seen in products by Ernie Ball and Soloton). Figure 3b shows an adaptation of this high-level approach to side-mounted spring-levers, spring loaded to return to a default position as force is reduced or released, to control continuous-range parameters. Such side-mounted spring-levers are particularly advantageous for continuous-range parameters that have a specific nominal or default value. For example, these can be used in conjunction with pitch-shifters to modulate pitch, as do the foot and knee levers of a pedal steel guitar, or in complementary pairs, to emulate the action of a synthesizer modulation wheel or an electric guitar vibrato "whammy bar."

In Figure 3b, one or more side-mounted spring-levers may be positioned on either the base or rocker plate of a foot-pedal. For example, such continuous-range parameter controlling spring-levers may be located on either side of the toe area of the foot plate (as shown in Figure 3b), operable in mutual exclusion by pivoting the foot at the heel. As another example, continuous-range parameter controlling spring-levers may be located on either side of the heel area of the foot plate, operable in mutual exclusion by pivoting the foot at the toe area. Combining these adds highly functional mutually-exclusive control of four additional continuous-range parameters. Such spring-lever arrangements can also be positioned at the base of the heel area and the far-end of the toe area, but these can be more problematic to operate while standing. These arrangements can be employed without the use of an underlying volume pedal, i.e., in a “bull-pen” tray accepting motions of the foot. The spring-levers themselves may directly operate a slide, geared, pulleyed, or otherwise actuate a potentiometer, optical sensor, magnetic sensor, pressure-sensor, etc. to produce an electrical signal. If two side-mounted spring-levers are positioned on opposite sides of the pedal, two mutually-exclusive parameter adjustments can be realized (as found in pedal steel knee-lever pairs, and in the action of a synthesizer modulation wheel or an electric guitar vibrato whammy bar). Such an arrangement may be extended to control larger numbers of parameters.

A pair of side-mounted levers such as those depicted in Figure 3b can be mechanically joined to form a displaceable U-shaped toe-area open-top enclosure as shown in Figure 3c. The resulting arrangement can be free-operating or may utilize a spring return. This arrangement can be used to provide a second continuous-range parameter to a conventional rocker pedal implementation as an alternative to the pivoting foot-plat pedal of Figure 3a.

In another type of approach, a freely-positioned or springed center-return modulation wheel, such as those found on keyboard synthesizers, may be positioned at the far end of the rocker plate, as shown in Figure 3d, or near the far end of the rocker plate, as shown in Figure 3e. An appropriate arrangement and choice of materials must be made so as to forego breakage in heavy usage situations. This can also be applied to the pivoting foot-plate arrangement of Figure 3a.

Additionally, it is possible to add continuous-range control capability on a rocker pedal by permitting and measuring its length-axis rotation forces (that is, side-to-side tilting) applied by the foot. This may be done in at least two ways:

- Permitting length-axis rotation of the foot, and measuring the degree of length-axis rotation with a potentiometer or other sensor, or
- Providing at least two pressure-sensors on the surface of the foot-plate, and deriving a control signal from these.

In any of the approaches, the resulting signals can then be electronically contoured so as to provide a selected response or variety of responses to the physical displacements and pressures provided by the foot. The processing of control signals is further discussed in a later section of this paper.

Pressure Sensor Array Touchpads for Foot-Operated Rocker Pedals

Foot-operated multiple-parameter touch pads are described in the next major section of this document. Although they can be used in isolation as an alternative to rocker pedals altogether, they also can be mounted on the foot-plate, or aligned along the surrounding vertical vicinity of the foot-plate so as to be within easy and operable reach of the heel and/or toe areas of the foot. Foot-operated multiple-parameter touch pads attached and positioned in this way can provide yet more continuous-range parameters that can be controlled by the foot simultaneously.

Positioning Motors for Foot-Operated Rocker Pedals

One problem with foot-operated rocker pedals is that the position they may be in when a new preset configuration is recalled and activated may not match the position required to produce the desired value at the onset of the activation of the recalled preset configuration. One approach is to store the desired initial value of each foot-operated rocker pedal, output that initial value for the parameter regardless of the pedal’s current position, and then either:

- Change the control value the moment the pedal’s position is first moved (usually causing abrupt jumps in the parameter’s value), or
- Continue to ignore the pedal’s position until it is adjusted to where it matches the stored initial value, and at that point then smoothly join and follow responsively to the pedal’s current position.

A third approach to add to the above two alternatives is to use one or more motors to position the moving mechanism(s) of a foot-operated rocker pedal to a position corresponding to that associated with the stored initial value. Once positioned, the motors relinquish control to the foot. The motors can be configured so that should the foot offer resistance pressure beyond a specified level of force, the motor relinquishes control early. These ideas are similar to the notion of "automated faders" found on automated mixing consoles.

Foot-Operated Multiple-Parameter Touchpads

Another method for realizing multiple-parameter foot controllers involves the use of null/contact touch-pad and pressure-sensor array touch-pad elements discussed earlier, which can be adapted for foot operation as described below. The adapted touchpads can be used as an alternative to, in addition to, and/or as part of a foot-operated rocker pedal. These may be used as components of a larger foot controller system, as optional modules of a larger foot controller system, or as stand-alone controller devices. In stand-alone configurations, these may provide outgoing MIDI signals, analog control-voltage signals, or both.

Null/Contact Array Touchpads

The simplest form of user interface touchpad is a null-contact touch pad as now commonly found on laptop computers and stylus-based PDAs. These typically comprise two sheets of electrically resistive material, one configured to produce a voltage that varies proportional to the distance in one direction and the other configured to produce a voltage that varies proportional to the distance in the perpendicular direction. These materials are sandwiched together atop a rigid surface, and touching the exposed side of the sandwich (which forms the user interface side of the touchpad) with a finger, stylus, or other object creates a contact between each layer of electrically resistive material and an associated layer of conductive film. Voltages corresponding to the position in each direction are thus produced and interpreted as position signals. Other technologies and techniques involving capacitive, inductive, optical, acoustic, and other properties, may be used in place of electrically resistive material. These technologies may be implemented in optically opaque, optically translucent, and optically transparent form. The latter are commonly employed in the form of touchscreens overlaid atop LCD or CRT monitors. The Korg™ Kaoss Pad uses a backlit optically translucent null/contact touchpad to produce outgoing MIDI control signals.

U.S. Patent 6,689,947 provides for null/contact touchpads to be configured for operation by the foot. The foot-adapted touchpads may be used in isolation, as part of a larger floor controller, or may be attached to the foot-plate of a foot-operated rocker pedal. Although in conventional usage a null/contact touchpad only recognizes the location of one small point of contact, both U.S. Patent 6,689,947 and US 6,570,078 describe how some null/contact touchpad may be further adapted to measure two points of contact or two width dimensions of a large area of contact, as may result from making contact with the pad by a shoed or unshoed foot.

In addition, foot-operated null/contact touchpad technology may also be applied to foot-operated switch surfaces, even replacing the otherwise comprised mechanical switch with threshold detection of a pressure measurement. This would allow for the basic foot-switch mechanism to also serve as a timbre, volume, or other control, based on the position of contact. Additionally, applying foot-operated null/contact touchpad technology to pitch-oriented "organ pedals" results in rich multiple-parameter "organ pedal" analogs to the rich multiple-parameter keyboard keys described in U.S. Patent 6,570,078 and U.S. Pre-Grant Patent Application 2004/0074379, as illustrated in Figure 4.

Pressure Sensor Array Touchpads

A far more sophisticated degree of control by the shoed or unshoed foot may be obtained through use of pressure sensor array touchpads as described in U.S. Patent 6,689,947 and U.S. Patent 6,570,078. Although in the latter, the human hand was used throughout as an example, it is readily possible for contact with the human foot to serve as controlling input process as well.

For either the human hand or foot, there are, typically, artifacts such as shape variation due to elastic tissue deformation that permit recovery of up to all six degrees of freedom allowed in an object's orientation in 3-space. Figure 5a illustrates how six degrees of freedom can be recovered from the contact of a single finger. In the drawing, the finger makes contact with the touch-pad with its end segment at a point on the touch-pad surface determined by implied coordinates and (these would be, for example, left/right for and forward/backward for). Fixing this point of contact, the finger is also capable of rotational twisting along its length as well as rocking back and forth. The entire finger can also be pivoted with motion about the contact point defined by coordinates. These are all clearly independently controlled actions, and yet it is still possible in any configuration of these thus far five degrees of freedom, to vary the overall pressure applied to the contact point. Simple practice, if it is even needed, allows the latter overall pressure to be independently fixed or varied by the human operator as other parameters are adjusted.

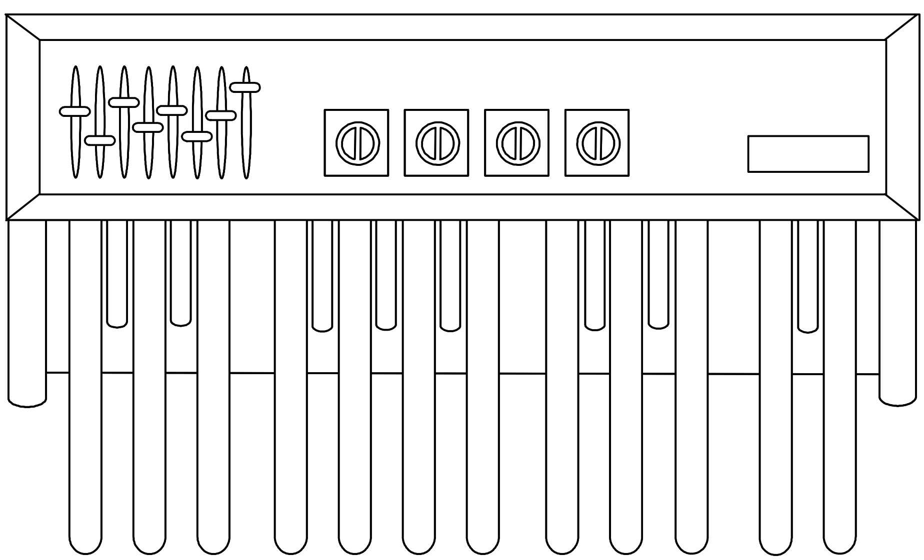
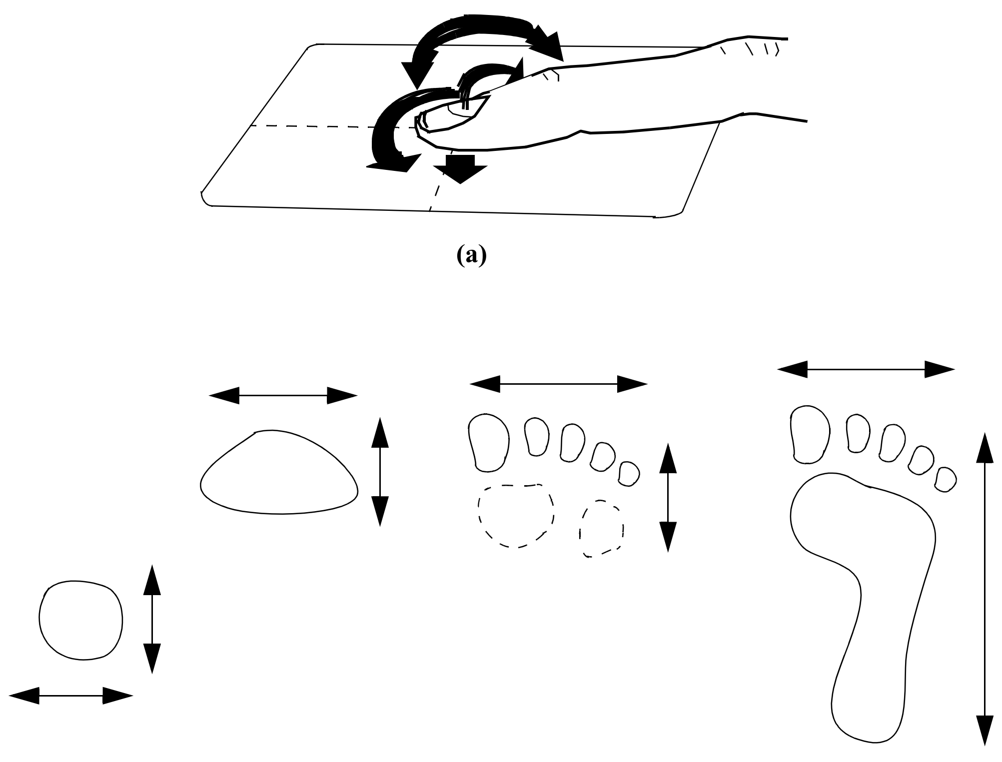


Figure 4

Similar types of measurements and interpretations may be applied to the human foot in similar fashion. As shown in Figure 5b, the heel portion of a shoeprint can be recognized as differing in shape from the toe potion of a shoeprint shown in Figure 5c. In rocking the foot forward and back, the resulting pressure image will resemble a combination of Figure 5b and 5c. For each of the range of cases, the following parameters can be extracted and independently controlled:

- Left-right location of geometric center;
- Forward-back location of geometric center;
- Left-right location of center of pressure, measuring the left-right tilt of the foot;
- Forward-back location of geometric center, measuring the forward-back tilt of the foot;
- Overall spatially-averaged applied pressure.

In the case of the toe-area shoeprint, most forms of contact with the pressure sensing touchpad would produce an oblong shape as depicted in Figure 5c, thus making the measurement of an angle of rotation possible. Similarly, most forms of contact of a full foot with the pressure sensing touchpad, would produce an angle-signifying shape (combination of Figure 5b and 5c), thus making the measurement of an angle of rotation possible. (For some types of



(a)

(b) (c) (d) (e)

Figure 5

shoes, the heel-area shoeprint would also possess enough orientation-signifying attributes to make reliable measurement of an angle of rotation possible for it as well.)

