New Renaissance Institute®
Technology White Paper

THE NRI® RICH TOUCHPAD
Overview

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ABSTRACT

The NRI® rich touchpad is a novel human-machine interface that can be used for a wide range of real-time applications. This document provides a brief overview of the touchpad's user-level operation, the technology on which the touchpad is based and its applications.

The touchpad incorporates a pressure-sensor array for gathering information in the form of real-time images of the pressure exerted on it. The information is processed using a sequence of stages: a data acquisition and compression stage, an image processing stage and an application interface. The touchpad extracts the values of a large number of continuous parameters (three to six) from each region of contact, and can simultaneously process multiple regions of contact. The application interface assigns the values to control signals, which can be used to control arbitrary external systems. Special hardware and algorithms permit the data acquisition and processing to be carried out in real time.

Because the touchpad provides simultaneous control over so many continuous parameters and can process multiple regions of contact, it is a significant improvement over conventional computer pointing devices, which typically provide simultaneous control over only two continuous parameters and can process only a single region of contact.

The general-purpose nature of the touchpad permits the same basic system to be used in many different applications. They include CAD/CAE workstation control, real-time machine control, assistive technology for the physically disabled and electronic musical instruments. The touchpad can be modularized so that aggregations of sensor arrays can operate as a single large array.

Detailed hardware and software reference designs can be discussed under negotiable terms. All financial or in-kind proceeds from such arrangements will be used to fund pure academic research at NRI®. Contact inquiries@newrenaissanceinstitute.com *for more information.*

Table of Contents

1 Introduction

The NRI® rich touchpad is a novel controller that can be used for a wide range of real-time applications. This document provides a brief overview of the touchpad's user-level operation, the technology on which it is based and its applications. As such, this document summarizes material in three other NRI® whitepapers: one devoted to the touchpad's user-level operation and applications [1], one to its music and performance applications [2], and one to its implementations and underlying technology [3]. Where more detailed information might be desired, citations will be given to the other whitepapers. All these whitepapers are based on U.S. patent 6,570,078 [4] and related issued and pending patents [5-9].

The touchpad incorporates a pressure-sensor array for gathering information in the form of real-time images of the pressure exerted on it, typically by the hand, though it can be operated in other ways. The pressure images are presented to a data acquisition and compression stage, which sends its output to an image processing and recognition stage. The touchpad can process multiple regions of contact simultaneously, and can extract the values of a large number of parameters (three to six) from each region of contact. An application interface assigns the values to control signals, which can be used to control arbitrary external systems. Special hardware and algorithms permit the data processing and image processing to be carried out in real time. The touchpad can be modularized so that aggregations of sensor arrays can operate as a single large array.

Because the rich touchpad provides simultaneous control over so many continuous parameters and can process multiple regions of contact, it significantly advances the capabilities of conventional computer pointing devices, such as the mouse, trackball and conventional touchpad, which typically provide simultaneous control over only two continuous parameters and can process only a single region of contact. In addition, the way in which the rich touchpad is operated is much more natural and intuitive.

The touchpad can be used as a human-machine interface in a wide range of applications, including CAD/CAE workstation control, real-time machine and robotics control, assistive technology for the physically disabled and electronic musical instruments.

This whitepaper is organized as follows. Section 1 discusses the user-level operation of the touchpad. Section 2 discusses its architecture and describes some ways in which it can be implemented. Section 3 provides some examples of applications.

2 User-Level Operation

In this section we consider the user-level operation of the touchpad. We begin by showing, as an illustration of the rich control the touchpad provides, how it can enable a single finger to control six different parameters. We next describe how different forms of contact with the pressure-sensor array produce different kinds of pressure images, and then how the way in which an image is processed can be made to depend on the kind of contact that produces the image and on its context. We conclude this section by discussing how the pressure-sensor array can be divided into functionally-discrete regions. For more information about the user-level operation of the touchpad, see [1].

Controlling Six Parameters with One Finger

Assume the pressure-sensor array is touched by the end of a single finger, as shown in Figure 1a. The pressure image produced by the contact will be like that shown in Figure 1b. Note that the darker the image, the higher the pressure.

