EXHIBIT 3.08

the gesture-sensing technology, combine to make certain mappings more playable than others. As an example, consider how the required resolution of a force sensor would depend on whether the force measurement mapped to amplitude or to pitch; whether the pitch is perceptually continuous or discrete, and on the range and nuance of force changes a player can produce. In the following section, we examine common sound parameters, making use of research results from the field of psychoacoustics. This will be followed by sections on the application of ergonomics to study the limits of gesture and the limits of some existing sensing technologies.

Psychoacoustics for Instrument Designers

In this section we summarize the results of some psychoacoustical studies pertaining to human perception of time, amplitude, pitch, and timbre. We concentrate on the just noticeable differences (JNDs) in sound control parameters from the point of view of the listener. The JNDs of each parameter often depend on other parameters; here we state the smallest values for the JNDs. The conservative instrument designer, by assuring that his or her instrument controller is sensitive enough to produce these minimal JNDs throughout its range, can be confident that the instrument can produce smoothly changing sounds over its entire range.

As early as 1903, it was known that very short clicks up to 2 msec apart still fuse into a single experience (Licklider 1951; Woodrow 1951). Clynes (1984) has shown that altering durations of notes by as little as 2 msec can be quite noticeable, and he goes on to claim that even smaller changes would be effective. See also Stewart (1987). We conclude that an instrument controller should have a temporal resolution of less than 2 msec.

Riesz (1928) found that under optimal conditions the ear is sensitive to smooth amplitude changes of 0.25 dB. He further calculated that under ideal conditions we can distinguish at most 370 different intensities over the entire audible range. In studies using isolated tones, the smallest reported intensity difference that can be noticed by the average listener under optimal conditions is reported as 0.25 to 0.5 dB (Woodson 1957; Harris 1963b; Pierce 1983). For much of the range of common musical instruments, 0.5 dB is a more accurate fogure.

Psychoacoustic studies show that humans have a remarkable ability to detect small variations in pitch. For isolated tones, the minimum JND reported varies from two cents (Harris 1963a) to eight cents (Woodson 1957), with three cents being the commonly accepted figure (Pierce 1983). A study in which a single tone was modulated (pitch bends) reported minimum sensitivities of slightly over three cents (Shower and Biddulph 1931). Over the entire range of human hearing, 1800 different pitches are distinguishable (Van Cott and Warrick 1972). When two tones are presented simultaneously, beats may be perceived even when the frequencies differ by less than 1 Hz, a difference less than three cents for high pitches. The closer the two frequencies are, the longer it takes to notice the beats.

The perception of timbre is much more difficult to quantify than is the perception of pitch or amplitude. This is mainly due to the multidimensional nature of timbre. There have been a number of studies that measure just noticeable differences in filter bandwidth and resonant frequencies. For typical filters, a one percent change in filter resonant frequency was found just noticeable. Slawson (1985) enumerates much of the work in this area.

We have summarized some psychoacoustic results that are relevant to the design of programmable instruments. Since many results come from studies of pure sine waves, their application to musical sounds must be made cautiously. Nevertheless, they are important in that they give us an idea of the sensitivity of the listener.

Ergonomics for Instrument Designers

Ergonomics is the applied science concerned with characteristics of people that need to be considered when designing machines with which they interact. Ergonomics is a multidisciplinary field that draws on results from physiology, anatomy, experimental psychology, physics, and engineering. In this section we consider the ergonomics of instrument design—the characteristics of a performer relevant to his or her interaction with an instrument. The topic is vast, and here we touch upon only a small part of it, leading the interested reader to the references.

The design of an instrument controller necessarily contains assumptions about the physical size, strength, and reach of the player. In order to avoid needlessly excluding people from playing the instrument, average values and variations for these measurements must be known. Fortunately, extensive tables of anthropometrical data, including body, finger, hand, and foot size, strength, reach, and range of movement have been compiled (Woodson 1957, 1981; Hertzberg 1972). Some data relevant to a particular instrument design may be hard to find (e.g., lip pressures); in these cases, the designer must rely on informal measurements and common sense and should be conservative.

Tests have been conducted to measure the accuracy with which a performer can control various sound parameters. Performers attempting to tap at a specified rate (300 msec) show standard deviations in the time intervals between taps of from 1.5 to 4 msec (Vorberg and Hambuch 1978). Violinists attempting to play a scale with "even" loudness often varied in intensity by about 5 dB (Patterson 1974; Sloboda 1982; Pierce 1983). Measurements of good violinists often show deviations in pitch of 10 cents or more (Lundin 1953; Pierce 1983). In the case of timing and pitch, we see that performers come quite close to achieving the precision of their JNDs. Interestingly, for amplitude this does not seem to be the case.

An interesting question is that of the role that feedback plays in performance. Since human reaction times tend to be around 250 msec (Sternberg et al. 1978), it will often be the case that the hearing of a short note can be used only to affect subsequent notes. For longer notes, auditory feedback does play an important role, as can be shown by the increase in vibrato speed and depth when auditory feedback is delayed (Sloboda 1982). For the initial portions of notes, the performer must rely on information gathered before the note is initiated—this includes tactile, kinesthetic, and visual cues, as well as auditory cues from previous notes. Thus it is important to design instruments that utilize senses other than hearing. To examine these, we now shift our focus from sound control parameters to gestural parameters.

The kinesthetic and tactile senses are particularly important to instrument design. In general, instruments should be designed so that performers need not look at them while playing, thus freeing their vision for tasks such as sight reading and watching a conductor. *Kinesthesia* is the sensation of bodily position and motion. It is exploited by many instruments, and with practice, blind positioning can be made with extreme accuracy (Woodson 1957). To achieve ten cent pitch accuracy on a violin string, for example, performers must position their fingers with an accuracy of 1 mm in the middle range of the fingerboard. Once positioned, performers can control their depth of vibrato (by rolling the finger along the length of the string), with submillimeter accuracy.

Tactile feedback is important, and instruments should be designed to utilize such feedback to enable the accurate control of force, especially where the force is continuously controlled (i.e., an envelope parameter). Examples include bow pressure for violin, air pressure for wind instruments, and aftertouch on some keyboards (e.g., clavichords and some synthesizers). Pitch bends on guitar show how force feedback (due to the elastic properties of the string) and positioning may be combined to make extremely accurate small motions possible. The range of forces needed to operate a control should be tailored to human ability; for example, control of the velocity with which a piano hammer strikes a string is made more accurate by the inertia (weight) of the piano key.

For accurate control, feedback from the various senses should reinforce each other. The brass instruments are good examples of this—in general, a constant air flow produces a constant loudness across the range of the instrument. Brass players attempting to play evenly usually do not vary their amplitude by more than one or two dB. This is in contrast to the 5dB variation of the violinist mentioned above. Due to resonances of the violin body, a constant bow pressure produces fairly large variations in amplitude according to pitch. Thus, the tactile feedback is not consistent with the aural

Table 1. Recommendations for representing time, amplitude, and pitch

	Musically Useful Range	*Recom-mended Resolution*	*Bits Re-quired for Entire Range*
Event time	n/a	1 msec	n/a
Amplitude			
Instantaneous	60 db	.5 db	8
Envelope	60 db	.25 db	9
Pitch			
Instantaneous	10,000 cents	2.5 cents	12
Envelope	10,000 cents	1 cent	14

feedback, resulting in a much larger variation in amplitude (Patterson 1974).