It is also possible to provide adaptations to the stockinged or bare foot. The heel area of the bare foot also resembles the shape of Figure 5b, while the toe area resembles the form of Figure 5d. As the toe-area is rocked forward, the two dotted areas lighten in pressure and eventually vanish. As the toe-area is rocked backward, the two dotted areas reappear and increase in applied pressure. In rocking the foot forward and back, the resulting pressure image will resemble a combination of Figure 5b and 5d. Under significant pressure, many human feet flatly planted on the pressure sensor will eventually create a pressure profile approaching that suggested in Figure 5e. For each of the range of cases, the following parameters can be extracted and independently controlled:

- Left-right location of geometric center;
- Forward-back location of geometric center;
- Left-right location of center of pressure, measuring the left-right tilt of the foot;
- Forward-back location of geometric center, measuring the forward-back tilt of the foot;
- Overall spatially-averaged applied pressure.

In the case of the toe-area (Figure 5d) and full foot (combination of Figure 5b and 5d, evolving under pressure to Figure 5e), most forms of contact with the pressure sensing touchpad would produce an angle-signifying shape, thus making the measurement of an angle of rotation possible.

As indicated above, in regards to null/contact touchpad technology, foot-operated pressure sensor array touchpad technology may also be applied to foot-operated switch surfaces, even replacing the otherwise comprised mechanical switch with threshold detection of a pressure measurement. This would allow for the basic foot-switch mechanism to also serve as a timbre, volume, or other control, based on the position of contact. Additionally, applying foot-operated pressor sensor array touchpad technology to pitch-oriented “organ pedals” results in rich multiple-parameter “organ pedal” analogs to the rich multiple-parameter keyboard keys described in U.S. Patent 6,570,078 and U.S. Pre-Grant Patent Application 2004/0074379, as illustrated in Figure 4.

Geometric Touchpad Parameter-Control Metaphors

With these adaptations of the foot, rich metaphorical aspects of interacting with the pressure-sensor array touch-pad may be added. In many cases one or more natural geometric metaphor(s) may be useful. These metaphors could include:

- Associating left-right position, left-right twisting, or left-right rotation with stereo panning
- Associating overall pressure with volume or spectral complexity.

In other situations, it may be useful to employ metaphors where pairs of parameters are associated together. Here, for example, with the toe area it may be natural to:

- Associate one parameter pair with (left/right and forward/backward) contact position
- Associate another parameter pair with (left/right and forward/backward) twisting/rocking.

In this latter example there is available potential added structure in the metaphor by viewing the twisting/rocking plane as being superimposed over the position plane. The superposition aspect of the metaphor can be viewed as an index, or as an input-plane/output-plane distinction for a two-input/two-output transformation, or as two separated processes which may be caused to converge or morph according to additional overall pressure, or in conjunction with a dihedral angle of intersection between two independent processes, etc.

Touchpads with Visual Display

With the relatively transparent null/contact or pressure-sensor array touchpad, it is possible to aligned visual displays such as LCDs, fluorescent, plasma, CRTs, etc. beneath to supply back images. The visual display can be used to provide visual guidance cues applicable to the current operational mode of the transparent touchpad. The visual guidance cues can be used to label regions or distinguished areas of the sensor array, illustrate gradients, etc.

The visual displays may also be used as general purpose information displays when this is not problematic. Additionally, such touchpads with visual display may be used to provide a feature-configuring user interface.

Impact Sensors

Since foot motions ranging from gentle tapping to brutal stomping are often employed in musical performance, the patents provide for floor controllers to additionally incorporate impact sensors. These may be positioned as independent physical controller elements, be attached to foot-operated rocker pedals, or be mounted behind (or otherwise implemented with) foot-operated touchpads. In the case of foot-operated rocker pedals, the impact sensor may be located in a variety of places:

- Just over the axle of the rocker pedal so that tapping on it will not disturb the pedal position; and/or
- In the heel and/or toe areas so as to capture impact from a stomping realignment of the pedal position.

The signal produced by an impact sensor may be used to trigger percussion sounds, audio-sample playbacks, lighting events, video effects, special effects, a synthesized sound, etc., or may be used for tempo management of sequencers, drum machines, and low-frequency oscillators. It may also be used to trigger internal envelope generators. The force of impact can be measured and thus used as a continuous-range control parameter.

In the case of foot-operated touchpads, the impact point can also be used to convey at least two additional continuous-range control parameters. These may be used to control timbre aspects of sounds, spatial locations of sound images or lighting events, cross-faded mixing of percussion sounds or audio sample playbacks, etc. The impact event may also be interpreted as a discrete data entry event, as it is on the touchpads within laptop computers.

Paged and Hierarchical Assignment Structures

U.S. Patent 6,689,947 provides for arbitrary assignment of names, control signal generation functions, associated state machines, MIDI messages, and control signal processing actions to specific foot-switches, rocker-pedals, touchpads, impact sensors, and/or other physical controller elements. Stored program memory may be used to retain these assignments. Multiple stored program assignments can be recalled, thus allowing for varying assignment sets for each physical controller element. The stored program assignments can hypothetically be organized in a variety of ways.U.S. Patent 6,689,947 provides for such flexible hierarchical organization of assignments.

To illustrate the general idea, Figure 6 shows various examples of a simple two-level hierarchy involving ten foot switches. In Figure 6a, the top-row foot switches select a high level preset {A, B, C, D, or E}. Once selected, the high-level preset determines the interpretation assigned to the group of bottom-row foot switches {1, 2, 3, 4, 5}. For example, foot switch A in top-row foot switches could select a group of presets assigned to bottom-level foot switches {1, 2, 3, 4, 5} useful for one group of songs or solos. Foot switch B could select a second group of presets to be assigned to bottom-level foot-switches {1, 2, 3, 4, 5}, and so on.

Continuing this simple example, each high level foot-switch could be additionally configured to invoke any of a number of the following additional actions:

- Activate one of the lower level presets in the group of its lower-level preset;
- Activate one or more of the presets outside its group of lower level presets;
- Activate a special set of instructions;
- A combination of two or all of the above;
- Take no operation, retaining the same state of affairs before it was activated.

The arrangement of Figure 6a partitions the ten foot-switches of this example into two equal parts, giving a total of 5 x 5 = 25 possible selections. Figure 6b shows a two level partitions having four high-levels presets and six low-level presets (having a total of 6 x 4 = 24 selections) while Figure 6c illustrates another two-level partition comprising three high-level presets and seven low-level presets (having a total of 3 x 7 = 21 possible selections).

Employing the ten foot-switch arrangement of Figure 6 to illustrate the next simple illustrative example, Figure 7 shows arrangements where the same ten foot-switches is partitioned into a three-level hierarchy. In such a hierarchy, activation of a foot-switch in the highest level determines a group of interpretations assigned to the middle level of the hierarchy, and in turn selection of a middle foot-switch determines a group of presets assigned to the foot switches at the lowest level of the hierarchy. Each of the highest level and middle-level foot-switches could additionally be configured to invoke any number of the additional actions listed above (for the higher level foot switches of the two-level hierarchy).

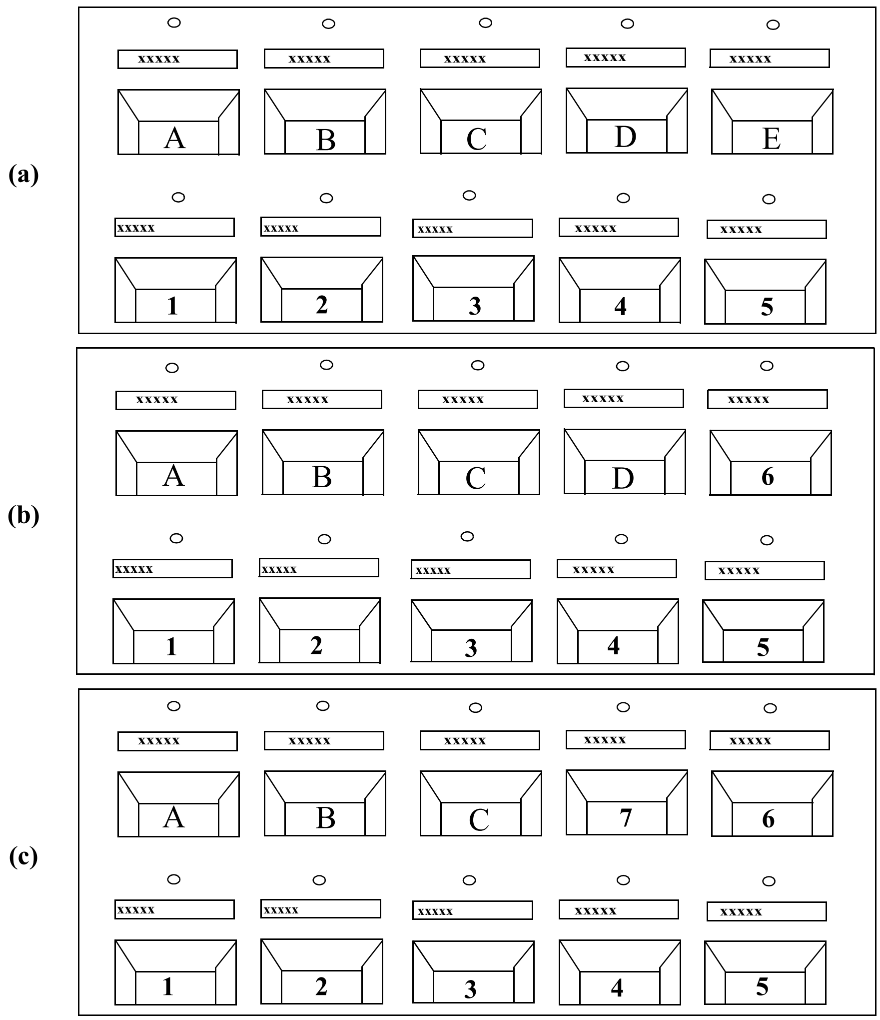


Figure 6

Figure 7a illustrates a three-level hierarchy where the ten foot-switches are partitioned with two highest-level, three middle-level, and five lowest-level assignments (providing 2 x 3 x 5 = 30 selections). Figure 7b illustrates another three-level hierarchy involving three-level assignments (providing 3 x 3 x 4 = 36 selections), while Figure 7c illustrates yet anther involving three highest-level, four middle-level, and three lowest-level assignments (providing again 36 selections).

More levels can be added, although each hierarchy must have at least two foot-switches to be meaningful. In a general case with n foot-switches and k-level hierarchy, the maximum number of selections will be obtained where each level has a number of foot-switches of approximately the same number (equal to or near $\frac{n}{k}$), and the maximum number of selections will be an integer equal to or near $\left(\frac{n}{k}\right)^k$ (for more detail see the Appendix).

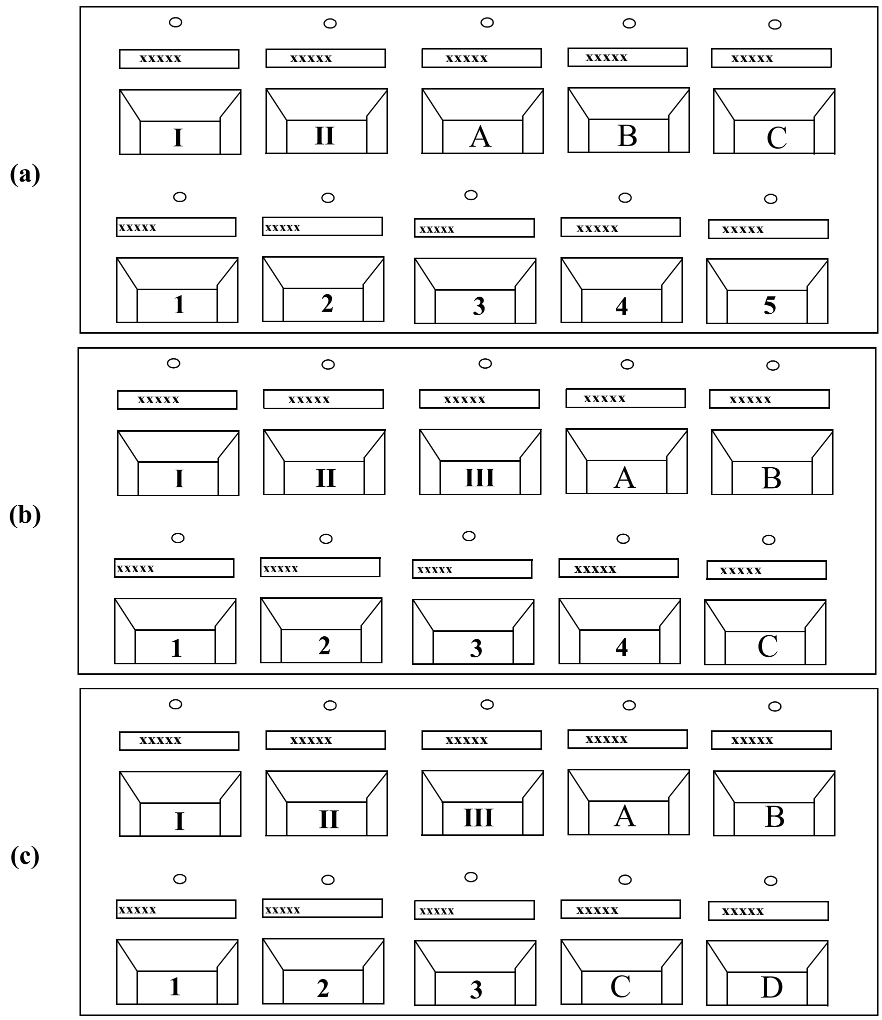


Figure 7

By adding a cyclic state machine at one or more levels of the hierarchy, only two foot-switches are needed to navigate through a much higher number of selections within each level. Figure 8 illustrates this approach where an n-stage cyclic state machine, shown in Figure 8a, is employed at the highest level of a three-level hierarchy. Two foot-switches are used to step up or down through the stages of the state machine. Figure 8b illustrates an example where three of the remaining foot-switches are assigned to the middle-level, and five are assigned to the lowest level of the hierarchy. This second three-level example permits n x 5 x 3 = 15n possible selections, giving 120 selections for n = 8. Use of a cyclic state machine may be very useful to some application areas, such as stepping through a predefined sequence of settings that are ready, applicable to being "scrolled through" (such as a song list), or a rapid sequence of events (such as in a solo's crescendo). In other application areas it may be more appropriate to devote a larger number of foot-switches to a given hierarchy level so as to facilitate fast non-sequential random access. Additional use of more sophisticated state machines (of cyclic and other types) are described later.