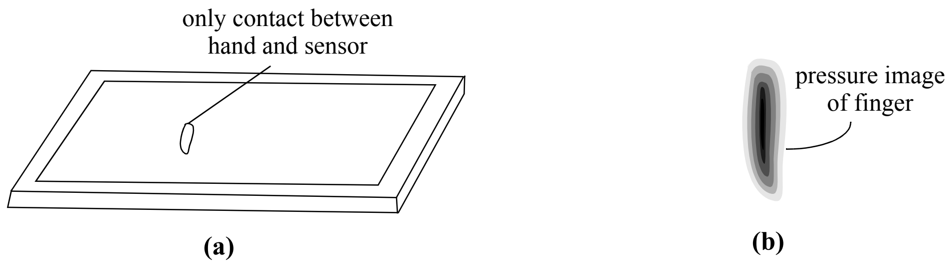


Figure 1. Contact of Finger with Pressure-Sensor Array and Resulting Image

The finger can contact the sensor array anywhere on its surface, so the geometric center of the image determines two parameters -- the center's x and y coordinates -- that the user can control. The roughly elliptical form of the image has a measurable angular orientation, which the user can vary. The user can also control two parameters of the finger's tilt, the degree to which pressure is concentrated with respect to the left-right axis and the forward-back axis. Finally, the user can vary the average or total pressure. All told, there are six parameters that the user can control independently of one another. These are illustrated in Figure 2.

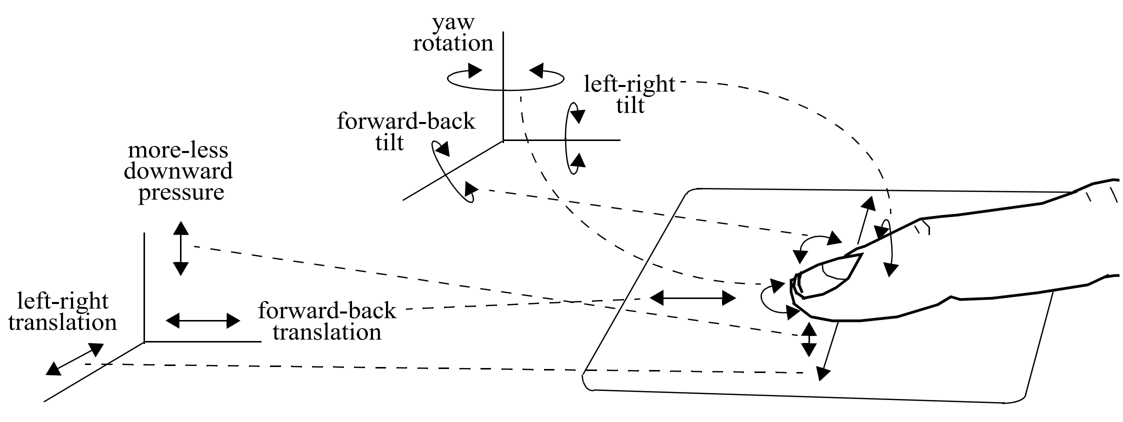
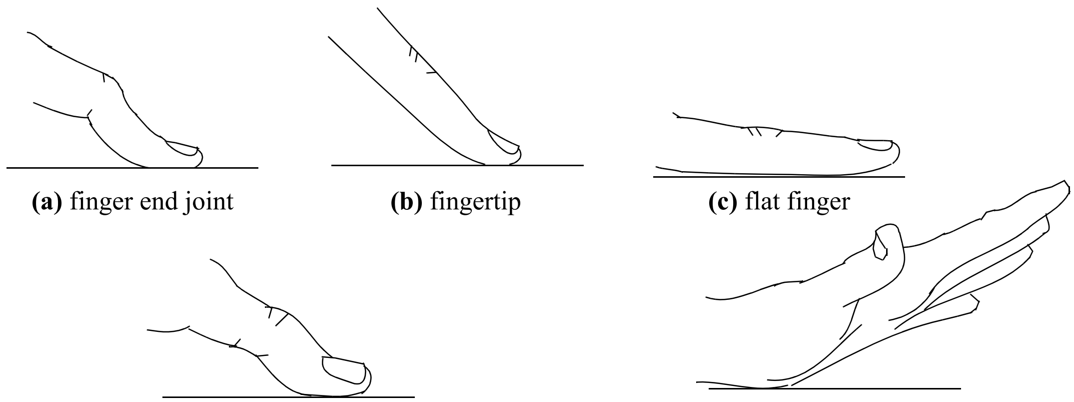