Table 1 summarizes the authors' recommended requirements for representing sound control parameters. We would have liked to produce an analogous table for common gestural parameters, but the literature seems sparse on this topic. In many cases, maxima are available for gestural parameters, but minimum useful values as well as accuracy and just producible differences have not been extensively studied. Further experiments are required to determine, for example, minimum usable finger velocities and the accuracy with which such velocities may be reproduced in air. Similar velocity measurements might be made for fingers pushing weighted keys and drum sticks moving through air. In addition to velocity, minimum, maximum, and just producible differences of acceleration, position, finger force, lip pressure, and air flow would all be invaluable to the new instrument designer. This is a ripe area for future research. Fitts (1951), Chapanis and Kinkade (1972), and Mackenzie (1985) discuss related topics.

While in this paper we have concentrated on the data produced by experimental psychologists, two generalizations of this data, known as Weber's law and Fitt's law, are quite relevant to instrument designers. Weber's law pertains to perception and states that the ratio of the just noticeable difference to the size of a stimulus is constant (Stevens 1951). Weber's law turns out to be approximately true over much of the usable range of stimulus intensities; it justifies the use of the relative units dB and cents for subjective measurements of amplitude and pitch. In other words, Weber's law predicts that the size of a JND in frequency is proportional to the starting frequency (thus a constant number of cents), and the JND in amplitude intensity is proportional to the magnitude of the amplitude (and thus a constant number of decibels).

Fitt's law of positioning accuracy may be considered the analogue to Weber's law of perception. Consider a movement where a subject attempts to move a stylus rapidly from a starting point to a target a few centimeters away; this sort of motion occurs when playing violin or trombone. Fitt's law states that for a given time per movement, the positioning error is proportional to the length of the motion (Singer 1980). In other words, the standard deviation in the distance moved is proportional to the total distance moved. Similarly, Schmidt has shown that when a person attempts to produce a given force, the standard deviaion of the force is proportional to the magnitude of the force (Woodson 1957; Schmidt et al. 1978). Schmidt's data show that the standard deviation was approximately five percent of the total force, or about 0.4 dB. Although we have not seen them published, it seems plausible that similar statements hold for finger velocity (as noted in Fig. 1), air pressure and flow, and movements of other parts of the body.

One implication of Fitt's law is that a logarithmic scale (such as decibels) is appropriate for measuring many gestural parameters. In situations where we use linear units (e.g., position measurements), Fitt's law implies that the magnitude of the unit is irrelevant and that the total number of units is what matters. For example, Fitt's law tells us nothing about the desirable width of piano keys, since the ratio of the key widths (targets) to the sizes of the positioning motions remains constant independent of key width. In cases such as this, anthropometric data (e.g., finger widths and finger spread) must be considered. It should also be noted that, like Weber's law, Fitt's law is approximately valid over much of the usable range of the parameters to which it is applied, but tends to fail at the extremes.

Fig. 1. Clock resolution required for logarithmic velocity sensing. See page 41 for further explanation.

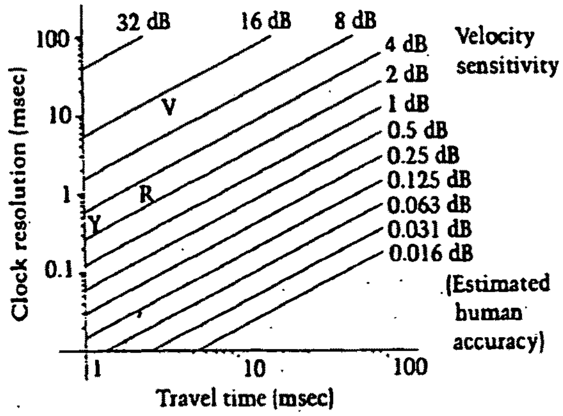
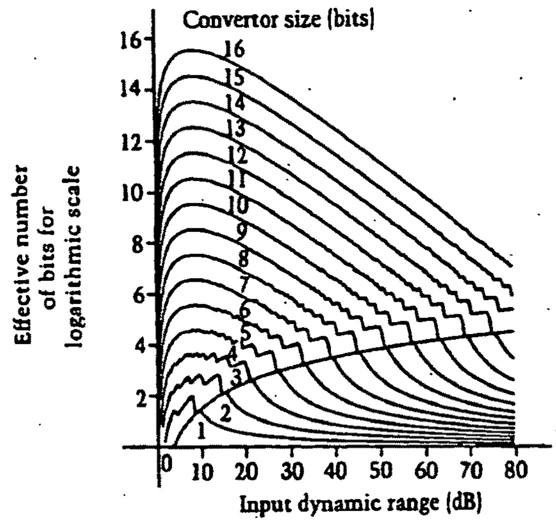


Fig. 2. The effect of using a linear analog-to-digital converter when a logarithmic scale is required See page 41 for further explanation.



Sensing Technology

In our view, an instrument controller is a device that maps gestural parameters to sound control parameters. The preceding sections are intended as an aid in evaluating the suitability of particular gesture-sensing technologies for capturing musical gestures. In this section, we briefly examine the suitability of some sensing technologies for use in instrument controllers.

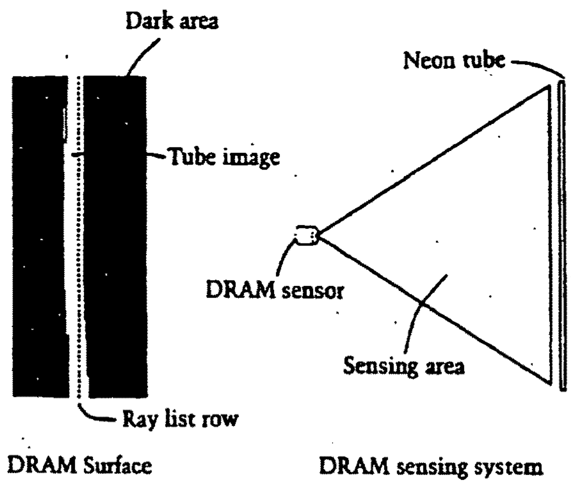
It is not often the case that instrument designers invent totally new sensing technologies; what usually occurs is that an existing technology is adapted for musical use. Often such technologies have been developed for applications quite different from—and less demanding than—instrument control. In these cases, we must consider the possibility and practicality of modifying the sensors to meet the requirements of musical gesture sensing.

Many general-purpose sensors, such as force, acceleration, and pressure sensors, can be successfully utilized in instrument controllers (Moog 1987; Downes 1987). These sensors usually produce analog voltages as output; these analog values must be digitized for use in digital instruments. For such sensors, a 1 kHz sample rate is often used (the sensor is read every microsecond); this is adequate, being below the thresholds for human perception and production discussed earlier. The other consideration is the resolution (the number of bits) of the analog-to-digital converter (ADC). It is usually the case that a logarithmic scale is desired from the sensor, but for economic or convenience reasons linear converters are used. Figure 2 addresses this issue in some detail.

One example of an instrument using only this kind of sensor is the Air Drums (Downes 1987; Roads 1987). They consist of two tubes, each of which contains three rotational acceleration sensors. Each sensor produces an analog output that is mapped by something between a linear and logarithmic scale and is sampled at a one kHz rate by an eight-bit ADC. The eight bits are converted by table lookup to a seven-bit MIDI key velocity. Downes was unsure of the dynamic range of the accelerations expected.

Bob Boie of Bell Laboratories has invented two very exciting sensor technologies. His proximity sensors are able to determine the position of three points in a 10 by 15 by "a few" inch volume; these are the sensors used in the Radio Drum (Mathews, Boie and Schloss 1989). The sensors are sampled at 1 kHz; Boie states that 10 kHz is possible. The resolution in X and Y is 50-by-50 units; this is adequate for the current application, creating multiple regions, each with its own drum. If the resolution could be improved by an order of magnitude (possible according to Boie), this instrument could give the player more control over nuance than is available to the violinist. Even in their current form, Boie's proximity sensors are among the best avail-

Fig. 3. *A sensing triangle and sensor image (a) The DRAM sensing system (b) The DRAM surface*



able for tracking multiple objects for musical purposes.