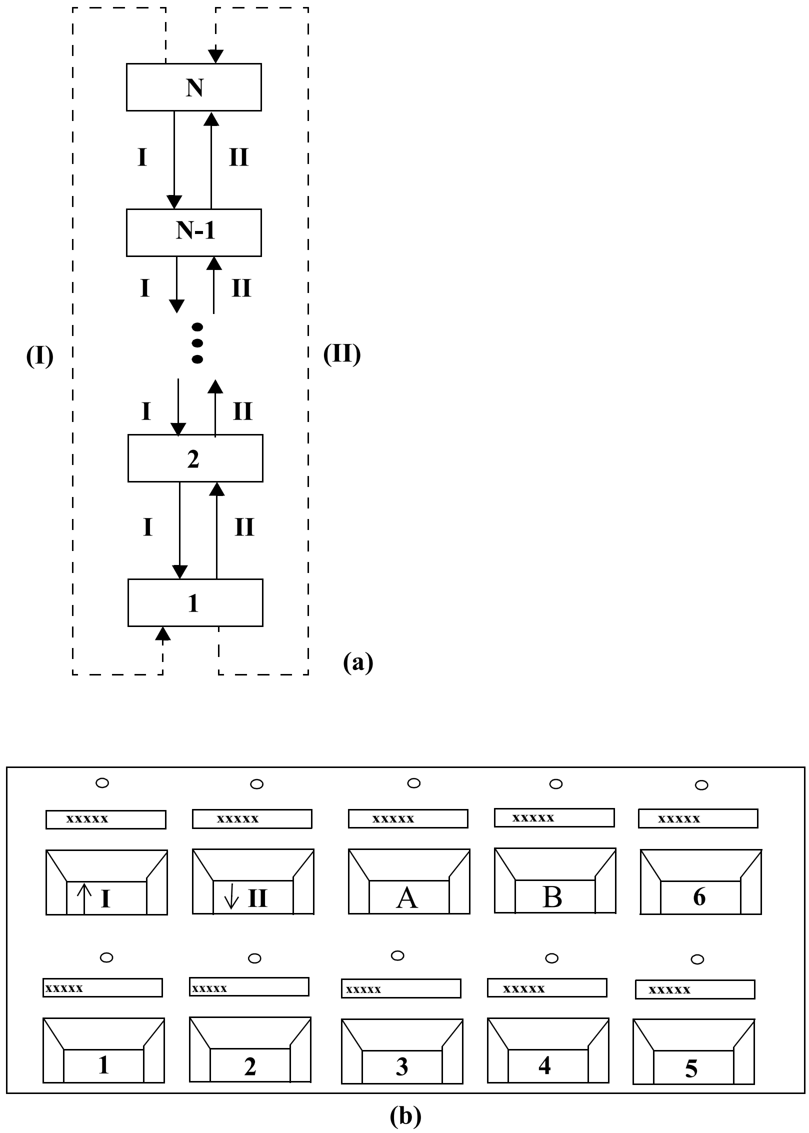


Figure 8

Continuing yet further with the illustrative ten foot-switch arrangement, variable structure hierarchies can now be discussed. As a preliminary example, a hierarchy involving at least three levels for some highest-level choices may offer fewer or additional levels for other choices. The number of choices within a level can also be permitted to vary. As an illustration of these capabilities, Figure 9 shows one highest-level choice (chosen here via an n-stage cyclic state machine) which, when active, invokes a three-level hierarchy with two choices at the middle-level and six choices at the lowest level. Another highest level choice may, as depicted in Figure 9b, invoke a differently-structured three-level hierarchy comprising four options at the highes level, and four options at the middle level, and four options at the lowest level. Figure 9c shows yet another three-level hierarchy with five middle-level options and three level options. In contrast to this, Figure 9d shows a highest level choice that invokes to a two-level hierarchy, while Figure 9e shows a highest level choice that invokes a four-level hierarchy. A performer may sequentially employ these arrangements for the performance of various songs: for example the first song may use the arrangement of Figure 9a, the second song may use Figure 9b, etc. Should the order of the songs need to change unexpectedly, it is simple enough and unencumbering to use the highest-level state machine's up/down foot-switches I and II to scroll to another song choice lying outside the sequential order.

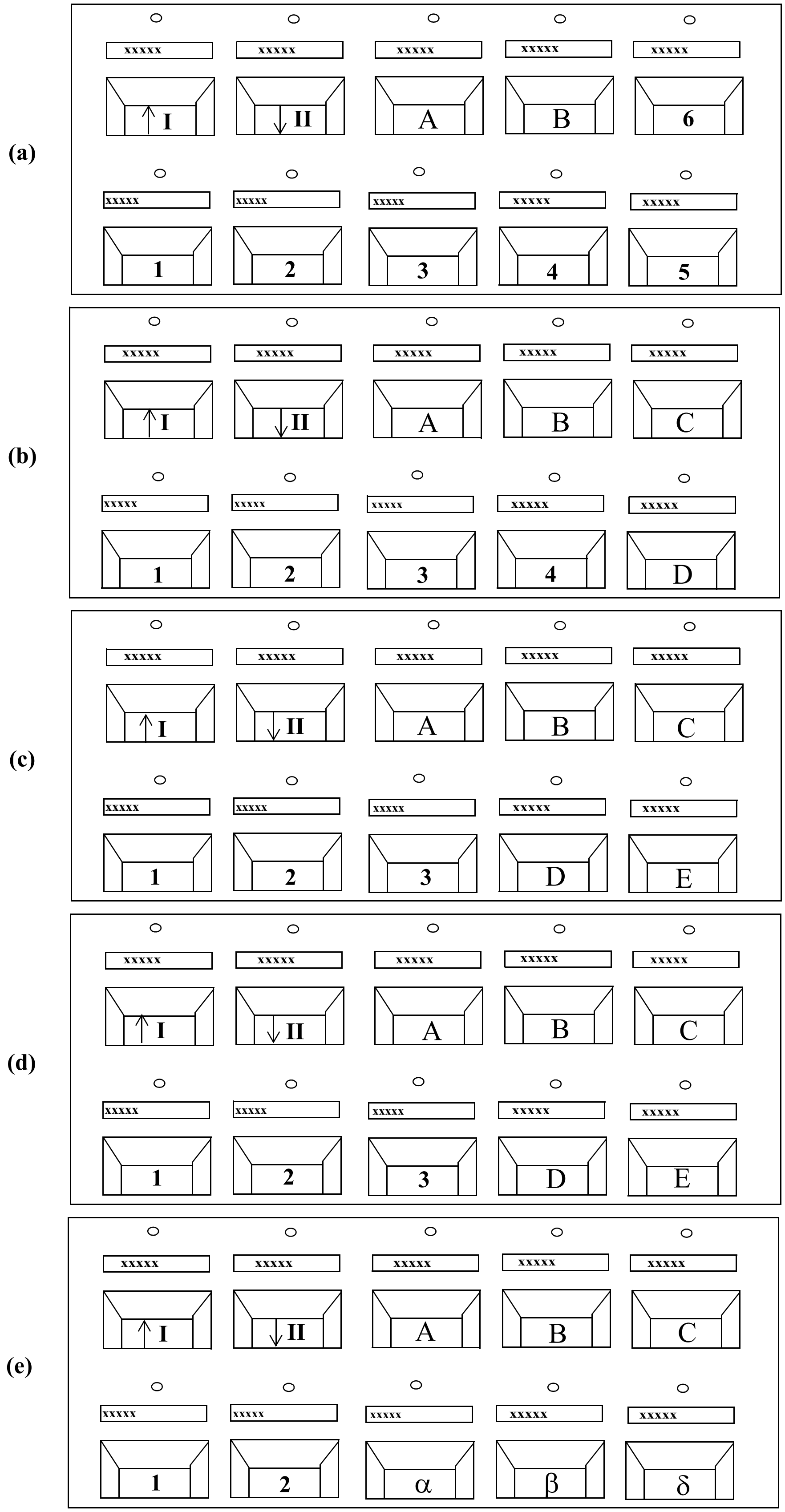

(a)
xxxxx
I
II
A
B
6
1
2
3
4
5
(b)
I
II
A
B
C
1
2
3
4
D
(c)
I
II
A
B
C
1
2
3
D
E
(d)
I
II
A
B
C
1
2
3
D
E
(e)
I
II
A
B
C
1
2
α
β
δ

Figure 9

The general approaches described above may be arranged in a simplified presentation, or may be extended to additional levels of flexibility. Further, individual lowest-level presets, or higher-level actions, may be used to affect other aspects of the floor controller, such as the assignments of rocker pedals and other physical controller elements.

Figure 10 shows a simplified presentation that might be started as an option for new users or as a product for less-technical users. Here a uniformly structured three-level hierarchy is used. The highest level is represented as an “UPPER-LEVEL PRESET,” the middle-level is represented as a “lower-level preset,” and the lowest level is represented as a “variation.” The outgoing message assignments made to continuous parameter elements (such as rocker pedals) may be determined by the choice of lower-level presets and/or the choice of variation. In the simplest implementation, the number of foot-switches devoted to lower-level presets and variations may be fixed. In a more sophisticated realization, the assignment of foot-switches between lower-level presets and variations can be made arbitrarily, and be made to vary as a consequence of the UPPER-LEVEL preset that is chosen. Figure 11. shows a more flexible implementation. Here, arbitrary mixes of hierarchies comprising varying numbers of levels are supported, and actions at any level can determine assignments of continuous parameters, physical controllers, use of various types of state machines (cyclic and others to be discussed), type and use of control signal processing (to be discussed), and of course outgoing MIDI messages to be transmitted.

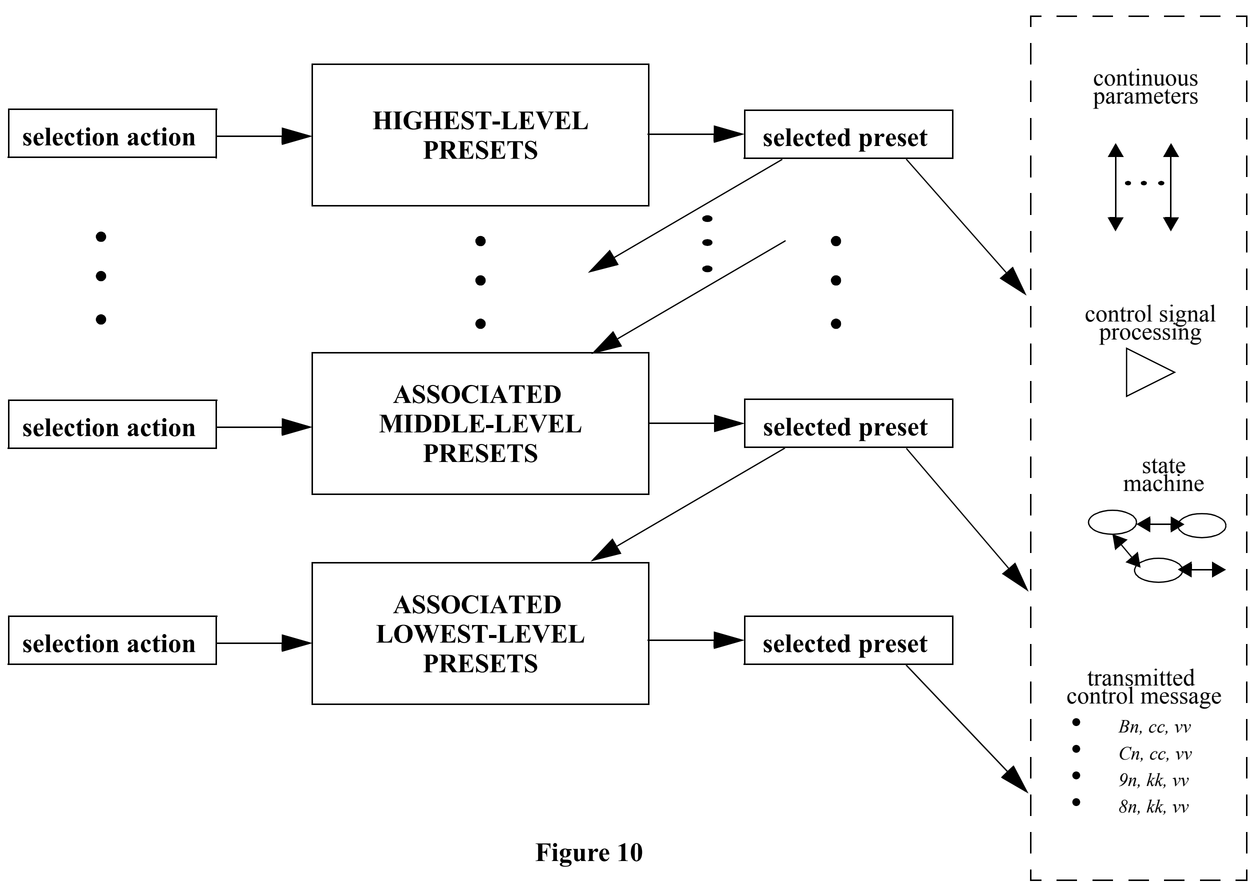


Figure 10

Enhanced Display and Status Indication

Because of the number of controller assignments and the diversity of possibilities, it is desirable to add physically adjacent to each foot controller an alpha-numeric display indicating the current assignment and status of that controller. In particular, for each given selected page, each controller display may show one or more of the currently assigned functions, the current value(s) transmitted or last-transmitted, and any additional identifying information such as short-hand names or relationships with other controllers, etc.