Figure 2. Six Parameters Can Be Controlled Simultaneously with One Finger

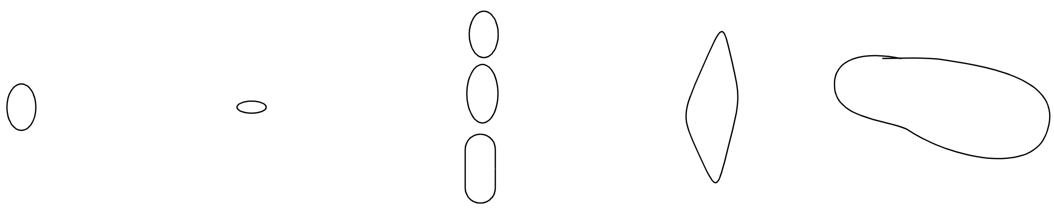
Hand Positions and Pressure Images

The user can make contact with the pressure-sensor array using a variety of hand positions, some of which are shown in Figures 3a-e. The outlines of images created using the different forms of contact are shown, respectively, in Figures 4a-e. Note that some hand positions create a single region of contact (4a-b, 4d-e), while others create multiple regions (4c). Figure 5 shows the outlines of more complex pressure images created using multiple parts of the hand, including some with multiple regions of contact (5b-c). Contact with the pressure-sensor array made using multiple parts of the hand will, in general, forfeit some degrees of freedom but introduce even more. For instance, contact with the whole hand, as shown in Figure 5c, can enable the user to control as many as 17 parameters at once [1].



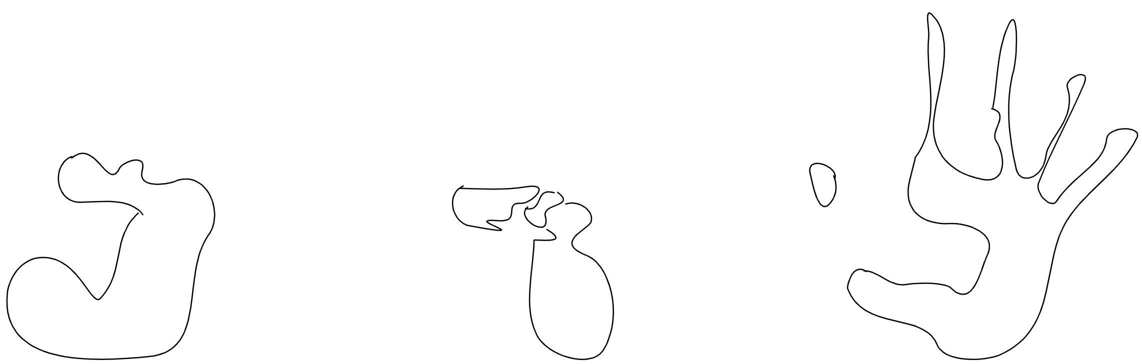
(a) finger end joint **(b)** fingertip **(c)** flat finger **(d)** thumb end joint **(e)** wrist

Figure 3. Examples of Hand Positions Used to Operate the Touchpad



(a) finger end joint **(b)** fingertip **(c)** flat finger **(d)** thumb end joint **(e)** wrist