Boie's other sensor is a multiple-finger touch pad. We have seen it sense the X and Y position of 10 fingers simultaneously. It can sense the pressure of each finger as well. The resolution is outstanding: 1 mil (0.025 mm.) accuracy in X and Y and 10 bits of pressure information are possible. Currently, the main drawback for musical use of this sensor is its 30 Hz sample rate (which is perfectly adequate for the current use of the pad as an input device to personal computers). Boie believes that the sample rate can be increased, though doing so would increase the cost of the device. If one kHz can be achieved, this pad could be turned into an incredibly expressive and responsive programmable finger-tracking instrument controller.

Other sensors that have been used to create instrument controllers are television cameras (Collinge and Parkinson 1988) and sonar distance sensors (Waisvisz 1985). Television cameras have an inherent 30 Hz scan rate, and sonar sensors sample from 10 to 60 Hz. Both devices appear useful for the relatively slow and imprecise gestures useful in some forms of conducting, but they are neither temporally or spatially precise enough for the more demanding aspects of instrument control.

In the next several sections, we discuss the VideoHarp, starting from the sensor and proceeding upward to progressively higher levels. For brevity, we gloss over many details of the VideoHarp that have previously been published (Rubine and McAvinney 1988; 1989).

The VideoHarp Optical Scanning System

The first VideoHarp prototype (which we call V0) uses an optical sensing method originally developed by one of the authors for use in a multiple finger touch-screen device. (McAvinney 1988). In V0, the image of a neon tube is focused by a lens system onto the surface of a 64 Kbit dynamic RAM with a transparent cover. The lens system is such that the Dram sensor has a 60-degree field of view; thus the triangle with the neon tube as one side and the sensor at the opposite vertex is equilateral. In V0, we use a 68 cm neon tube. Because the sensing triangle is equilateral, each side is 68 cm long.

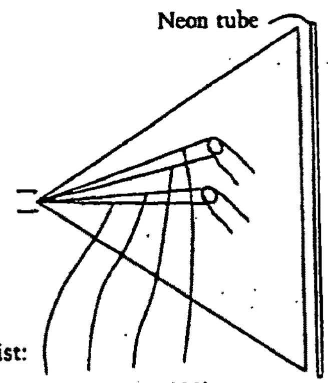
Figure 3 shows the sensing triangle and the unobstructed image of the tube on the sensor. Any opaque objects placed in the interior of the equilateral triangle will be interposed between the neon tube and the DRAM sensor and will thus affect the image of the tube on the sensor.

The memory cells used in dynamic RAM chips are light sensitive. Light falling on a single DRAM cell causes its bit to change from one to zero more quickly than it otherwise would. Conversely, the cells upon which light does not fall (because that part of the focused image falling on them is relatively dark) can retain their charge for several hundred milliseconds.

When a neon tube is used as a light source, about 13.5 msec are required for a DRAM cell to change reliably from one to zero. The overhead involved in initializing and reading the DRAM—and the increased reliability that results when the exposures are synchronized with the 120 Hz flicker from the neon tube—effectively increase the scanning period to about 17 msec.

The DRAM used in the current VideoHarp prototype is a 64 Kb device consisting of two 128-by-256 arrays of light-sensitive memory cells. The arrays are separated by a non-light-sensitive area. While one could utilize an entire half of the DRAM for sensing, we use only a single row in the center of

Fig. 4. The ray list formed by two fingers.



the tube image, as indicated in Fig. 3. Each of the 256 cells in a sensor row watches a particular section of the neon tube.

Figure 4 shows two fingers placed in the sensing triangles. The rays at the edges of the fingers are shown; these correspond to each cell whose value (0 or 1, light or dark) is different from the previous cell. The list of such cells is called a *ray list*. A ray list is a succinct description of the image seen by a single row of the DRAM sensor. Each successive pair of rays in a ray list represents an object in the sensing triangle. We call the average of the two rays the *angle* of the object (a slight misnomer) and the difference between the rays the *apparent thickness* of the object.

In the dimension parallel to the tube, when close to the tube, the resolution is 2.7 mm. At the closest reachable point to the sensor, 26 cm away, this resolution is 1.1 mm. The apparent thickness of an object varies as it moves radially (along a ray) toward or away from the sensor. For finger-sized objects, approximately 15 mm wide, this thickness measure is very coarse. Close to the tube, a finger has to move radially 90 mm to change its thickness by a single unit. At the point 26 cm from the sensor, a 20 mm radial movement causes a unit thickness change. Over the entire range, only three bits of thickness information are derivable from 15 mm wide fingers.

For large objects (such as clustered fingers), the thickness resolution improves somewhat. To produce a one-unit thickness change, a 45 mm wide object need only move radially 37 mm (near the tube) or 6 mm (26 cm from the sensor). The result is 5 bits of thickness. In practice, the most dramatic changes in apparent thickness occur when, for example, clustered fingers are placed in the sensing triangle so that the maximum width is parallel to the tube (thus blocking the most rays), giving a large apparent thickness. A pronating motion that results in the fingers lined up along a ray will make the apparent thickness small. In order to appear as separate, multiple objects must not touch or occlude each other. This seems like a disadvantage, but has turned out to be a useful idiosyncrasy. The VideoHarp player, when controlling apparent thickness and angle simultaneously, often appears to be tracing out a contour with the hand, an example of how the idiosyncrasies of an instrument give rise to new instrumental gesture and technique.

The V0 optical scanning system described above poses some problems for musical use. Foremost is the relatively slow sample rate. The sample rate can be improved either by using a light source that is more intense in the infrared region than is the current neon tube, by using a more sensitive sensor, or both.

We are currently evaluating the use of "line-filament" incandescent tubes and quartz-halogen-lamp/reflector assemblies as a way of increasing light-source intensity. At the same time, we are considering alternatives to DRAMs, such as charge-coupled devices (CCDs) and phototransistor arrays. We are also investigating the use of custom MOS phototransistor arrays to create better sensors.

Physical Design of The VideoHarp

The physical design of the current VideoHarp is almost completely a result of the decision to use a single sensor. We decided that one sensing triangle was adequate to sense the fingers of a single hand; for two-handed playing, two such triangles would be needed. For economic reasons, we decided it would be best if we could generate multiple sensing triangles with a single sensor and one light source.

Fig. 5. Two images of the neon tube on the sensor.

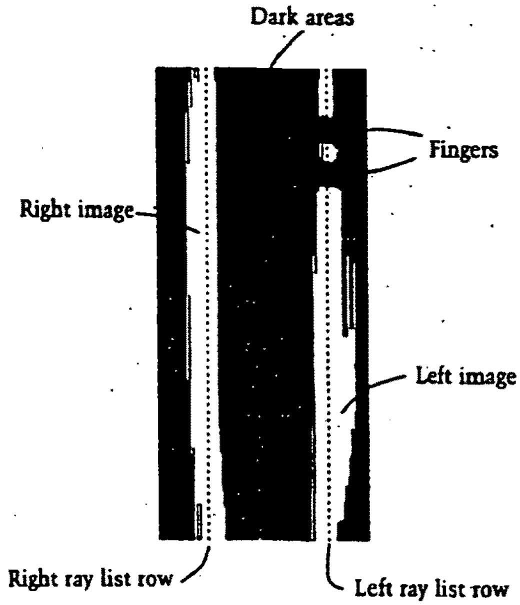


Fig. 6. Folded sensing triangles.