Multi-color LEDs may be dedicated to individual physical elements so as to provided a variety of information.

- Bi-color LEDs may be configured to light in either of two color and blends in the additive color scale in between: for example, the common Red/Green bi-color LED may light as pure red, pure green, pure yellow (when both are lit), or a range of shades of each, mixing in various degrees of yellow as the intensity proportion varies. Other types of bi-color LEDs are also available although less widely used.
- Tri-color LEDs can produce a full range of color as well as white. With simple on-off selections of each of the red, green, and blue elements yields 8 different conditions (off, red, blue, green, yellow, magenta, cyan, white). With additional intensity levels of primary colors a wide variety of rapidly discernible color and shades are possible.

The colors associated with a given condition may be solid or may be varied over time so as to create distinguishable animated visual effects. The animations could be used to call special attention to a particular physical controller or its status.

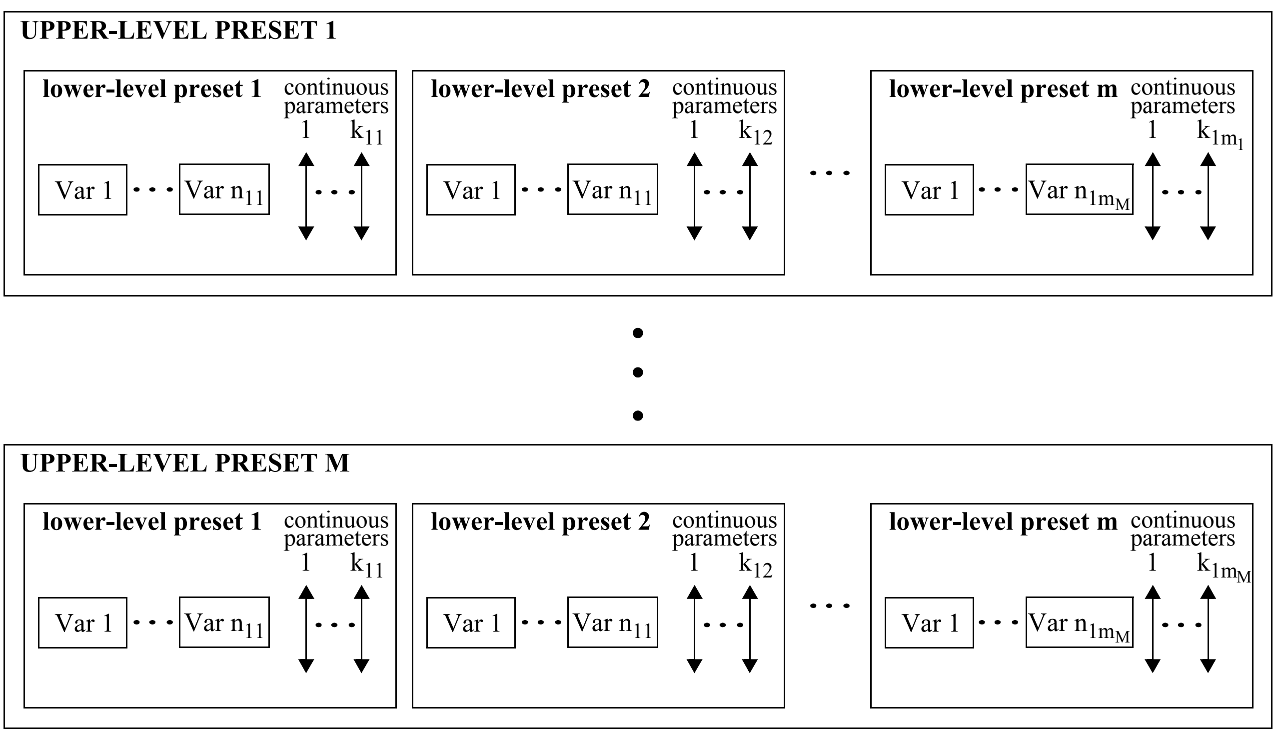


Figure 11

These solid or animated color indications may be used for a variety of purposes, including:

- Quick reference as to which foot-switch and which continuous foot controller (pedal, touch-pad, etc.) were last operated,
- Status (Active/Inactive) information (color animation is a good choice here),
- State in a moderately complex state machine,
- Group affiliation,
- Level in hierarchy,
- User-programmed attention-getter to call out a special choice or collection of choices.

Figure 12 illustrates some example implementations of multi color visual indication LEDs. Figure 12a shows a number of physical controllers or other items (here eight foot-switches, two rocker pedals, and a rectangular items which may be a foot operated touch pad, large graphical display, etc.). Each of these item is shown provided with at least one dedicated multi-color LED. These LED's are depicted as standard rounded/domed LEDs, but may have other shapes or sizes. Such LED styles are readily available inexpensively in high brightness formats. High brightness can be very valuable in brightly lit stage situations. However, that level of brightness can be overwhelming in low ambient light settings. For this reason it may be further advantageous to employ one or more ambient light detectors for use, together with appropriate circuitry, in modulating the brightness of the visual indication LEDs, as shown in Figure 12b. The light modulating circuitry may comprise direct voltage or current modulation, pulse-width modulations, etc. Since high-impedance high-gain audio equipment may be physically nearby, care may be needed to prevent (EMI) interference. This may include EMI shielding, slow-limiting of high-current signals, etc. Additionally, the light modulating circuitry may provide one or more response curves for adjusting the way in which the brightness of the high intensity visual indicators is varied in response to ambient light levels.

Alternatively, visual indication devices may be integrated directly into physical controllers themselves. Figure 12c illustrates possible implementation of this. Here the individual foot-switch housings are illuminated via single or multicolor LEDs in such a way that significant portions (if not the entire foot-switch housing) glows as the means of providing the visual-indication associated with that foot-switch. Such arrangements require more power and typically involve higher implementation cost, but provide dramatic effect and high degrees of precise visual differentiation. It is also possible to combine glowing foot-switches with associated LEDs such as those depicted in Figure 12a.

Multiple Alphanumeric Displays:

The technology provides for separate alphanumeric displays for several or all of the physical controllers. An example of this is shown in Figures 12a and 12c. A key value in this is providing more detailed descriptions of function, role, result, mode, etc. currently associated with that physical controller. The information displayed would, in the most useful implementations, change along with any corresponding change in function, role, result, mode, etc. associated with that physical controller. The rendered characters may be monochrome

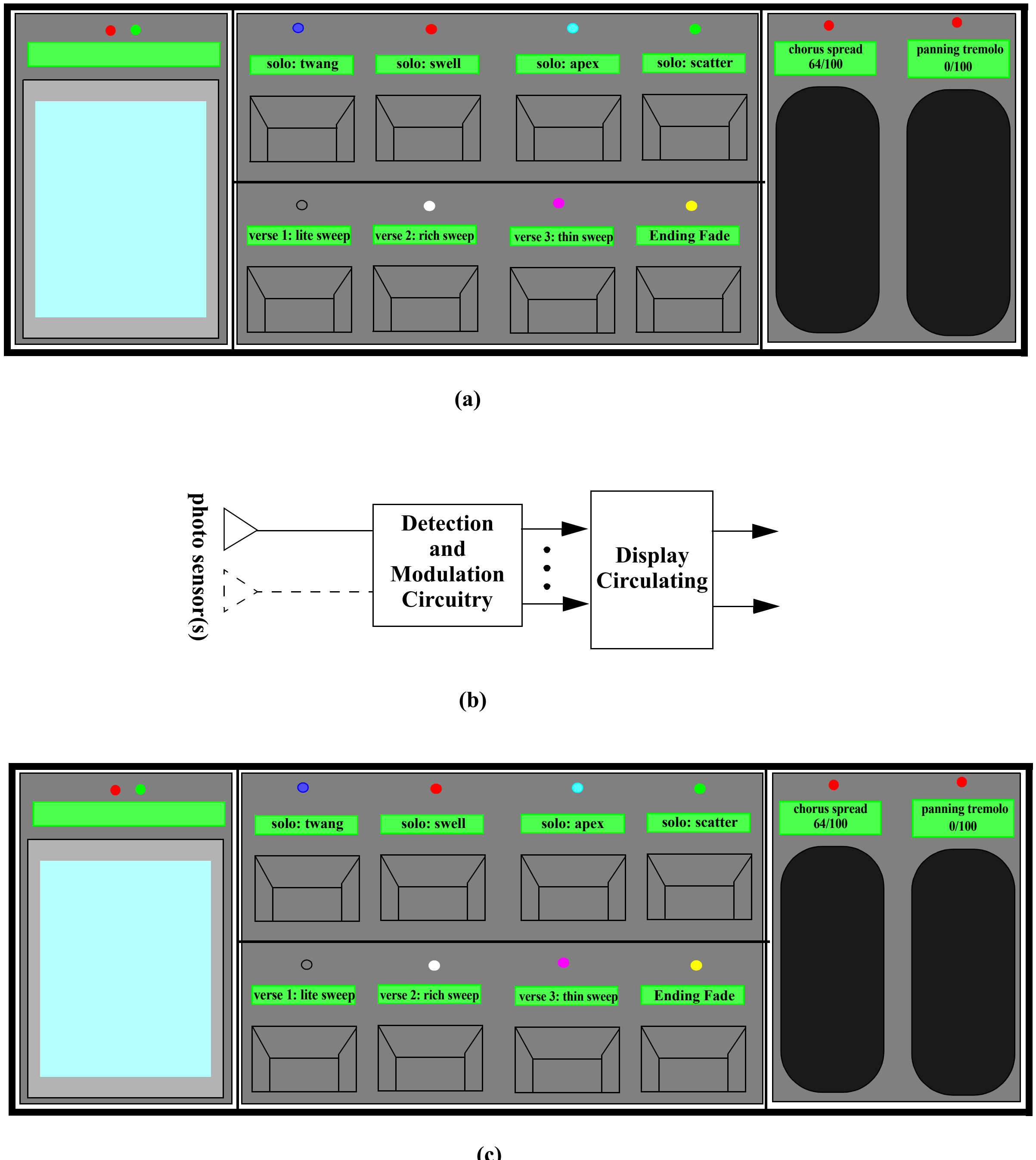


Figure 12

or color. Individual portions of the display may in some implementations support blinking, color fluctuation, sequential motion across the display, or other animation effects.

Graphical Displays

The technology includes provisions for displays capable of rendering and displaying graphical information so as to enhance the presentation or understanding of the alphanumeric information aforementioned. The technology also provides for the use of such graphical capabilities to render visual display of geometric symbols and boundaries representing various associated information such as:

- currently-assigned function,
- current, next, and/or last value transmitted,
- controller relationships:
    - hierarchical organizations,
    - state machine groupings,
    - sub-page affiliation;
- activation status,
- state machine status.

Physical controllers may be represented as dots, icons, text, etc. on the graphical display. Graphical highlighting, such as reverse video, half-tone change, color change, line-width change, etc. may be used to indicate status information. The graphical controller may further provide visual boundary indications, the depiction of nesting arrangements, etc. These may be rendered via lines, curves, etc. of fixed or varying line width, and/or as regions differentiated by half-toning, dither patterns, colors, etc. Additionally, discrete-graph representations (vertices linked by lines or arcs) of various associating information may be displayed to form or flow, block diagrams. In there diagrams, the vertices may be dots, icons, text, etc. and represent physical controller elements or active states they may be in. In representing state machine information, lines or arcs linking vertices may have arrows, highlighting, etc. which call out possible next state transitions and/or the current state. For touch-pads that are transparent (as in the case of a null/contact touch screen overlay) one or more video, graphics, or alphanumeric displays may be placed under a given pad or group of pads.

An exemplary integration of a large graphical display into a floor controller is shown in Figures 12a and 12c. The large graphical display depicted on the right side of the exemplary floor controller arrangement may itself be integrated together with a transparent touchpad as described earlier.

Alternatively, the separate alphanumeric displays individually associated with various physical controllers shown in Figures 12a and 12c may include graphics capabilities for rendering relevant graphical symbols, diagrams, animations, etc.

In one implementation approach, at least some foot-switch, alphanumeric display, and LED components described earlier may be entirely replaced with visual representations displayed on a physically-robust graphical display fitted with an overlay touchpad (i.e., a foot-operated touchscreen). This many be done repeatedly, each replacing one associated set of foot-switch, alphanumeric display, and LED, or may be done for a larger group of two or more foot-switches, alphanumeric displays, and LEDs.

Specifiable and Assignable State Machines

A foot-switch may be configured to operate in a toggle mode using a divide-by-two counter, and messages can be issued on each toggle transition. These useful features can be found on, for example the Digitech PMC-10, but a number of useful enhancements are provided for in the patents. One enhancement so allows any specific foot-switch to independently operate in a generalization of a push-on/push-off (toggle mode) to permit a round-robin selection of 3 or more states (for example "off," "slow," "medium," "fast"). This is illustrated in Figure 13a. In this situation, an appropriate type of state machine is assigned to a selected foot-switch and the issuance of one or more specified control signals may be assigned to one or more of the states, transitions into the states, or transitions out of the states. Typically the issued control signals would comprise a one-time burst of MIDI messages sent upon entering or leaving a specified state. As described later, a time-driven sequence of messages may be issued, for example a scored sequence of MIDI note commands (one-time or a loop), continuous controller messages carrying outputs of an LFO or envelope generator, etc. Other foot-switches may independently be assigned to other state machines. States of a given state machine may also invoke hierarchical structures and/or assignments to other foot-switches and other physical controller elements.