Figure 4. Outlines of Some Simple Pressure Images



(a) palm **(b)** fist **(c)** flat hand

Figure 5. Outlines of Some Complex Pressure Images

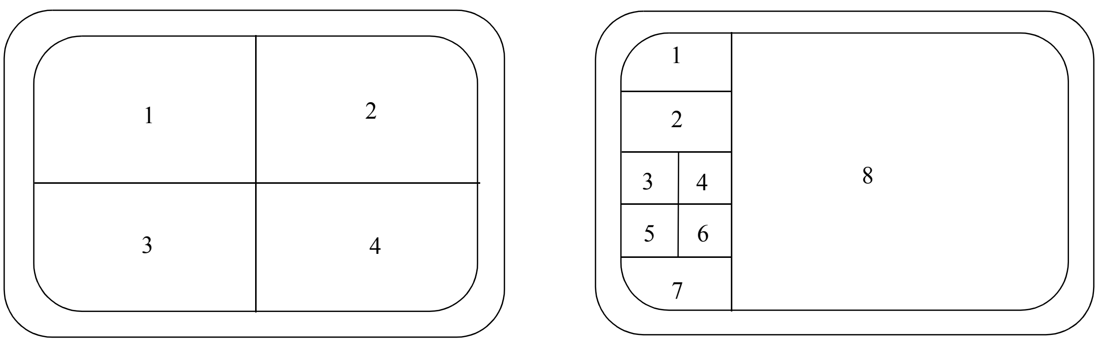
Image Recognition and Context-Dependent Processing

The image processing stage of the touchpad incorporates an image recognition capability that enables the touchpad to distinguish different types of images resulting from different forms of contact [3]. The parameters whose values are derived from a region of contact, and how those parameters are assigned to control signals, can be made to depend on the form of contact [3]. Parameter extraction and interpretation can also be made to depend on the mode in which an application is being used -- for instance, in a graphics or CAD/CAE application, some types of images might be processed in one way in a drawing mode and in another way when menu items are being selected [1].

Image processing can also be made to depend on context: an image of a region of contact might be processed in one way when it occurs by itself and in another way when it occurs as part of a more complex image, or is preceded or followed by certain types of images [1,2]. It is even possible to create image languages with syntactic rules that specify how images can be combined, and semantic rules that specify how particular combinations of images are to be processed and what kinds of control signals will be generated [1,2].

Partitions

It is possible to partition the pressure-sensor array into multiple, functionally discrete regions, as illustrated in Figure 6 [1-3]. Each partition operates independently of the others, and different partitions can respond to the same kind of input in different ways, though it may be useful to have them respond to some forms of input in the same ways. For instance, touching different partitions with a fingertip might produce different pitches, like a keyboard, but tilting the finger left-to-right might bend the pitch.



(a) **(b)**

Figure 6. Examples of Partitions of a Pressure-Sensor Array

3 Architecture and Implementations

In this section we start by discussing some of the ways the touchpad can be implemented. We next discuss a central component of the touchpad, the pressure-sensor array, and then explain how the information the pressure-sensor array collects is processed to enable the user to control an external system through contact with the sensor array. For more detailed information, see [3].

Physical Formats

Figures 7a-d show some possible physical formats for the touchpad. The pressure sensor array and its supporting hardware can share the same housing (7a-b); they can be separately housed for a more portable sensor array (7c); or the supporting hardware can be incorporated in the system the touchpad controls, such as a computer workstation (7d).