Fig. 6

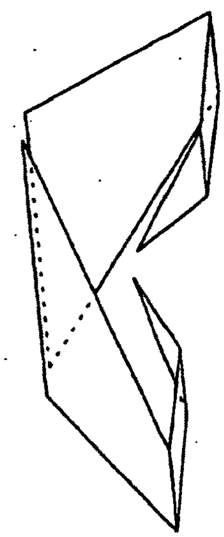
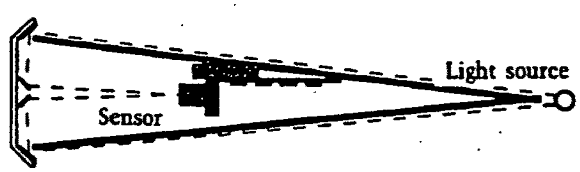


Fig. 7. VideoHarp top view showing the light source, light path, and sensors.

Fig. 7



Sensing two light source images on the V0 sensor was no problem; we simply used two distinct rows of the DRAM, as shown in Fig. 5. Less obvious was how we could separate two sensing triangles that share a common base (the light source) and vertex (the sensor). We solved this by "folding" the sensing triangles with mirrors, as can be seen in Fig. 6. The resulting light path is shown in Fig. 7. The addition of two trapezoidal Plexiglas plates (one per sensing triangle) gave a physical indication of the location of the sensing triangles, as well as a place to house the additional electronics.

We decided 68 cm was a good length for sides of the sensing triangle (thus V0 uses a 68 cm long neon light source) with the outer folds 44 cm from the light source edges. If this were any larger, parts of the trapezoids would only be reachable when the player's arm and elbow were held (unsupported) away from the body—a difficult position to maintain. Also, the sensor's resolution diminishes with distance, while the weight of the instrument increases. A trapezoid much smaller than the one we used would make the instrument feel cramped. We also wanted the volume between the plates to be as small as possible, the constraint being that the sensor and electronics had to fit in this volume without obstructing the sensing triangles. We settled on joining the trapezoids at a 15-degree angle.

We required that the inner mirror and sensor locations and orientations be adjustable so that we could experiment to find the proper settings. We also wanted the instrument to feel and look good and to be mechanically rigid. As we were not particularly skilled in detailed mechanical design and construction, we hired Stephanie Claudie, a recent graduate of the Carnegie-Mellon University industrial design department, to build the first VideoHarp to our specifications. With her help, we decided on final dimensions and materials. Claudie built the first prototype, and Eric Colburn of Sensor Frame Corporation designed and implemented a usable mirror-adjustment mechanism. Thus the V0 VideoHarp (see Fig. 8) was constructed.

Fig. 8. Paul McAvinney playing the VideoHarp.

VideoHarp Electronic Controller Hardware

In other papers (Rubine and McAvinney 1988; 1989), we discuss details of the electronic hardware and software used in the VideoHarp; we only summarize them here.

The DRAM sensor is connected via a flat cable to the V0 controller hardware, a small circuit board containing an MC68008 microprocessor, 64 KB of RAM, a timer, and DRAM control circuitry. The controller plugs into a Multibus slot in a Sun 2 computer. The Sun computer also has hardware for MIDI input and output. As this article is being written, the obsolete Sun 2 is being withdrawn from service by its donors, and the first VideoHarp will soon be history.

A second VideoHarp, V1, is now being built in Pittsburgh by Sensor Frame Corporation. It will house a faster 68000-based controller with up to 512 KB of RAM, MIDI ports, and battery-backup memory. V1 will also have a small liquid-crystal display and eight momentary-contact switches to aid in random selection of playing-surface region presets when V1 is used in "stand-alone" mode, wherein it is directly connected through MIDI to external synthesizers.

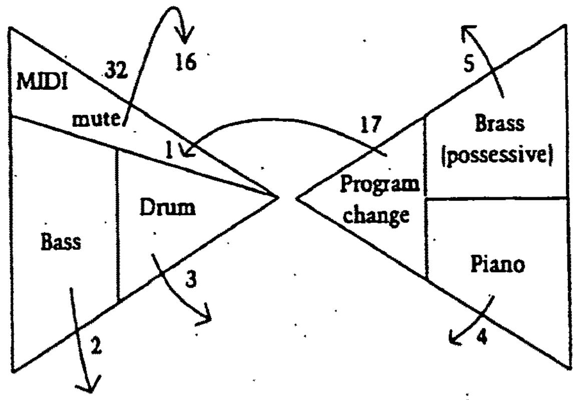
We also envision connection of an optional Macintosh host computer to the V1 through its MIDI port, permitting users to program VideoHarp presets with the aid of a more graphically oriented interface. Sensor Frame Corporation currently plans to build a limited number of V1 VideoHarps, beginning in late 1989.

VideoHarp Software

VideoHarp V0 software is divided into four parts. The *scanner* exposes and reads the sensors, generating a ray list for each side of the VideoHarp at 16.7 msec intervals. The *tracker* groups pairs of rays into objects (fingers) and decides when objects have entered, left, or moved within a sensing triangle. The *assigner* assigns objects to regions. Regions are analogous to "windows" on a work station or "splits" on a synthesizer keyboard. A region is determined by range constraints on an object's side, angle, and apparent thickness. Each region has a *mapper*, a program that maps objects in the region to MIDI.

The individual mappers determine the kinds of gestures to which the VideoHarp responds. We have labored to make the writing of mappers as simple as possible in the hope that sophisticated VideoHarp players and composers would create their own. For the most part, we expect players to use the existing mapper types: keyboard, strum, program-change, and various MIDI manipulators (which transpose, invert, delay, and reassign the channels of their MIDI input in response to gestural input).

Fig. 9. An example VideoHarp preset showing the mappings of regions on the two playing surfaces.



The most commonly used mapper type is the keyboard region, intended to be played somewhat like a keyboard. Like all regions, keyboard regions can be parameterized. In keyboard regions, the following are all parameters: the width of the keys (in pixels); the lowest note, whetheer the low notes are up or down; the scale from which the notes are selected; and the MIDI channel(s) upon which output occurs. When an object enters a keyboard region, the angle of the object determines the MIDI pitch of the note. The apparent thickness determines the MIDI velocity, and one parameter is a table that controls the mapping between thickness and velocity. Note-on commands are generated when objects first enter the region, note-off commands are generated when objects leave. For existing objects, changes in angle from their initial position can be mapped to any MIDI parameter, key or channel pressure, or pitch wheel commands. Tables can easily be specified to do the mapping. Changes in apparent thickness can trigger similar MIDI commands. Individual objects can be assigned to separate MIDI channels, making the use of pitch bend and channel pressure commands practical. Rather than bending pitch, a keyboard region may also be configured to trigger new notes when an existing object moves to another virtual key.

Keyboard regions only generate MIDI output; other kinds of regions may take MIDI input as well. Indeed, it is possible for regions to communicate with each other via MIDI. For example, a strumming region takes MIDI input and uses the note-on pitches as frettings for a virtual guitar. The MIDI input could be generated externally (e.g., from a synthesizer keyboard), or—more likely—from a VideoHarp keyboard region. If the keyboard region generates output to MIDI channels 17–32, the output will be wrapped around, appearing as input on MIDI channels 1–16 and can be read by the strumming region. The latter region will actually send notes when objects in the region strum virtual strings; the MIDI velocities will depend on the speed (angle derivative) of the object doing the strumming.