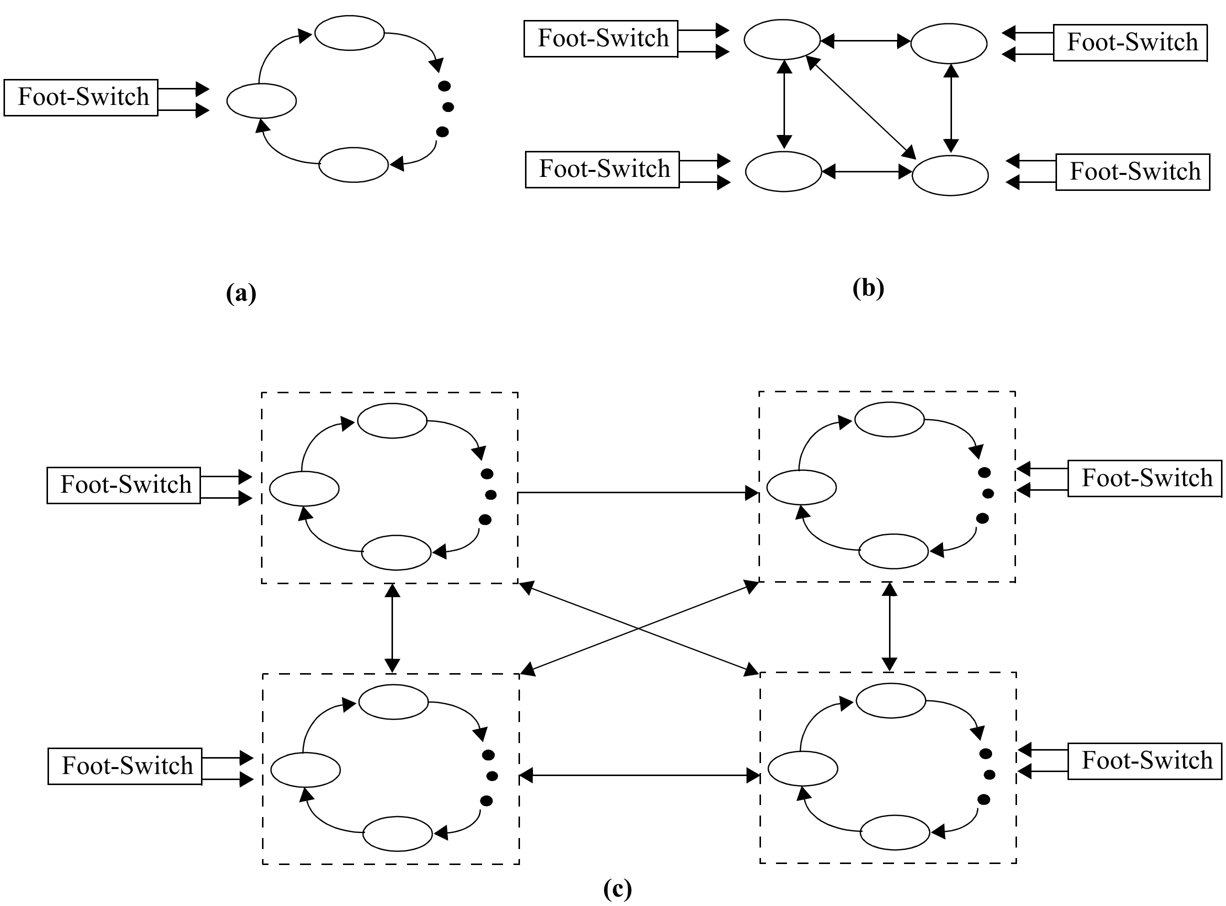


Figure 13

Another enhancement is to allow a more complicated state transition map involving a group of foot-switches. An example of such a state machine is shown in Figure 13b. In this situation, an appropriate type of state machine is assigned to two or more selected foot-switches, and the issuance of one or more specified control signals may be assigned to one or more of the states transitions into the states, or transitions out of the states. Time-driven sequences of messages may be issued, for example a scored sequence of MIDI note commands (one-time or a loop), continuous controller messages carrying outputs of an LFO or envelope generator, etc. Other foot-switches may independently be assigned to other state machines. Again, states of a given state machine may also invoke hierarchical structures and/or assignments to other foot-switches and other physical controller elements.

The two types of state machines (as well as other possible types) may further be combined as shown in Figure 13c. A given round-robin state machine, such as found in this example, may be configured to always begin at a designated initial state or, alternatively, at the last state active when the state machine was left for another under control of another foot-switch.

Temporally-Sequenced Control Message Generation

For most MIDI-oriented foot controller products, operation of a foot-switch may be assigned, under stored program control, to issue one or more control signals, or short burst of contiguously-sequenced control signals, for example a group of MIDI messages. In almost all of these MIDI-oriented foot controller products, assignable control signal events are issued at the depression of a selected foot-switch. In at least the Digitech PMC-10, assignable control signal events are issued at the depression of a selected foot-switch, at its release, or both. As describe above, the New Renaissance Institute floor controller patents provide for all of these modalities as components of the broader functionalities and contexts of enhancements to foot controller technologies.

Additionally, the New Renaissance Institute floor controller patents further provide for more precisely timed control events to be issued responsive to the operation of a foot switch. The simplest implementation of this would be timed pause operations between control signal events as shown in Figure 14a. Here, in addition to the particular message, the delay time between messages (or equivalently the schedule of relative transmission times) are additionally stored and enacted when invoked. The message editor may allow for the delay or schedule of relative transmission times to be hand-entered, or a MIDI recording or MIDI-file transfer function may be used to load the temporally-specified sequence of MIDI messages. In the case of hand-entry, numerical values or tempo-related timings may be specified, perhaps responsive to MIDI time-code.

A further enhanced implementation would permit nearly contiguous real-time control event play-back as shown in Figure 14b. Such real-time event sequences could include note sequences, general trajectories of continuous parameters (for example, exponential transients, linear ramp slow-frequency oscillators), and recorded sequences from human-operation of physical controllers, etc. Generated sequences and recorded sequences of con-

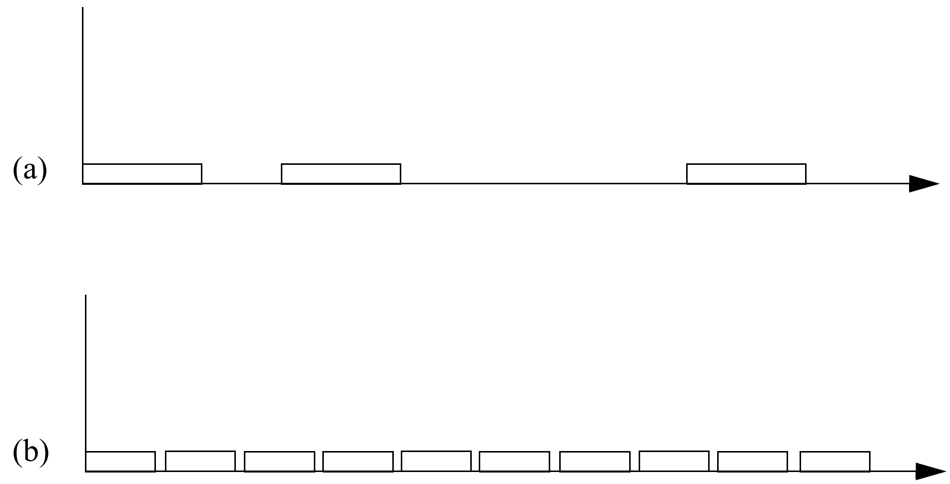


Figure 14

trol events can be used for Leslie speaker speed-transition simulation, cross-fades, moving pans, lighting control, short ornamental, or accenting note sequences, etc.

With sufficient gaps between consecutive messages in the temporal transmission script, or by leveraging more than one (parallel) control output (as described below), several such temporally-sequenced control message generation functions can in fact be active simultaneously.

Internal Control Signal Processing and Parallel Outputs

The patents provide for control signal processing of internally generated control signals as well as the (effective or actual) parallel output of associated outgoing control signals. Figure 15a illustrates an exemplary implementation of this. Physical controller elements are directed to originated control signals. Some of these may be directed to subsequent signal processing steps, resulting in one or more associated outgoing control signals. If there are two or more associated outgoing signals generated, these may be multiplexed together on the same physical output interface (i.e., sent out through the same MIDI output connector) or may be directed to separate physical output interfaces (i.e., sent out through different MIDI output connectors. The control signal processing functions themselves may be selected under the direction of an active stored preset, an action by a physical controller element, external control signal etc. The control signal processing may operate on a single control signal or on a group of control signals, one of which may be externally provided.

A particularly noteworthy example is that of issuing continuous controller messages that oppositely complement the control signal value of a continuous controller message generated elsewhere. For example, consider a MIDI continuous controller message with a useful range of control values ranging 0 to 127, as may be used to control volume, pan location, or an audio filter parameter. If a continuous foot-pedal position causes a first control signal to be issued with value of "x" of 0 to 127, a second separate control signal can be generated and issued essentially simultaneously (immediately afterwards, or simultaneously on a parallel output port) with a value determined by the algebraic relation "127-x". Such complementary signals may be used for many purposes, for example prorating an audio mix between two sources (audio “seque”), prorating modulation indices among two synthesizer voices, lighting fades, bringing up lights as volume is reduced, etc.

Figure 15b illustrates signal processing of a single input control signal to produce output control signal. Some example control signal processing operations of this type may include:

- warping of a control signal by a nonlinearity,
- slow-limiting of a control signal,
- generating the compliment of a control signal (as described above),
- filtering of a control signal,
- converting from one type of control signal to another,
- an envelope generator triggered by the input control signal,
- a low-frequency oscillator started or controlled by the input control signal.

Such functions may be used in isolation, combined with other functions, or used together with the original input control signal. Figure 15c shows an example of the latter. Uses here include:

- using a complement signal processing operation to create a pair of complementary-valued control signals for use in cross-fading, cross panning, prorating a modulation across-two synthesizer voices or lighting channels, etc.
- generating associated note-control and continuous control signals for use in coordinated lighting, audio signal processing, etc.
- generating slewed and non-slewed control signals for use in coordinated lighting, audio signal processing, etc.

Figure 15d shows an example of a control signal processing function that accepts two or more control signal inputs and generates an output control signal. Some examples of this type of function may include:

- multiplying the input control signals together
- adding the input control signals together
- averaging the input control signals together
- scaling the range of one input control signal by a second input control signal and centering the result according to a third control signal
- a low frequency oscillator, slow-limiter, or envelope generator which has various parameters controlled by various incoming control signals.

Figure 15e shows an example where a single input control signal is used to generate two or more output control signals. An example is to produce two or more piece-wise continuous sequentially-stage ramping functions for sweeping through a group of audio sources or creating a swelling crescendo.

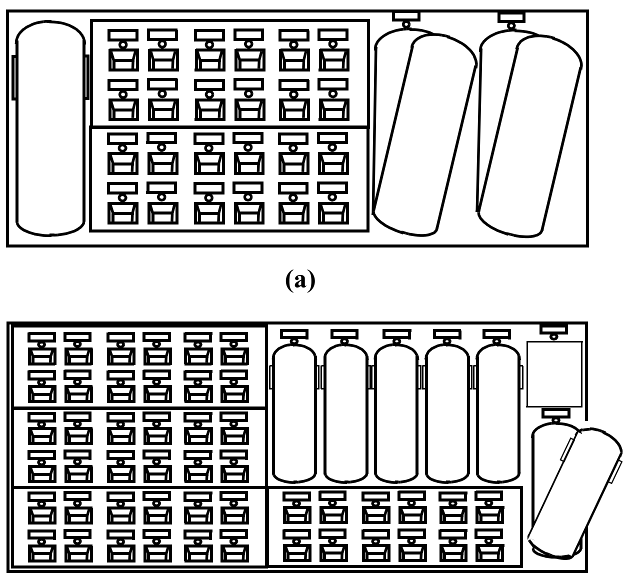
Clearly, other general and specific types of control signal processing functions may be added to or substituted for the examples provided above.

The control signal processing system may further allow for two or more control signal processing functions to be used in series, parallel, or more complex topologies.

Geometric Control-Element Layout for Larger Scale Control Metaphors

For larger foot controller assemblies, appropriate organizational and ergonomic layout become important and are provided for by the patents. Among the factors at play are: overall ergonomic operation, putting some foot controlled elements closer to the user for fast or intimate use, with others farther away for background or occasional use, and an overall physical and operational organizational hierarchy.

Figure 16a shows some example layouts involving two geometric regions for a moderate



(a)

Figure 16 **(b)**

number of foot operated controllers. Figure 16b shows an arrangement with four geometric regions for a larger number of foot operated controllers. The smaller arrangement illustrating features a rocker pedal with two side-mount spring controllers and two rock/twist pedals as well as two geometric regions of foot-switches, one proximate, another remote. Each foot-switch and pedal is provided with an alphanumeric display and a last-operation indicating-LED.