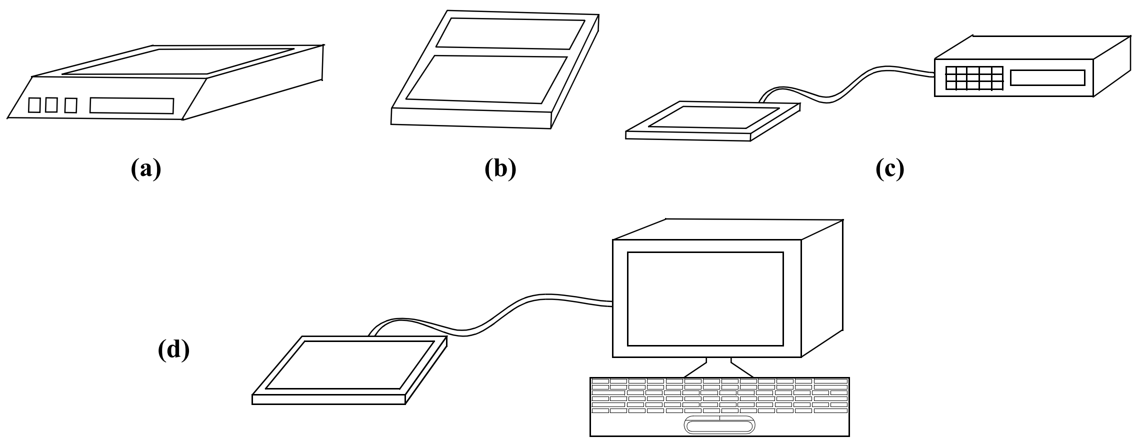


Figure 7. Examples of Physical Formats for the Touchpad

Many other implementations are possible. For instance, the touchpad can be implemented as a flexible “fabric” and installed inside or on the surface of a glove or sock. The touchpad can also be modularized so multiple pressure-sensor arrays can be combined in assemblages that behave collectively as a single large array. A special case of the latter is a dedicated chip incorporating a small sensor array. Such chips can be tiled and affixed to various surfaces, as will be illustrated in section 4.

Pressure-Sensor Array

An array of pressure sensors, illustrated in Figure 8, is a central component of the touchpad. As mentioned, the user operates the touchpad by touching the surface of the array. The dimensions of the array range from several inches on each side to a little more than an inch or even less, depending on the application. The spatial resolution of the individual sensors is 1 to 2 square millimeters, and the number of gradations in pressure they can measure ranges from 16 to 256, depending on the application. Note that the sensor array can incorporate a display, which can be used, for instance, to mark the boundaries of partitions when the touchpad is used in a partitioned mode.

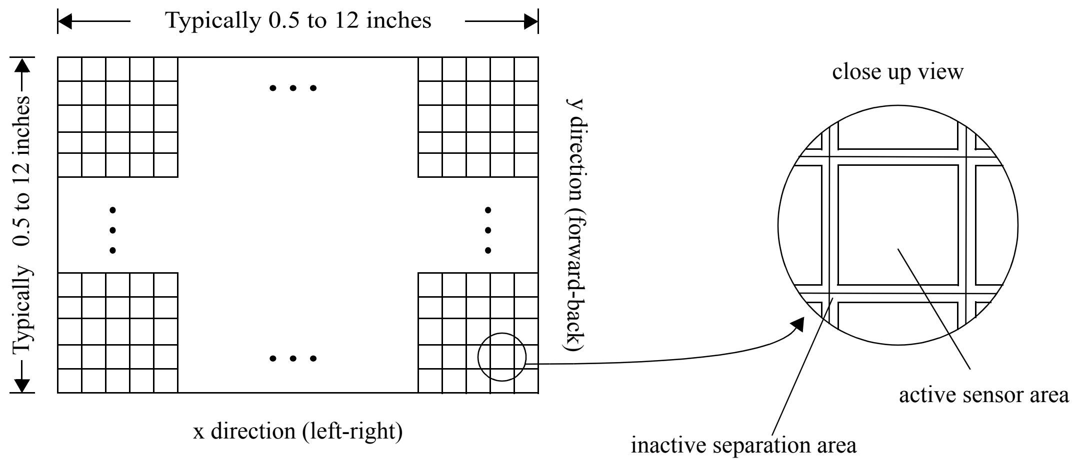


Figure 8. Pressure-Sensor Array

Information Flow

Tactile input to the pressure-sensor array is processed to enable a user to control an external system through contact with the array. The processing can be implemented as a sequence of stages, such as the following:

1. A data acquisition stage, which can incorporate a data compression capability, identifies sensors whose pressure value exceeds a noise threshold and records their pressure value and location.
2. Contiguous regions of those sensors are defined.
3. The regions are classified as members of a pre-defined category and, if appropriate, their context is determined.
4. The values of various parameters, such as the geometric center and the center of pressure, are derived for each region.
5. The derived values are assigned to control signals, which are output to a signal routing entity.

This information flow is illustrated in Figure 9. Note that though the information flow need be in only one direction, feedback, such as that shown, can be useful.