As an example from Rubine and McAvinney (1988), Fig. 8 pictorially represents the configuration of the VideoHarp while executing an interesting preset. The regions labeled bass, drum, brass, and piano are all keyboard regions. In this preset, the left hand is able to play bass and drum (by outputting to MIDI channels 2 and 3, respectively) while the right hand has access to piano (channel 4) and brass (channel 5) sounds. In Fig. 9, radial divisions represent regions separated by constraints on angle, while vertical lines indicate regions separated by constraints on apparent thickness. For example, the bass is played by normal sized fingers of the left hand while the drum sound is played by using multiple fingers of the left hand, or, more naturally, the palm of the left hand (which appears to the sensor as a single, large finger).

Placing a finger of the right hand in the upper part of the VideoHarp results in brass sounds being produced. Moving this finger up and down results in the pitch of the brass note being smoothly bent up and down. If this finger is moved from the brass region into the piano region (without being lifted from the plate), the brass tone continues to be sounded, suitably bent in pitch, since the brass region is possessive and will continue to track objects that leave the region. If a finger is placed in the piano region, a piano note will be sounded, its amplitude being determined by the apparent thickness of the finger. As the finger is moved within the piano region, new notes will be triggered. When the finger moves into the brass region, the piano note will be released and a brass tone will begin, since the piano region is not possessive.

Playing the VideoHarp with the palm of the right hand will cause a program change to be sent out on

MIDI channel 17, which gets wrapped around to appear as input to channel 1 of the VideoHarp. This MIDI data is thus passed to the MIDI mute region that is listening for data on channel 1. If there are no fingers present in this region (the upper part of the left side of the VideoHarp), any received MIDI data will be discarded. If a finger is preset in this region, however, the program change will be output on channel 32. The program change message then appears as input on channel 16, which is being monitored by the main loop of the VideoHarp software. Seeing a program change on this channel will cause the VideoHarp to recall another preset, possibly completely changing the configuration of regions and sounds. The MIDI mute region is used to assure that the program change message does not get sent accidentally.

Discussion

What should the designer of electronic instrument controllers take from this article? We began by advocating the separation of control and sound generation; we then proceeded to show just how difficult it is to adequately capture the nuance so taken for granted in traditional instruments. A violin instantaneously transforms the tiny motion of a fingertip along a string into a minute modulation of pitch. The speed and accuracy of this process is derived from the mechanical coupling between the control and sound generation parts of the violin. If we desire to substitute a digital connection for this coupling, we must labor extensively to restore the sensitivity and immediacy that we had so effortlessly before. We hope that this paper gives the digital instrument designer some idea of how fast and how precise an instrument needs to be in order to capture the subtlety of human instrumental gesture.

In general, the data quoted in this paper for just noticeable and just producible differences, while accurate in a laboratory setting, are possibly more stringent than need be in a musical setting. It is possible to be outside the ranges of the JND for a single one of these parameters and still end up with a very responsive instrument controller. Our data are intended as guidelines only.

Robert Moog has participated in the creation of a number of synthesizer keyboards with goals similar to those of the VideoHarp (Moog 1987; Roads 1987). In particular, the Big Briar multiply-touch sensitive keyboards have a two-dimensional position and pressure sensing pad on each velocity sensitive key. For each note the performer controls two instantaneous parameters (key number and velocity) and three envelope parameters (X, Y, and pressure). This keyboard may be considered a finger-tracking instrument, as it tracks the position of a finger on a single key. The VideoHarp does not allow the performer to manipulate quite as many envelope parameters as the Big Briar keyboard, but it does allow more general gestures than the latter, such as bowing and strumming. The question we wish to consider now is—do these instruments give performers control over more parameters than they can reasonably hope to provide?

There seems to be a limit to the amount of information a single performer can generate. Earlier we discussed the playing of the guitar. The guitarist can play chord passages and can bend pitches; he or she seldom does both simultaneously. Nonetheless, it is convenient to have all these parameters available all the time, allowing the guitarist to switch rapidly between various techniques. Similarly, even if it is not possible for a performer to manipulate all of the VideoHarp parameters simultaneously—and we are not sure this is the case—it is still worthwhile to have all the parameters available at any time, as with the guitar.

Moore (1987) addresses some problems relating to the information bandwidth of MIDI. While he enumerates many valid shortcomings, one surprising result of our work is that MIDI's 7 bits of velocity, 14 bits of pitch bend, and 1 msec note transmit time coincide quite well with the psychoacoustic and ergonomic studies cited above. Moore's criticism that *N* notes played simultaneously will be smeared over *N* msec is true. But his assertions about the amount of gestural information a human performer can generate warrant closer attention.

Moore claims a performer can, with modest effort, consume all the bandwidth of a single MIDI channel—3,125 8-bit Bytes per second. It behooves us to ask, however, if the performer is truly generating this quantity of information, or if these large bit rates are simply an artifact of our representation. In nonmusical tasks, experiments that have attempted to measure the amount of information a human can generate report results of 3–43 bits per second (Van Cott 1972). A musician likely produces many times this rate; nonetheless, we believe the number to be much less than the MIDI bandwidth. This is not to say that MIDI, in its current form, is adequate for representing musical gesture. Instead, we claim that the problems with MIDI stem from its inefficient representation of gestural data and could be solved either by increasing the bandwidth or by more sophisticated coding of the information.

MIDI in its present form will likely be with us for some time. If we evaluate it using the ergonomic criteria discussed in this article, we find that, although it has faults, the faults may not be as debilitating as some would have us believe. While the instrument designer has cause to be concerned that MIDI may prove inadequate for the representation of musical gesture, we believe that instrument designers must work hard before they can blame MIDI, or low bandwidth as such, for the lack of responsiveness of their instruments.

Conclusion

This article has covered several topics. We began by stating some reasons for building new instrument controllers, especially programmable finger-tracking controllers. We considered the requirements that various psychoacoustic and ergonomic factors place on controllers and on the sensors used in controllers. We then examined some existing sensor technologies, particularly the sensors used by the VideoHarp. The physical design, hardware, and software of the VideoHarp were presented as an actual example of the way in which a programmable, finger-tracking instrument might be built from such a sensor.

How will new controllers, such as the VideoHarp, affect the composition and performance of new music? Part of the answer comes from considerations of different representations of music. A score by itself only hints at the music; it is up to a performer to bring it to life. The sounds that listeners hear—and also what they see—contain the music (that which could be captured by a good recording) but the sounds also contain a large amount of what we may consider extraneous detail (e.g., room acoustics). We are left with the view that music is something performers, guided by the composer, communicate to and through their instruments. This article is solely concerned with the interface between performers and their instruments. It is here that we hope to capture the essence of music with a minimum of superfluous detail.

We are concerned with the performance of music—with the communication that takes place between a performer and an audience. It is ironic that so many of the advances of technology that have been applied to music have actually hindered rather than helped this communication. A piano is remarkably sensitive to touch; early electronic keyboards are simply arrays of switches. Analog synthesizers had a myriad of knobs to turn; many current digital synthesizers have a single "data slider." According to Clynes (1984), much of the musicality of a performance exists in the minute variations of timing, but these variations are often totally eliminated by digital sequencers. It is easy to enumerate examples where technology has reduced the amount of communication between performer and audience.

Typically, this reduction results in music that sounds mechanical to a large number of listeners. The term *mechanical* is a telling one—it seems to imply that music produced with the aid of machines will have a lifeless quality. It is for this reason that we are concerned with capturing human musical gesture. Others in the computer music community have the same goal (Appleton 1984; Lohner 1985).

Michel Waisvisz, designer of THE HANDS (Waisvisz 1985), has provided one of the best counterexamples to the notion that electronic music is inherently lifeless. Waisvisz has done it all: he designed THE HANDS, built them, composed for them, and now gives electrifying performances.