The larger arrangement features an advantageous layout of two proximate geometric regions of foot-switches, two increasingly remote geometric regions of foot-switches, one proximate rock/twist pedal, remote pedals of rocker only, single side spring lever, and double side spring lever, as well as a foot or toe operated touch-pad. Each foot operated controller is also provided with an alphanumeric display and a last-operation indicating-LED. The layout used in the larger unit permits logical association of groups of switches and pedals in a wide variety of contexts. In either the smaller or larger arrangement, the more remote controllers can be put on progressively higher risers to create a staircase layout. These arrangements permit for arbitrary logical layouts for hierarchies and arbitrary assignment of which foot-switches may be used to do this. In some cases it may be desirable to have an additional summary display showing the status information in one location, at a glance.

Modular Field-Configurable Assemblies

Employing a collection of formalized modules and mounting frames to floor controller product design, a wide range of floor controller types may be implemented. Only a few illustrative approaches are described, but those of ordinary skill will appreciate that a vast assortment of variations are possible. These illustrated approaches and other variations are covered in other pending patent applications.

Figures 17a-17d depict a few exemplary modules that may be useful in implementing modular floor controllers. Figure 17a shows a foot-switch controller module comprising four foot-switches, while Figure 17b shows a foot-switch controller module comprising two foot-switches. Visual status and context indicators may be incorporated in a number of ways. Here, for the sake of illustration, active-status LEDs are provided for each foot-switch, and dedicated alphanumeric displays are provided for each foot-switch. Either of these visual indications may be omitted, and one or both may be incorporated in other manners (for example, LEDs may be implemented into the foot-switches themselves, alphanu-

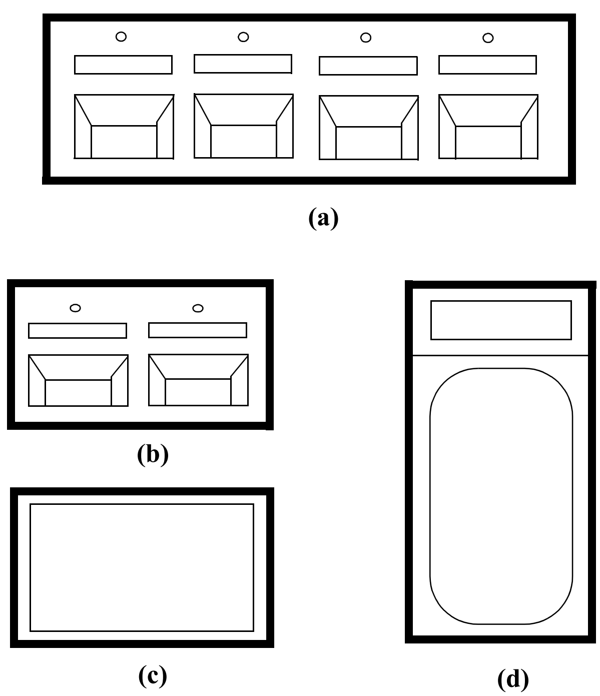


Figure 17

meric information for each foot-switch may be consolidated into a single, larger multiple-line alphanumeric display shared by a group of foot-switches, etc.). For the sake of illustration, a smaller two-foot-switch version is also provided. This will have utility when the total foot-switch counts are preferably between two integer-multiples of four, in filling available open areas in a hierarchical frame, etc.

Figure 17c shows a touchpad or pressure sensor array pad configured for operation by a user's foot. In principle, the same touchpad or pressure sensor array pad hardware described earlier for hand operation, may also be used for foot operation. However a mode change (from "hand" to "foot") in pattern recognition and parameter extraction may be advantageous, but not necessarily required for useful operation. As with the hand-operated configurations described earlier, the pad may be fitted with an impact sensor for supporting percussion applicants. In this illustration, it is assumed that visual status and context indications are incorporated into the pad itself, using a transparent pad and underlying visual display. However, other arrangements or omissions of these are of course possible. The transparent pad and associated underlying visual display may be implemented using conventional techniques, such as those disclosed in U.S. Patent 6,570,078.

Figure 17d illustrates a rocking foot pedal module comprising a rocking foot pedal, again, with exemplary visual indication provided by optional alphanumeric display (or other suitable display device). The rocking foot pedal module width may be kept narrow, or widened enough to allow other degrees of motion, such as pivoting rotation. Such additional degrees of motion and/or the addition of other structures can be used to obtain greater parameters of control with a common pedal (examples of such techniques may be found in U.S. Patent 6,570,078). Thus, a common module size and format of rocking foot pedal module may serve as a simple rocking foot pedal and a variety of multiple parameter foot pedals for both varying styles and complexities. Note the modules shown in these figures are purely exemplary - other possibilities may include foot-operated strumpads, individual foot-operated impact sensors, Western pipe-organ style bass pedal board pedals, etc.

Further to the examples of Figure 17d, a common module size and format may be scaled together with additional types of modules:

- Two-foot-switch module, pad module, and foot pedal module are all the same length and half the length of four-foot-switch module.
- Two-foot-switch module, pad module, and four-foot-switch module are all the same width and half the width of foot pedal module.

Employing this dimensioning scheme, Figures 18a-18c illustrate an evolving heterogeneous aggregation of the floor controller modules of Figures 17a-17d. For example, the configuration of Figure 18a shows a pair of foot pedal modules at either end of a mounting frame. Using hierarchical frames or other techniques, the configuration of Figure 18a may also include a four-foot-switch module, a two-foot-switch module, and a pad module. A musician initially employs a simple pad module comprising a contact-null pad with a common underlying pressure sensor as a two-dimensional controller (via toe-pointing) and as a toe-pressure sensor, employing these two modalities selectively or simultaneously. Later the musician may expand the detail and nuance of a musical composition that uses the pad module by upgrading to a pressure sensor array pad module to control six parameters simultaneously using known techniques, such as those described in U.S. Patent 6,570,078.

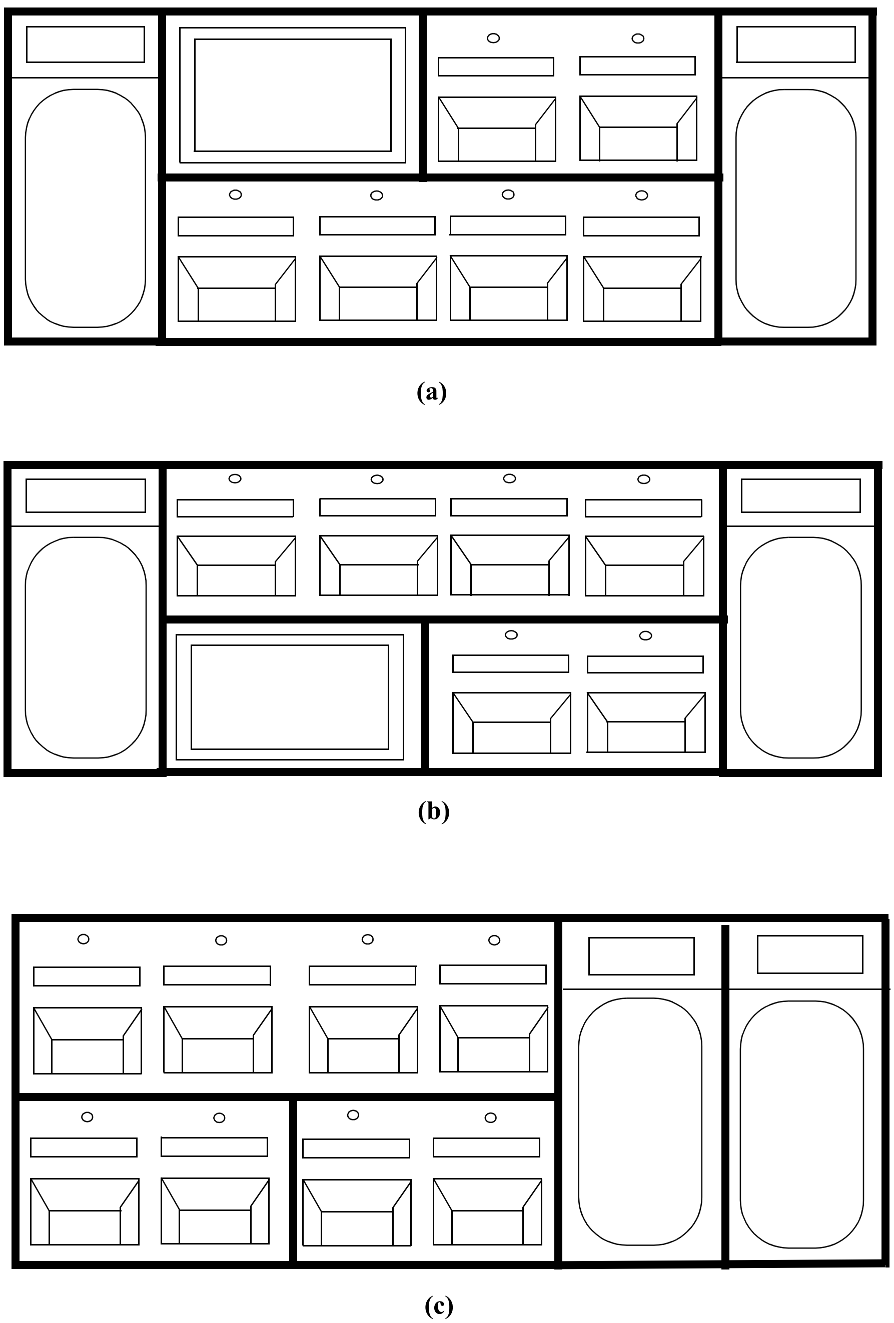
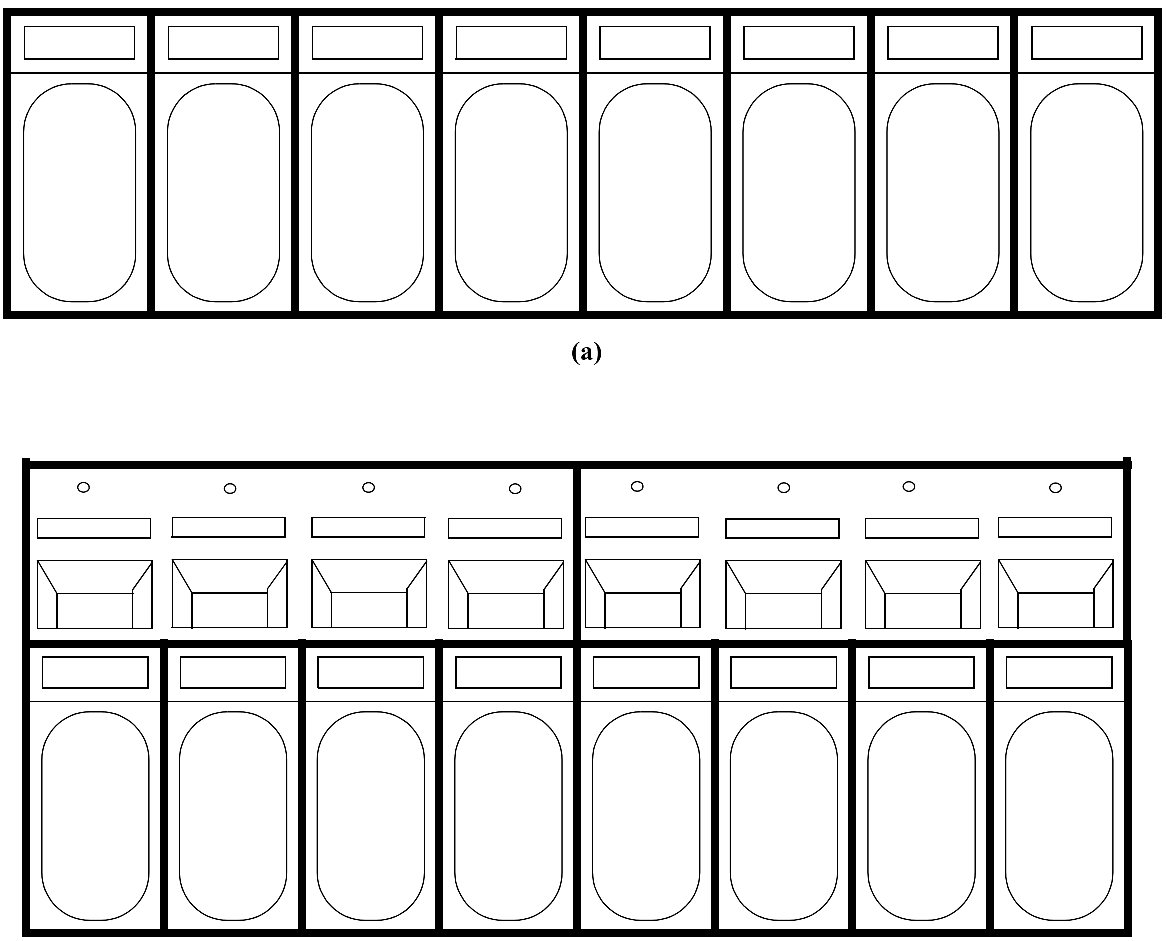


Figure 18

The musician may find that during recording it would be advantageous to restructure the configuration of the pad by moving it closer to the foot's normal standing position and moving the modules around to result in the configuration of Figure 18b.

Continuing with this scenario, a CD containing the recording may be later released to great acclaim for its sensitive solo rendered with the pressure sensor array pad module and so the musician may go on tour. Once on tour the musician finds the deafening crowd noise drowns out all those careful subtleties made available by the pressure sensor array pad module, and furthermore, that in the excitement and nervousness of playing in venues before large noisy audiences of screaming high-energy fans with flowers (and other objects) being thrown on stage, there is at times trouble concentrating enough to use the pressure sensor array pad module as well as it was done in the now famous recording. The musician reviews the solo and artistically decides to instead simply use one of the rocker pedals to create an easy-to-operate one-parameter variation over time with a simple foot motion, and derive a plurality of control signals from that one-parameter rocker pedal control signal (using, for example, the control signal processing to produce a net effect that sounds "close enough" to the now famous recording on the musician's CD. Not needing the pressure sensor array pad module any more on this tour, the musician simply replaces it with another two-foot-switch module, for example, which finds immediate applicability in controlling a recently added on-instrument miniature fog-generation machine while performing. Later the musician finds a preference to use same right foot for both foot pedals, so the unit is finally reconfigured with rocker pedal now moved to the right next to rocker pedal as shown in Figure 18c. The fortune and perils of a musician's career have been improved in all phases by the principles of the invention.