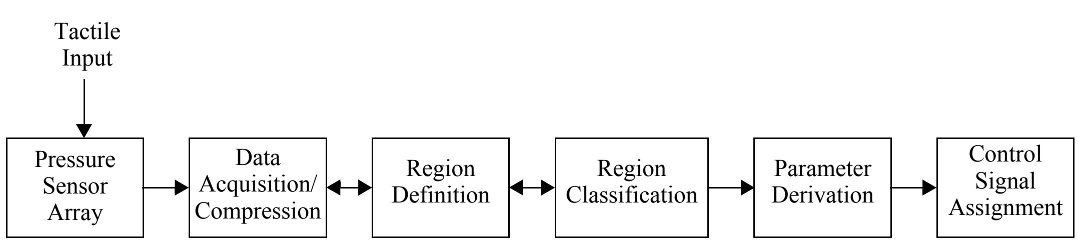


Figure 9. Information Flow

4 Applications

In this section we consider a few applications for the touchpad. We will describe, in turn, how it can be used for CAD/CAE workstations, for robot arm control, as a general-purpose controller, to enhance a musical instrument keyboard, as an addition to other musical instruments and as a foot-operated controller. For more examples, see [1,2].

CAD/CAE Workstation Control

As mentioned, one application for the touchpad is as an interface for a CAD/CAE workstation or software program. A schematic drawing of such a workstation is provided in Figure 10. The front-to-back and left-to-right dimensions of a finger's tilt might be used to make selections from a two-dimensional array of graphical objects or icons, while the x and y coordinates of the finger's location on the sensor array can be used to position the object in the drawing area. Note that in the first case, the two dimensions of tilt can be thought of as selecting a location in a two-dimensional "tilt plane," as shown in Figure 11. This is just one of many possible user interface metaphors to which the touchpad naturally lends itself.

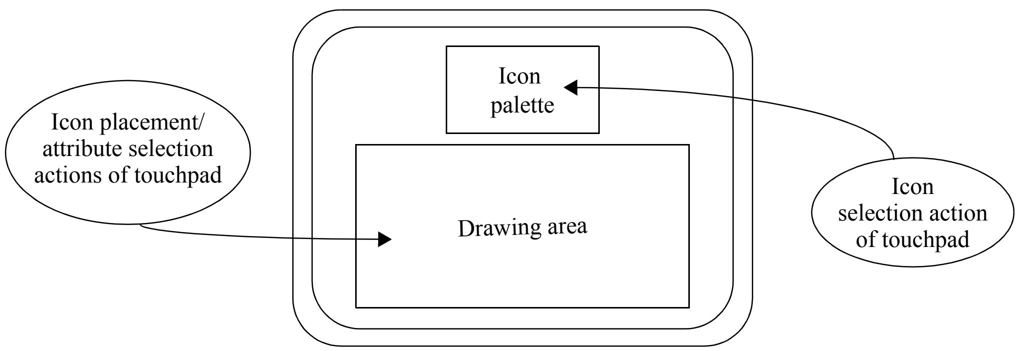


Figure 10. CAD/CAE Workstation Screen (schematic)

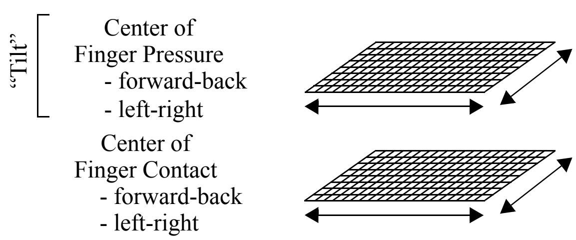


Figure 11. One Possible Metaphor for the Tilt of a Finger

Another CAD/CAE application of the touchpad involves the manipulation of images of three-dimensional objects. The six parameters controlled by a single finger can be used to control the three parameters of an object's angular orientation and the three parameters of its location in space.

Robotics Control

Because the touchpad enables the user to easily and rapidly adjust large numbers of parameters, it is attractive for applications that involve controlling the position, orientation and movement of physical objects, such as the robot arm shown in Figure 12. A robot arm like this might be used in manufacturing or handling hazardous materials. The figure gives one possible assignment of a user's hand movements to movements of the robot arm.