Following Waisvisz's example, designers of new controllers should attempt to maintain or even enhance the bandwidth and parallelism of expression beyond that of traditional instruments. Furthermore, new controllers should allow the performer to flexibly redirect expression at whatever functional level is appropriate. For example, one might want to maintain careful control of the timbre of a cello in a quartet environment or during a solo, but then redirect one's expressive capabilities to the control of orchestral timbre during a finale. In the latter context, the orchestra can be thought of as a large, expressive instrument. As another example, the Sequential Drum (Mathews and Abbott 1980) eliminates the need for producing correct pitches, thus allowing the performer to concentrate on matters of rhythm and articulation.

The goal of the VideoHarp project was to give the performer control over as many simultaneous gestural parameters as possible, with adequate dynamics and temporal control. In the process of evolving this new instrument, we have learned that musicians have incredibly well-developed perception and performance skills. We have attempted to address some of the issues that arise as we ask, "How good is good enough?" for musical gesture sensing. The information uncovered will be of great use to us in the ongoing development of the VideoHarp, and we present it here with the hope that it will be useful to others as well.

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Figure 1
Logarithmic scales—such as dB—are preferable for velocity measurements, as the standard deviation of a human motion tends to be proportional to the magnitude of the motion. Our unsubstantiated estimate for the constant of proportionality in an experienced musician (based on Schmidt's data) is three percent or 0.25 dB. By brashly interpreting the MIDI specification for velocity (7 bits—1 = ppp, 127 = fff), and assuming Patterson's 5 dB per musical dynamic, we get a value for the MIDI velocity unit of 0.28 dB, indicating that MIDI is adequate for representing human velocity nuance (over a 35 dB range).

Most digital instruments compute velocities by measuring the time it takes for an object to travel a certain distance. Referring to the graph shown in Fig. 1, the ordinate—travel time—is this travel distance divided by velocity. When determining the worst case velocity sensitivity the maximum expected velocity should be used. (Some useful expected maxima are: weighted piano key—1 mm/msec, unweighted key—3 mm/msec, drum stick tips—8 mm/msec). The abscissa of Fig. 1 is the clock resolution used to measure travel time. The resulting point determines the velocity sensitivity (in dB). Each line represents an additional bit of logarithmic velocity information. Assuming humans have a usable dynamic range of 64 dB (an overestimate) then 32 dB sensitivity is 1 bit of velocity information, 16 dB is 2 bits, etc.

The graph may also be used for instruments (such as the Radio Drum) that compute velocity by measuring the distance traveled over a given time period. The ordinate, travel time, is now independent of velocity, and the distance resolution (i.e. the maximum error in the distance measurement) divided by velocity gives the value for the abscissa. For the worst-case velocity sensitivity, use the minimum expected velocity (say -35 dB of the maximum).

The point labeled V represents the achievable z-axis velocity sensitivity of VideoHarp V0—generously 2 bits (which is why we did not bother to measure velocities in V0). Point R represents our estimate of the current Radio Drum system (5 bits), achievable with Radio Point Y represents a Yamaha keyboard, 5 bits of logarithmic velocity sensitivity. The Radio Drum information was supplied by Bob Boie, the Yamaha information was supplied by Hal Mukaino. All of the actual instruments mentioned fall short of the MIDI standard of 7 bits of logarithmic velocity. Either these instruments are not using all 128 possible values—i.e., certain large or small velocity values are never generated—or the scale is not logarithmic.

Figure 2
It is often the case that a linear analog-to-digital converter is used in a sensor where a logarithmic measurement is desired. Just how well this works depends on the size of the converter and the dynamic range of the input, as shown in Fig. 2.

For best results, the maximum input value should yield a full scale reading from the converter. When the input dynamic range is small, the minimum useful input results in a rather large reading. Thus, only a small fraction of the possible converter outputs ever occur; this fraction accounts for the loss of bits. When the input dynamic range is large, the minimum input results in a small reading. In this case the accuracy lost to quantization error causes the loss of bits.

As an example to show how the graph was computed, consider a 4-bit linear ADC used on an input of dynamic range 10 dB. If we call the maximum input 15 (=$2^{(4-1)}$), the minimum input is 4.7 (=$15*10^{(-10/20)}$). This implies that we will get the maximum quantization error when the input is 5.5, an error of one part in 11, 0.83 db. Using 0.83 dB as the logarithmic unit results in a scale of 12 (=10/0.83) different values or 3.6 (=$\log_2$ 12) bits, which is plotted on the graph.

Not shown is the effect of quantizing the logarithmic scale; in practice more bits than shown in the graph should be used to represent the logarithms to avoid effects of this quantization. This has the added advantage of increased accuracy at larger inputs, where the relative quantization noise is much smaller than at minimum input.

The maxima occur at about 8.5 dB; this corresponds to a minimum reading of approximately 3/8 maximum. At this point the loss due to not using the entire ADC range and the loss due to quantization error at the minimum value are equal. The ripples in the graph occur around the point where the minimum input value results in a unity ADC reading; when the input is below unity, a unity ADC reading is assumed for the purpose of plotting.

As an example of the use of this graph, consider building a force sensor with an accuracy of at least 0.4 dB throughout a useful range of 40 dB. We need 100 different values (=0.4/40) or 6.6 (=$\log_2$ 100) bits; referring to the graph we see that a 10-bit linear ADC will suffice. One way to convert the 10-bit linear value to a logarithmic value is by table lookup; to avoid significant roundoff error 9- or 10-bit entries should suffice.

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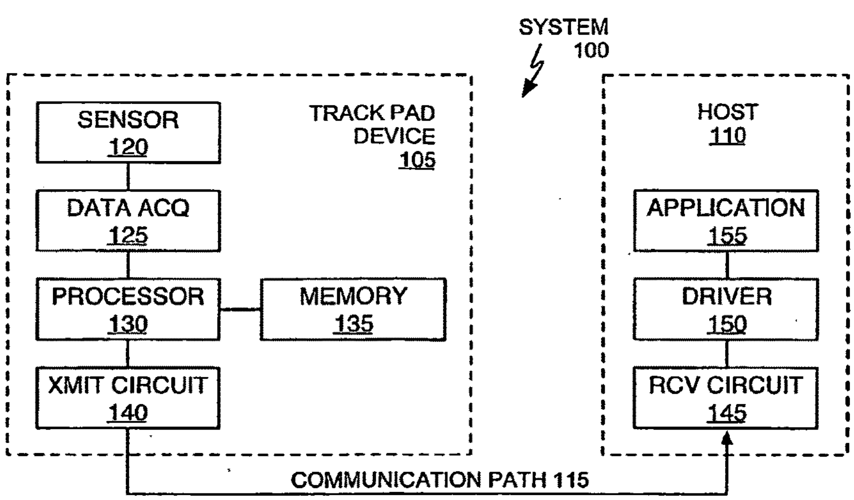

(Prior Art)

(57) Abstract: An input device and system are described that acquires (measures) raw track pad sensor data and transmits this data to a host computer where it is analyzed by an application executing on one or more host computer central processing units. The resulting input processing architecture provides a track pad input device that is both lower in cost to manufacture and more flexible than prior art track pad input devices. Lower costs may be realized by eliminating the prior art's dedicated track pad hardware for processing sensor data (e.g., a processor and associated firmware memory). Increased flexibility may be realized by providing feature set functionality via software that executes on the host computer. In this architecture, track pad functionality may be modified, updated and enhanced through software upgrade procedures.

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RAW DATA TRACK PAD DEVICE AND SYSTEM

Background

[0001] The invention relates generally to computer input devices and more particularly to a track pad input device that generates and transmits measured (raw) sensor data to a host computer system. Software executing on the host computer system analyzes the raw sensor data to determine the user's action.