Two other exemplary configurations are now considered. Figure 19a shows an aggregation of eight of the same type of modules, and in particular, foot pedal modules. This results in an eight rocker-pedal floor controller which may be used for controlling a synthesizer, signal processing parameters, 3D-sound localization, lighting, etc. This configuration is orig-



(a)

(b)

Figure 19

inally assembled as a flat layer, but later the performer may need to support a wider range of usage contexts for the group of pedals requiring foot-switches. A staircase frame may be used to position two four-foot-switch modules on a raised upper deck to control the contexts and settings of the group of foot pedal modules, as shown in Figure 19b.

Application To Rich Audio Signal Processing Environments

The floor controller technologies may be used to provide for the control of an environment of several audio signal processors reconfigurably connected, so that they may be used as needed in various parallel, series, or other interconnections serving one or more vibrating elements. Figure 20 shows a very general combined environment for multi-channel signal processing, mixing, excitation, and program control of overall configuration.

The exemplary audio signal environment depicted in Figure 20a comprises a flexible example method for providing signal processors with vibrating element audio transducer signals and audio signal processor outputs, via an audio switch matrix, and additional partial mix-downs by replacing the audio switch matrix with an input mixer. Partial mix-downs of vibrating element signals may be directed to a number of audio signal processors and straight-through paths *en route* to subsequent mix-down. A pre-signal processing input mixer is used to route and/or mix various multi-channel transducer signals to a structured and controllable multi-channel mix. An audio switching matrix can be used in place of the input mixer to select which individual vibrating element signal is assigned to which signal processor. This arrangement is particularly relevant to the generalized retuning of certain vibrational elements, as may be useful in the adapted pedal steel guitar and adapted sitar, to be described later.

The floor controller technologies may be used to reconfigure the resulting system via a shared common configuration preset storage and recall facility. This is simply a matter of putting all or some combination of the audio mixers, audio switch matrices, audio signal processors, and/or synthesizer interfaces, as relevant, under the control of logic circuitry and/or microprocessors which can provide such preset storage and recall functions.

A sophisticated floor controller is useful for controlling vibrating element excitation as may be supported by an extended signal processing environment. By combining the multi-channel signal handling with vibrating element excitation, not only can individual vibrating elements be assigned to various signal processing and synthesizer controlling roles, but also individual vibrating elements can now be assigned feedback modes where selected vibrating elements can sustain vibration as if they were bowed, in an electric-guitar feedback arrangement, etc. Through use of additional switching, signal processing can be introduced into the feedback loop dedicated hardware or on an individual vibrational element basis.

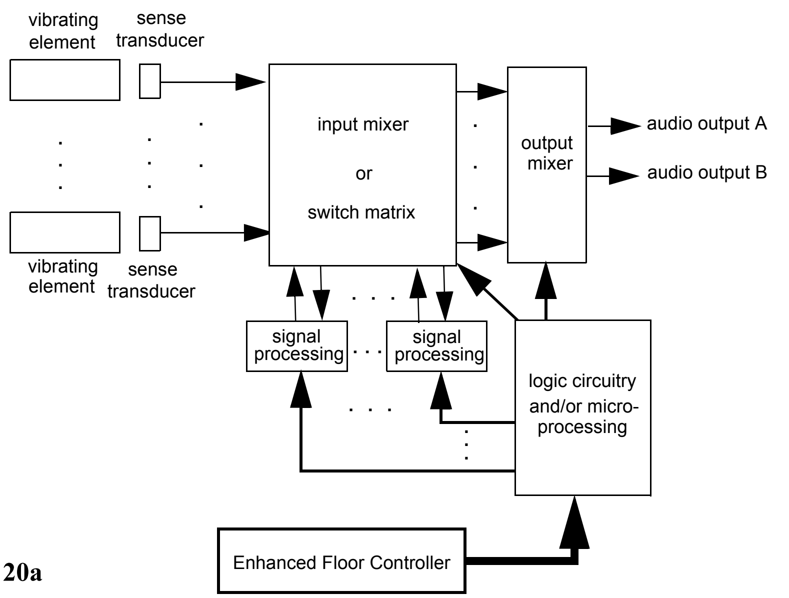


Figure 20a

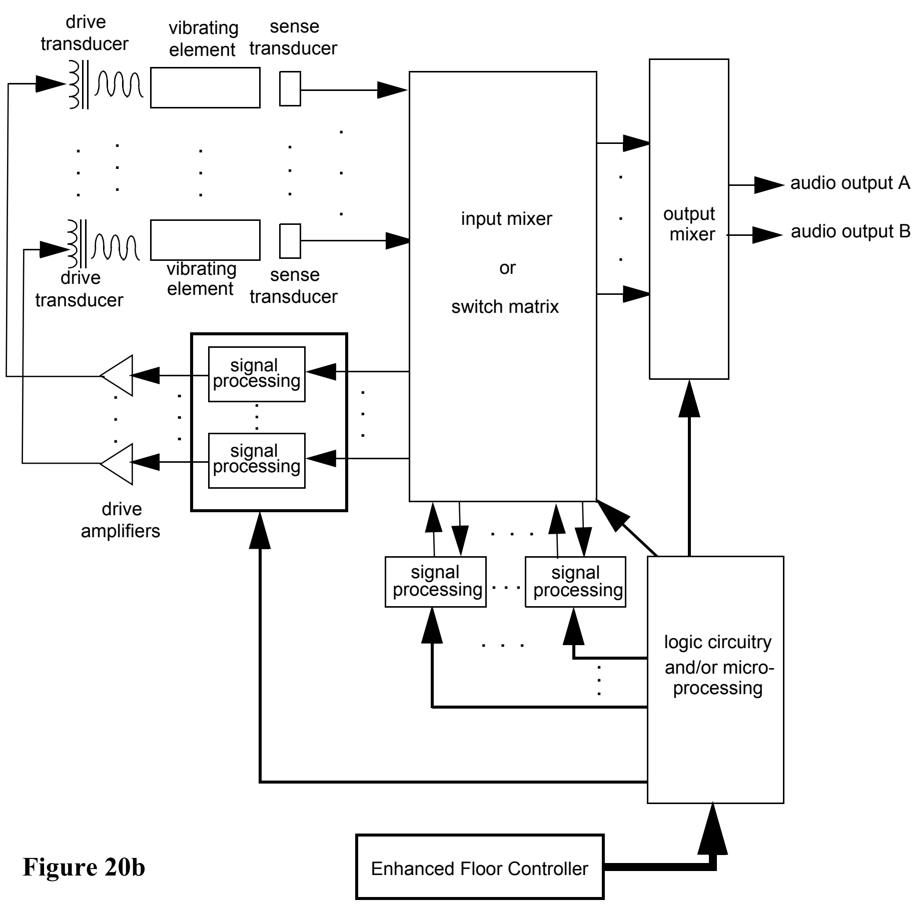


Figure 20b

In Figure 20b, a general combined environment is shown incorporating separate feedback loops for each vibrating element, each loop featuring a loop signal processor (which here could be as simple as a level control) sending signals to the excitation drive amplifiers. This is as provided for in U.S. Patent 6,610,917 "Activity Indication, External Source, and Processing Loop Provisions for Driven Vibrating Element Environments." The loop signal processors may also be controlled by control signals provided by the floor controller. Further, since feedback arrangements tend to emphasize higher harmonics of vibration, and dynamics of the relative levels of harmonics can be varied dramatically by touching elements or varying feedback characteristics (via signal processing in the excitation feedback loop), expanded signal extraction to respond to details of the overtone content (as discussed in Pre-Grant Patent Application US 2004/0069128, “Derivation of Control Signals from Real-Time Overtone Series Measurements.”) may be added.

Many possible variations of these which may omit simplify or any elaborate upon any of the elements shown in Figure 20 can be realized. In general, signal processors may be pooled together

- There can be one or more dedicated straight (un-switched, un-mixed) paths;
- There can be one or more paths fixed with a dedicated signal processor;
- Each signal processor may be any of a variety of types;
- Each signal processor may be internally reconfigurable and perform a variety of types of signal processing functions;
- Each depicted signal processor may internally comprise a plurality of internal signal processors arranged in a chain or other configurations;
- Although the interconnection details for connecting the synthesizer interface are shown, the synthesizer interface need not be included.

Such multichannel signal processing and handling environments, along with further variations, are covered by pending U.S. Pre-Grant Patent Application 2004/0069126 "Multi-Channel Signal Processing for Multi-Channel Musical Instruments" and are further described in its associated whitepaper.

Application To Specific Musical Instruments

The advantageous use of the enhanced floor controller technologies to two example enhanced electronic musical instruments is now considered. The floor controller technologies may also be used to control synthesizers, note assignments to strum pads, and other musical instruments.

Electronically Enhanced Pedal Steel Guitar

The pedal steel guitar is a remarkable instrument in which the pitches of individual strings are changed as a group by a hand-held metal slide and relatively within the group by mechanical bridge arrangement, usually called a "changer," which changes the tension on one or more selected strings in response to the action of a given foot-pedal or knee lever. The basic sound of the steel guitar is very attractive and it is possible to tastefully play Bach chorales and hymns on the instrument. Years of incremental development have led to specific standard pedal and knee lever configurations that are widely accepted.

Variations are sometimes difficult to implement because of mechanical limitations to provided adjustments. Because of the commitment involved in mechanically establishing an alternate pedal and lever configuration, immense experience and/or a computer-aided design tool may be required to make valuable accomplishments.

By providing a separate audio signal transducer (pickup) for each string, pitch bending and changes in open-string tuning can be implemented electronically, supplementing or replacing the traditional mechanical pitch bending arrangements. The audio signal of each string can also be processed separately or in groups, as desired, allowing for mixes of timbres. Audio-to-control signal extractions can be used to control synthesizers, signal processing, lighting, and special effects. Information from (mechanical or electronic) pedals, knee-levers and the steel bar position can be used to control the pitch shifting and other signal processing. The bar itself may feature a built-in control area, (detecting applied pressure, for example), and/or be subject to position-sensing along the length of the string area. The electronic pitch bending and other signal processing may be performed utilizing a rich audio signal processing environment such as that depicted in Figure 20. The instrument may also include a strumpad (electronically emulating a string array) and a miniature keyboard, each for controlling an internal synthesizer and/or issuing outgoing MIDI messages to external equipment.

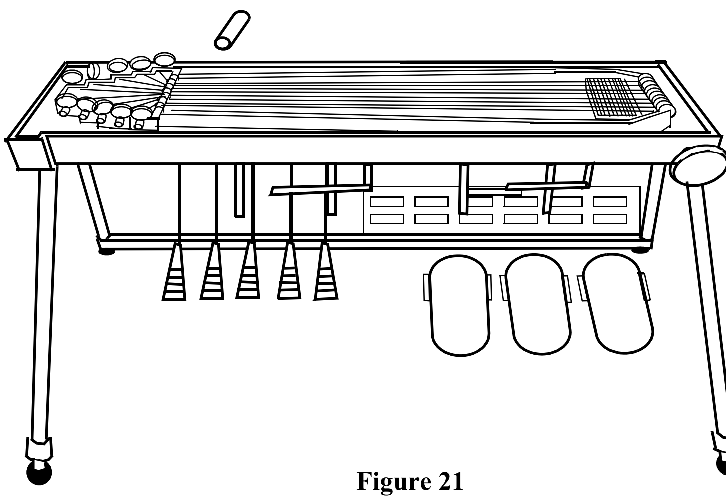


Figure 21

Because of the nature of the required control, and traditions associated with the instrument, enhanced floor-control of the rich signal processing environment is a natural choice. Figure 21 shows an example pedal steel guitar adaptation as provided for by US Patent 6,852,919 and utilizing enhanced floor-control of rich audio signal processing environments like those of Figure 20.

In a pure electronic implementation, no mechanical pitch bending equipment is involved. In this case enhanced foot controller technologies are used to control the tuning and pitch bend via pitch shifting within the rich audio signal processing environment.

In a hybrid mechanical/electronic implementation, the instrument may include a traditional mechanical changer with linkages to pedals and levers, or may be fixed if all pitch bends are to be done electronically. With a mechanical changer, the pedals and levers may be fitted with sensors that measure and convert their displacement into control signals. Other control signals may be issued by one or more enhanced foot-operated rocker pedals such as those shown in Figure 3 (which may be fitted with side-mounted spring-lever controls, twisting foot plates, adapted modulation wheels, etc.).