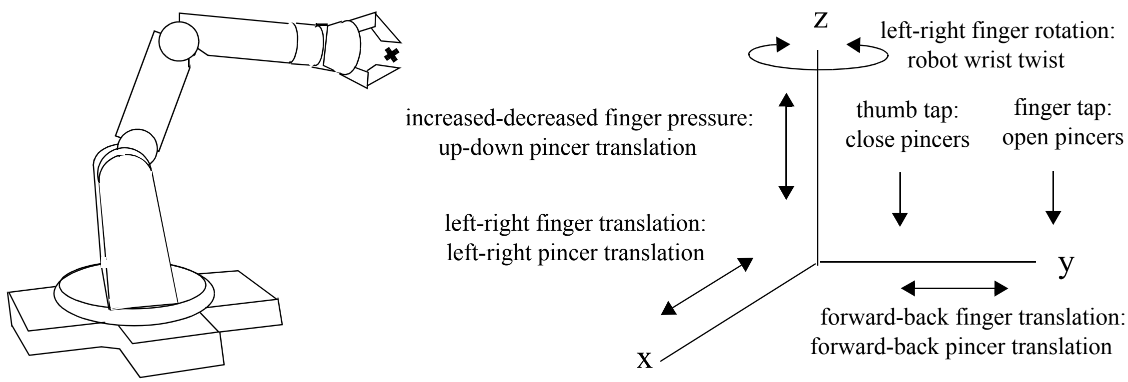
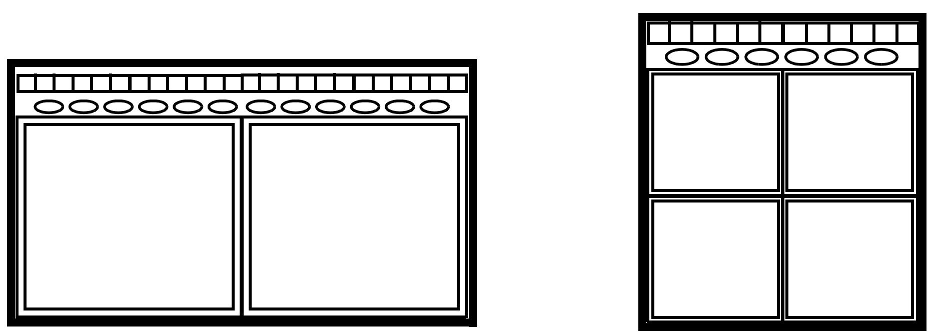


Figure 12. Robot Arm Control Using Fingers

Ganged Pressure-Sensor Arrays for General-Purpose Controllers

As mentioned earlier, it is possible to create modular implementations of the touchpad. Two such implementations, in which multiple pressure-sensor arrays are ganged, are shown in Figure 13. The ganged pressure-sensor arrays can operate independently of one another or behave collectively as a single large array. In these implementations, the pressure sensor arrays are supplemented with panel controls.



(a) **(b)**

Figure 13. Ganged Pressure-Sensor Arrays

Assemblages like those shown can be used as general-purpose controllers. In a music application, the assemblage with twin sensor arrays in Figure 13a can be used to emulate a two-headed hand drum, like the congas, with the sensor array on the left played with the left hand and the array on the right played with the right hand. Or each sensor array might be used by each hand to control a different device, such as two instances of the robot arm shown in Figure 12. Or the ganged arrays might be configured to function as a single large array. This would be useful where fine control is desired -- for instance, to make fine adjustments to the position of the robot arm described above. The panel controls can be used to modify the effects of hand contact with the sensor arrays, such as adjusting gain, or to provide additional kinds of control.

Touchpad Chips

As mentioned earlier, the touchpad can be implemented as a dedicated chip incorporating a small pressure-sensor array. Such chips could be laid as tiles and affixed to various surfaces, like the keys of a musical instrument keyboard, as shown in Figure 14. The tiled chips on the keyboard can be used to enhance the musician's control over the sound produced by pressing the keys. For instance, by touching different parts of a key or tilting a finger in various ways, a musician could bend the pitch, change the timbre or apply various kinds of filters.

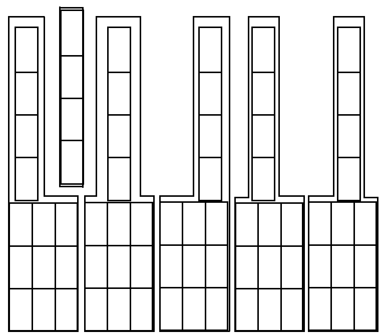


Figure 14. Arrays of Touchpad Chips on Instrument Keys

Hybrid Musical Instrument with Multiple Touchpads

As in the example just described, it is possible to create electronic musical instruments that incorporate touchpads. Figure 15 shows a full-tilt version of such an instrument, a "transcendental," guitar-based hybrid that incorporates multiple touchpads used in various ways. One touchpad, used for sound "finger painting," is located next to the bridge. There is a pair of keyboards whose keys incorporate touchpads, a touchpad implementation of a long strumpad (to the right) and several small, circular touchpads that can be used for generating percussion effects.