[0002] A track pad is a touch-sensing planar digitizer input device used instead of, or in conjunction with, a mouse or trackball. During use, an operator places a finger on the track pad and moves the finger along the touch-sensing planar surface. The track pad detects the movement of the finger and in response provides location and/or motion signals to a computer. There are two common types of track pad sensor devices: resistive and capacitive. A resistive track pad sensor is a mechanical sensor that uses two layers of material that are typically separated by air. Pressure from a finger pushes the top layer (generally a thin, clear polyester film) so that it touches the bottom layer (generally glass). The voltage at the contact point is measured and the finger's location and/or motion is computed and transmitted to a host computer system. After the finger is removed, the top layer "bounces back" to its original configuration. A capacitive track or touch pad sensor, in contrast, is a solid-state sensor made using printed circuit board ("PCB") or flex circuit technology. A finger on, or in dose proximity to, a top grid of conductive traces changes the capacitive coupling between adjacent traces or the self-capacitance of each trace. This change in capacitance is measured and the finger's location and/or motion is computed and transmitted to a host computer system.

[0003] Referring to FIG. 1, prior art computer system **100** includes track pad device **105** coupled to host computer module **110** via communication path **115.** Track pad device **105** comprises sensor **120**, data acquisition circuit **125**, processor **130**, memory **135** and transmit circuit **140.** In the case of a capacitive track pad device, as a user's finger(s) is (are) moved over the surface of sensor **120**, data acquisition circuit **125** measures changes in the capacitive coupling between adjacent sensor elements (or the self-capacitance of a given sensor element). Processor **130**, in conjunction with memory **135**, processes the acquired capacitance signals to compute a signal indicating the user's finger position on sensor **120** (e.g., a Δx and Δy signal). In some prior art track pad devices, processor **130** may also determine if multiple fingers are activating sensor **120** and whether certain predetermined finger motions (often referred to as "gestures") are being made – e.g., "select," "drag," "file open" and "file close" operations. At specified intervals (e.g., 50 times per second), the user's finger location and/or motion as determined by processor **130** is transmitted to host computer module **110** via communication path **115.** At host computer module **110**, receive circuit **145** receives the transmitted track pad signal and passes it's information to driver application **150.** Driver application **150**, in turn, makes the computed sensor information available to other applications such as, for example, window display subsystem application **155.** Thus, prior art system **100** utilizes a dedicated processor for measuring and analyzing raw track pad sensor data to generate a signal that indicates a user's action.

[0004] One of ordinary skill in the art will recognize that processor **130** may be embodied in a general purpose processor (e.g., a microprocessor), a microcontroller or a special purpose or custom designed processor or state machine (e.g., an application specific integrated circuit or a custom designed gate array device). Further, memory **135** is typically used to provide permanent storage for instructions (i.e., firmware) to drive processor **130** and may, optionally, include random access memory and/or register storage. A benefit of the architecture of FIG. 1 is that host computer module **110** does not need to know about or understand the type of data generated by sensor **120.** A corollary of this feature is that host computer module **110** does not process track pad sensor data.

[0005] It will also be recognized by one of ordinary skill that a drawback to the architecture of FIG. 1 is that the feature set (i.e., what motions are detectable) provided by track pad device **105** is essentially fixed by its dedicated hardware — processor **130** and associated firmware (memory **135**). Another drawback to the architecture of FIG. 1 is that each manufactured device **105** includes the cost of processor **130** and associated firmware memory **135.** Thus, it would be beneficial to provide a track pad device that overcomes these inherent drawbacks.

Summary

[0006] In one embodiment the invention provides a track pad input device that includes a track pad sensor element that generates output signals representing a track pad sensor characteristic (i.e., capacitance or resistance), a data acquisition circuit that measures a (digital) value encoding the track pad sensor's characteristic and a communication circuit that transmits the measured track pad sensor values to a general purpose processor for analysis, the general purpose processor is also responsible for executing user and other system level tasks or applications. In one specific embodiment, the track pad sensor is a capacitive track pad sensor so that measured values comprise raw track pad sensor values and the general purpose processor corresponds to a host computer system's central processing unit.

Brief Description of the Drawings

[0007] Figure 1 shows, in block diagram form, a track pad-computer system architecture in accordance with the prior art.

[0008] Figure 2 shows, in block diagram form, a track pad-computer system architecture in accordance with one embodiment of the invention.

[0009] Figure 3 shows, in block diagram form, a track pad device and host computer system in accordance with one embodiment of the invention.

[0010] Figure 4 shows, in block diagram form, a track pad sensor data acquisition system in accordance with one embodiment of the invention.

[0011] Figure 5 shows, in flowchart form, a data acquisition method in accordance with one embodiment of the invention.

Detailed Description

[0012] Referring first to FIG. 2, the general architecture of a system incorporating a track pad device in accordance with the invention is illustrated. As shown, system **200** includes track pad device **205** coupled to host module **210** through communication path **215**. Track pad device **205** comprises track pad sensor **220** that generates signals based on user manipulation thereof, data acquisition circuit **225** for capturing or measuring the sensor's and transmit circuit **230** for aggregating and periodically transmitting the measured sensor data values to host module **210** via communication path **215**. At host module **210**, receive circuit **235** receives the measured sensor data and passes them to driver application **240**. Driver application **240**, in turn, processes or analyzes the measured data to determine the user's conduct (e.g., a "single click," "double click," "scroll" or "drag" operation), passing the calculated location and/or movement information to other applications such as, for example, window display subsystem application **245**. In accordance with the invention, driver application **240** is executed by host processor **250** which, as shown, is also responsible for executing (at least in part) one or more user applications or processes **255**. It is significant to note that track pad device **205** has no capability to process or analyze data signals (values) acquired from sensor **220**. In accordance with the invention, sensor data is analyzed by a host computer system's general purpose processor or central processing unit ("CPU").

[0013] The architecture of FIG. 2 recognizes and takes unique advantage of the processing power of modern CPUs incorporated in host computer systems (e.g., notebook or other personal computers, workstations and servers). This recognition and the architecture of FIG. 2 permits a computer system **200** that is both lower in cost to manufacture and more flexible than the systems provided by the prior art. Lower costs may be realized by eliminating the prior art's dedicated hardware for processing track pad sensor data (i.e., a processor and associated firmware memory – see components **130** and **135** in FIG. 1). Increased flexibility may be realized by providing feature set functionality via software that executes on the host computer's

CPU – that is, processing/analyzing measured track pad sensor data on one or more of the host computer's CPUs. In this architecture, track pad functionality may be modified, updated and enhanced through conventional software upgrade procedures.

[0014] The following description is presented to enable any person skilled in the art to make and use the invention as claimed and is provided in the context of the particular examples discussed below, variations of which will be readily apparent to those skilled in the art. Accordingly, the claims appended hereto are not intended to be limited by the disclosed embodiments, but are to be accorded their widest scope consistent with the principles and features disclosed herein.