In either implementation, the enhanced floor controller technologies provided for in the New Renaissance Institute patents offer excellent support for this instrument:

- Spring-loaded actuators attached to foot-operated rocker pedals, as shown in Figure 3, may be used to control temporary pitch bends, directly emulating the spring-return operation of a traditionally pedal steel guitar's pedals and levers. Spring-return or motorized-return adaptations of a foot-operated rocker pedal may also be used in this fashion;
- Non-spring-return foot-operated rocker pedals can be used for various other control functions, but additional offer a natural way of (electronically) providing sustained pitch bending without having to devote a foot or knee to that purpose;
- Various tunings and pitch-bend setups (which actuator bends the pitch of which string by how much) may be used by foot-switches;
- The enhanced floor controller technologies can be used for the introduction or variation of signal processing on one or more selected strings, and can be configured to make such effects while simultaneously changing pitch of selected string or strings. Various signal processing setups and how they are controlled by various physical controller elements and other control sources may also be selected under the control of foot-switches;
- The flexible assignment of foot-switch functions and associated hierarchical structures provide a natural environment for organizing control and operation of the rich audio signal processing environment required for moderate to advanced playing of the instrument;
- Additional alphanumeric and/or graphical displays, as well as use of multi-color LEDs, additionally provide extremely useful orientation, management, and navigational capabilities greatly supporting the playing of the instrument.
- Foot-switches may be used for selecting issuing backing chords, sequences of notes or chords, and/or the operation of drum machines, sequencers, lighting systems, etc.;
- Should string drive transducers be incorporated (as is the case in the example of Figure 20b), foot-switches or other physical controller elements may be programmed to control selective use of string drive transducers and any associated signal processing;
- Should strumpads be incorporated, foot-switches may be programmed to control the notes assigned to the individual touch switches of the strumpad;

These and further variations covered by U.S. Patent 6,852,919 "Extensions and Generalizations of the Pedal Steel Guitar" and are further described in an associated whitepaper.

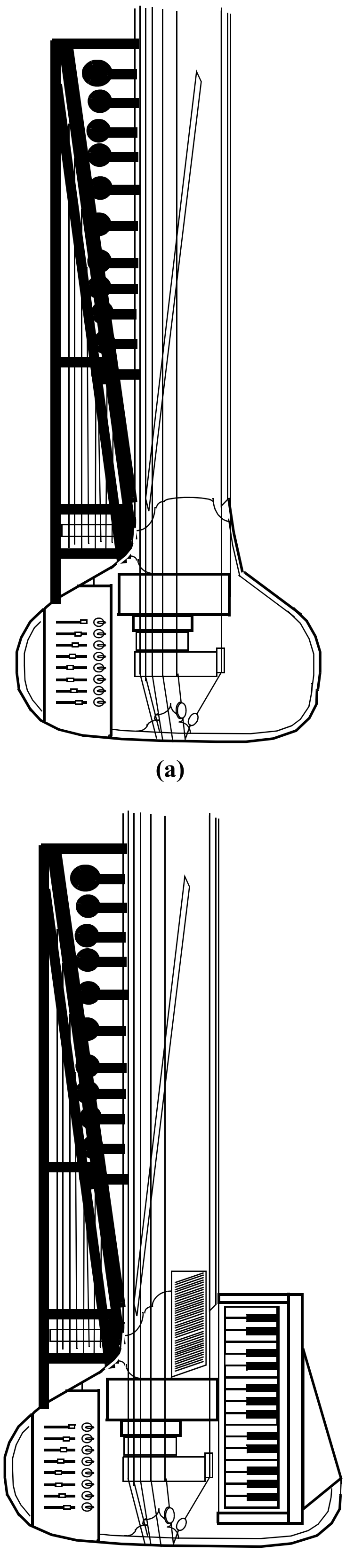
Electronically Enhanced South Asian Sitar

Figure 22 shows a patent-pending adaptation of a South Asian sitar. The core instrument is a standard Indian Sitar with a standard melody string, any one of a number of possible arrangements of drone strings (here two are shown), and the chikari pair, all sharing the common sloped bridge. Also part of the core instrument, not shown explicitly in the Figure for the sake of clarity, are the sympathetic strings, typically eleven in number, with their own sloping bridge and multi-length termination area on the neck under the Sitar's curved frets. Figure 22a shows a simpler implementation with a focus on strings, while the exemplary variation of Figure 22b includes a strumpad (electronically emulating a string array) and a miniature keyboard, each for controlling an internal synthesizer and/or issuing outgoing MIDI messages to external equipment.

Important in this adaptation is a multichannel transducer assembly which provides a separate audio signal for each melody string, each drone string, and either the chikari pair or its individual strings. The separate outputs allow for pitch shifting of individual strings; in particular, the pitch shifted retunings of the drone strings and chikari can be made while playing. The electronic pitch bending, electronic retuning of drone strings, and other signal processing may be performed utilizing a rich audio signal processing environment such as that depicted in Figure 20.

There is also valuable opportunity here for alternative stringing systems, particularly if pitch shifting of individual strings is used to create larger pitch-shifts. An additional melody string can be provided, and may be tuned in union or in an interval to the original melody string. With separate audio channels provided for each, they can be signal processed in different ways or panned into different positions in the stereo sound field. Further, the additional melody string, strumpads, and addition string assembly serve to expand an important orchestrational aspect of seasoned Sitar technique, namely a constant variety of timbres and effects, with attention constantly shifting among them.

Electronic pitch shift retuning capabilities allow for hitherto impossible tonality shifts within the Sitar environment, while the electronic pitch shift pitch-bend capabilities allow the drone strings to obtain pitch bending and the melody string(s) to be harmonized in a pitch-modulated manner.



(a)

(b)

Figure 22

Because of the nature of the required control, enhanced floor-control of the rich signal processing environment is natural choice. The enhanced floor controller technologies provided for in the New Renaissance Institute patents offer excellent support for this instrument, sharing the many advantages and applications listed earlier for the enhanced pedal steel guitar.

This instrument and further variations are covered by pending U.S. Patent Application 10/688,743, “Transcending Extensions of Classical South Asian Musical Instruments” and is further described in an associated whitepaper.

Further Design Details Available

This document has provided a quick overview of the concepts, capabilities, potential scope and areas of application of enhanced functionality foot-operated floor controllers, based on U.S. Patent 6,689,947 and other affiliated patents licensable from New Renaissance Institute®. New Renaissance Institute® can provide detailed hardware and software reference designs under negotiable terms. All financial or in-kind proceeds from such arrangements are to be used to fund pure academic research at New Renaissance Institute®.

Contact inquiries@newrenaissanceinstitute.com for more information.

REFERENCES AND ON-LINE LINKS

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[2] "Rich Multi-Parameter Touchpad User Interface: Overview: Background, Capabilities, and Applications," 2004 (PDF available at *www.newrenaissanceinstitute.com*).

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[4] U.S. Patent 6,570,078 "Tactile, Visual, and Array Controllers for Real-time Control of Music Signal Processing, Mixing, Video, and Lighting," May 27, 2003.

[5] U.S. Patent 6,610,917 "Activity Indication, External Source, and Processing Loop Provisions for Driven Vibrating Element Environments," August 26, 2003.

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[7] U.S. Pre-Grant Patent Application US 2004/0069126, "Multi-channel Signal Processing for Multi-channel Musical Instruments," April 15, 2004.

[8] U.S. Pre-Grant Patent Application 2004/0099131, "Transcending Extensions of Classical South Asian Musical Instruments," May 13, 2004.

[9] U.S. Pre-Grant Patent Application 2004/0074379, "Functional Extensions of Traditional Music Keyboards," April 22, 2004.

[10] U.S. Pre-Grant Patent Application US 2004/0069128, "Derivation of Control Signals from Real-Time Overtone Series Measurements," April 15, 2004.

[11] U.S. Pre-Grant Patent Application US 2005/00126378, "Modular Structures Facilitating Field-Customized Floor Controllers," June 16, 2005.

Appendix: Number of Selection States for 3-Level Non-Scrolling Hierarchies

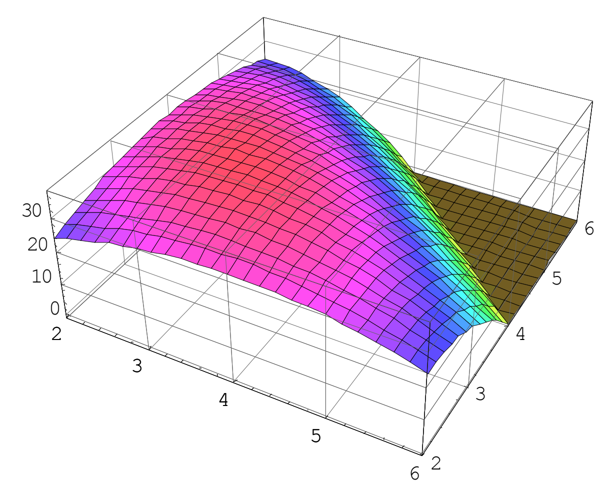
The graphs below show how the number of possible selection states varies as a fixed number of foot-switches are split into three groups of various sizes in a non-scrolling hierarchy.

(By non-scrolling hierarchy it is meant that a state is determined only by which one foot-switch in each hierarchy is currently active and/or most recently activated. Scrolling involves the cyclic state machine depicted in Figure 8a and allows a pair of foot switches in a layer of the hierarch to select more than between two states).

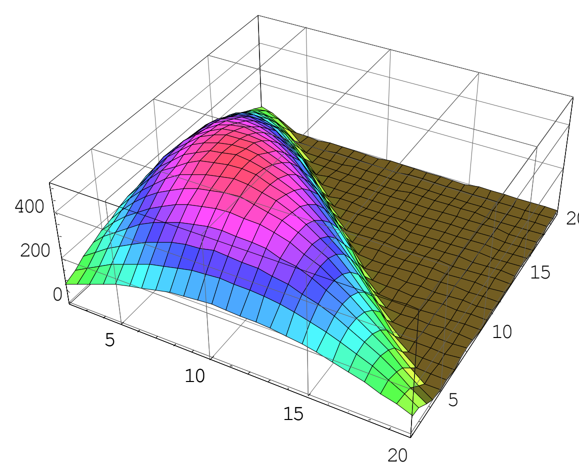
As mentioned earlier, for *n* foot-switches partitioned into *k* hierarchies, the maximum number of states is obtained when the number of foot-switches at each level of the hierarchy is an integer equal to or near the ratio $\frac{n}{k}$, and the maximum number of selections will be an integer equal to or near $\left(\frac{n}{k}\right)^k$.

This result is obtained by a simple calculus maximization calculation and a simple symmetry principle. It may be known elsewhere in other applications. The two expressions turn out to give exact results when *n* is an integer multiple of *k*. For example, if there are 12 foot-switches and three levels of hierarchy, the maximum number of selections is obtained when the number of foot-switches at each level of the hierarchy is exactly four (12 divided by 3), and the maximum number of selections is $4^3 = 64$.

The graphs below show a vertical axis capturing the number of possible states for partitions of the total number of foot-switches into a three-level hierarchy. One of the axes along the bottom of the graph is the number ("x") of foot-switches allocated to one hierarchy, and the other axis along the bottom of the graph is the number ("y") of foot-switches allocated to a second hierarchy. The number ("z") of foot-switches allocated to third hierarchy is not shown but is simply the number of remaining foot-switches, that is *n-x-y*. The reddest parts of the curved surface localize the maximum values, while the brownish portions fill in for impossible combinations which exceed the number of foot-switches.



Numbers of Possible States with
10 Foot-Switches



Numbers of Possible States with
24 Foot-Switches

Notice how the curves flex more acutely, and hence have a more localized (less forgiving) variation around the maximum value, as the total number of foot-switches increases from 10 to 24.

The tables to the right show, in tabular form, details for the cases of 10, 12, and 14 foot-switches. To be meaningful, each of the three levels in the hierarchy is provided with at least two foot-switches in each partition.

The table below shows the maximum possible for various numbers of number of footswitches. By way of orientation, the example of Figure 12 has 8 footswitches, the example for Figures 6-8 has 10 foot switches, the Digitech PMC-10 and similar products have 12 foot switches, and the examples of Figure 16a and 16b respectively have 24 and 48 foot-switches.

Number of Foot-Switches	Maximum Number of States
8	18
10	36
12	64
14	100
16	150
18	216
20	294
22	392
24	512
26	648
28	810
30	1000
32	1210
34	1452
36	1728
38	2028
40	2366
42	2744
44	3150
46	3600
48	4096

10 Footwitches in 3-Level Non-Scrolling-Hierarchy

First Level	2nd Level	3rd Level	Number States
6	2	2	24
5	3	2	30
5	2	3	30
4	4	2	32
4	3	3	36
4	2	4	32
3	5	2	30
3	4	3	36
3	3	4	36
3	2	5	30
2	6	2	24
2	5	3	30
2	4	4	32
2	3	5	30
2	2	6	24

12 Footwitches in 3-Level Non-Scrolling-Hierarchy

First Level	2nd Level	3rd Level	Number States
8	2	2	32
7	3	2	42
7	2	3	42
6	4	2	48
6	3	3	54
6	2	4	48
5	5	2	50
5	4	3	60
5	3	4	60
5	2	5	50
4	6	2	48
4	5	3	60
4	4	4	64
4	3	5	60
4	2	6	48
3	7	2	42
3	6	3	54
3	5	4	60
3	4	5	60
3	3	6	54
3	2	7	42
2	8	2	32
2	7	3	42
2	6	4	48
2	5	5	50
2	4	6	48
2	3	7	42
2	2	8	32

14 Footwitches in 3-Level Non-Scrolling-Hierarchy

First Level	2nd Level	3rd Level	Number States
10	2	2	40
9	3	2	54
9	2	3	54
8	4	2	64
8	3	3	72
8	2	4	64
7	5	2	70
7	4	3	84
7	3	4	84
7	2	5	70
6	6	2	72
6	5	3	90
6	4	4	96
6	3	5	90
6	2	6	72
5	7	2	70
5	6	3	90
5	5	4	100
5	4	5	100
5	3	6	90
5	2	7	70
4	8	2	64
4	7	3	84
4	6	4	96
4	5	5	100
4	4	6	96
4	3	7	84
4	2	8	64
3	9	2	54
3	8	3	72
3	7	4	84
3	6	5	90
3	5	6	90
3	4	7	84
3	3	8	72
3	2	9	54
2	10	2	40
2	9	3	54
2	8	4	64
2	7	5	70
2	6	6	72
2	5	7	70
2	4	8	64
2	3	9	54
2	2	10	40