Foot-Operated Touchpads

The touchpad can be operated in other ways besides with the hand. It can, for instance, be operated with other parts of the body, or even with inanimate objects in machine-sensing and robotics applications. Figure 16 shows examples of touchpads that are operated with the feet in a music application. Two kinds of touchpads are shown: a self-standing module (with a square shape) and a module affixed to a rocking foot-pedal (with an oval shape). The touchpads, along with other kinds of musical instrument modules, are inserted in a mounting frame to create an aggregate instrument, which in this case is a floor controller. The instrument modules can be rearranged (as shown in the figure), replaced with other modules or removed and inserted in other mounting frames.

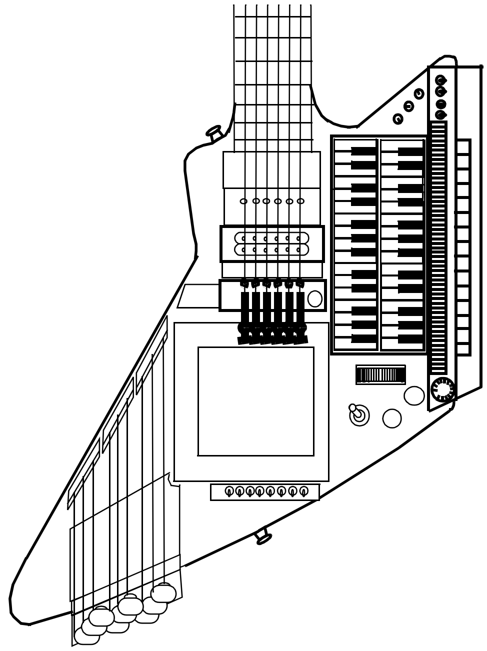
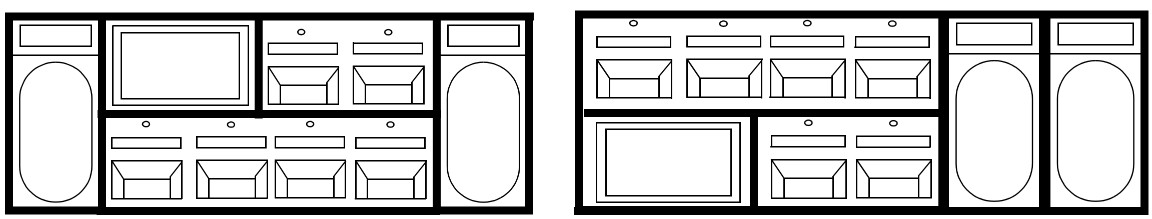


Figure 15. Advanced Hybrid Instrument with Multiple Touchpads



(a) (b)

Figure 16. Touchpad Floor Controller Modules

Other Applications

We have considered just a few of many possible uses for the touchpad. Besides those mentioned, it has many other possible uses in CAD/CAE and computer graphics applications; in real-time machine control and robotics; and in its chip and fabric implementations [1]. It also has applications as an assistive device for the disabled, and in automated assembly and handling [1]. It has many other music applications besides those mentioned, as well as other performance applications, such as lighting and video control [2]. It can also be used to create a general-purpose controller product or "kit," which can be configured or developed by end-users or engineers for specific applications they identify [1].

5 Further Information

This whitepaper has provided a brief summary of the user-level operation, technology and applications of the NRI® rich touchpad; these topics are discussed in more detail in the cited NRI® whitepapers. This document is based on U.S. Patent 6,570,078 [4] and related issued and pending patents [5-9], all licensable from NRI®. Detailed hardware and software reference designs can be discussed under negotiable terms. All financial or in-kind proceeds from such arrangements will be used to fund pure academic research at NRI®. Contact *inquiries@newrenaissanceinstitute.com* for more information.

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