[0015] Referring to FIG. 3, track pad device **300** in accordance with one embodiment of the invention comprises *m*-row by *n*-column capacitive sensor array **305**, data acquisition circuit **310** (itself comprising multiplexer ("MUX") circuit **315**, storage capacitor **320** and scan circuit **325**) and Universal Serial Bus ("USB") transmit circuit **330**. During operation, MUX circuit **315** is responsible for coupling and stimulating successive sensor array elements (e.g., rows, columns, or individual pixels – that is, an element at the intersection of a row and column) to storage capacitor **320** in a controlled/sequenced manner and indicating that a measurement cycle has begun to scan circuit **325**. When the charge on storage capacitor **320** reaches a specified value or threshold, scan circuit **325** records the time required to charge storage capacitor **320** to the specified threshold. Accordingly, scan circuit **325** provides a digital value that is a direct indication of the selected sensor array element's capacitance. USB transmit circuit **330** is responsible for aggregating the measured capacitance values into packets and transmitting them in accordance with the USB protocol to host module **335** via USB bus **340.** One of ordinary skill in the art will understand that depending upon the version of USB used and the bandwidth of bus **340,** USB transmit circuit **330** may transfer each frame of data to host module **335** in more than one, one or more than one packet. When the host module's USB receive circuit **345** receives the measured sensor data from track pad device **300** via USB bus **340,** it unpacks and passes the measured capacitance data to driver application **350.** Driver application **350,** in turn, accepts and processes the raw (measured) capacitance data to provide meaningful cursor movement input to operating system application **355.** (One of ordinary skill in the art will recognize that scan circuit **325** measures capacitance values from sensor array **305** in a predetermined order or sequence and that this sequence must be known by driver application **350** a priori or conveyed to driver application **350** along with the measured sensor data.) In one embodiment, driver application **350** implements track pad algorithms traditionally provided by a dedicated track pad processor such as, for example, processor **130** and firmware memory **135** of FIG. 1.

[0016] Referring to FIG. 4, a more detailed view of MUX circuit **315** as it can be implemented for a row and column addressable capacitive sensor array is illustrated. As shown, each row in sensor array **400** is electrically coupled to voltage source Vcc **405** through MUX-1 **410** and to storage capacitor **415** through MUX-2 **420.** (While not shown in detail, each column of sensor array **400** is similarly coupled to Vcc **405** and to storage capacitor **415** through other MUX circuits – block **425.**)

[0017] Referring now to FIG. 5, in operation MUX-1 **410** couples a first sensor array row to Vcc **405** for a specified period of time (block **500**) and then isolates or disconnects that row from Vcc **405** (block **505**). Next, MUX-2 **420** couples the same row to storage capacitor **415** for a specified period of time, or until the voltage on storage capacitor **415** reaches a specified threshold (block **510**). If, during the time MUX-2 **420** couples the selected sensor row to storage capacitor **415** the storage capacitor's voltage reaches a specified threshold (the "Yes" prong of block **515**), the digital value corresponding to the time it took to charge storage capacitor **415** to the threshold is recorded by scan circuit **325** (block **520**). If, during the time MUX-2 **420** couples the selected sensor row to storage capacitor **415** the storage capacitor's voltage does not reach the specified threshold (the "No" prong of block **515**), the acts of block **500-510** are repeated. Once a digital value corresponding to the capacitance of the selected row has been obtained (block **520**), a check is made to see if there are additional rows in sensor array **400** that need to be sampled. If all the rows in sensor array **400** have been sampled in accordance with blocks **500-520** (the "Yes" prong of block **525**), the same process is used to acquire a capacitance value for each column of sensor elements in sensor array **400** (block **535**). Once all rows and all columns have been processed in accordance with blocks **500-535,** the entire process is repeated (block **540**). If, on the other hand, there are rows in sensor array **400** that have not been sampled in accordance with blocks **500-520** (the "No" prong of block **525**), the next row is selected (block **530**) and the acts of blocks **500-525** are performed.

[0018] In one illustrative embodiment: sensor array **400** comprises a 16×32 capacitive grid, providing 48 output channels; Vcc is 3.3 volts; storage capacitor **415** is approximately 10,000 picofarads, an average row capacitance value is approximately 12 picofarads; an average column capacitance value is approximately 9 picofarads; the average change in capacitance of a row or column electrode due to a user's finger touching sensor array **400** is approximately 0.2 picofarads; the threshold value at which a digital capacitance value is obtained is 1.6 volts; and the rate at which MUX circuits **410, 420** and **425** are switched is 6 megahertz. It has been found, for these values, that its takes approximately 580-600 sample cycles to charge storage capacitor **415** to the threshold voltage. In one embodiment, the digital capacitance value is, in fact, a count of the number of sampling cycles required to charge storage capacitor **415** to the threshold value. One of ordinary skill in the art will recognize that this value is directly related to the sensor element's (e.g., row or column) capacitance value. In this embodiment, scan circuit **325** (in conjunction with MUX circuits **410, 420** and **425** and storage capacitor **415**) measures each of the 48 sensor array outputs 125 times each second, with each measurement comprising a 10-bit value (unsigned integer). Referring to the 48 measurements acquired by scan circuit **325** from sensor array **400** in each of the 125 epochs as a frame, the illustrative track pad sensor device generates:

$$\left(\frac{48\text{ channels}}{\text{frame}}\right)\left(\frac{10\text{ bits}}{\text{channel}}\right)\left(\frac{125\text{ frames}}{\text{second}}\right)\left(\frac{1\text{ byte}}{8\text{ bits}}\right)=7{,}500\,{}^{\text{bytes}}\!/_{\text{second}}.$$

[0019] As noted with respect to FIG. 2 and as further shown in FIG. 3, driver application **350** is executed general purpose processing unit **360** that is also responsible for executing user applications and tasks, e.g., **365.** That is, in accordance with the invention raw track pad sensor data is analyzed by one, or more, general purpose processing units associated with the host computer system and not by a dedicated processor or processing circuit(s) associated with track pad device **300.** A direct consequence of the architecture of FIGS. 2 and 3 is that the processing resources (e.g., CPUs) tasked with analyzing track pad sensor data must be shared with other computer system processing needs such as other system level and user level applications.

[0020] Various changes in the materials, components and circuit elements of the described embodiments are possible without departing from the scope of the following claims. Consider, for example, the system of FIG. 3. Other embodiments could include a smaller (e.g., 10×16) or larger (e.g., 32×32) sensor array **305.** Further, frame rates other than 125 Hertz ("Hz") and sample resolutions other than 10 bits are possible. It will also be understood that the host computer system may comprise more than one general purpose processing unit (e.g., processor **250**). In addition, some of the circuitry identified in FIGS. 2 and 3 as being integral to track pad device **205** or **300** may be embodied in circuitry also used for other functions. For example, transmit circuits **230** and **330** may be shared by other USB input devices such as, for example, a keyboard. In addition, one of ordinary skill in the art will recognize that the invention is also applicable to track pad sensor devices that are pixilated rather that row-column addressable. It will be further recognized that the operational procedure outlined in FIG. 5 may be modified. For instance, sensor column values may be obtained before sensor row values. Alternatively, sensor row and sensor column data may be interlaced and/or measured at the same time. In any event, it will be recognized that scan circuit **325** measures sensor pad characteristic values (e.g., capacitance or resistance) in a set order and that this order must be known or communicated to driver application **350**. In yet another embodiment, scan circuit **325** may measure sensor characteristic values in any convenient manner and reorder them into a sequence known or expected by driver application **350** prior to transmission by transmit circuit **330**.

What is claimed is:

1. A track pad input device, comprising:

a capacitive track pad sensor having a plurality of sensing elements, each sensing element associated with a region of the capacitive track pad sensor;

a data acquisition circuit electrically coupled to the capacitive track pad sensor for selectively encoding digital capacitance values for each of the plurality of sensing elements; and

a communication circuit for transmitting the digital capacitance values to a host processor for processing, wherein the host processor is also at least partially responsible for executing user-level tasks.

2. The track pad input device of claim 1, wherein the communication circuit comprises a circuit for transmitting the digital capacitance values in accordance with a universal serial bus protocol.

3. The track pad input device of claim 1, wherein the data acquisition circuit is adapted to repeatedly encoding digital capacitance values for each of the plurality of sensing elements.

4. The track pad input device of claim 1, wherein the track pad input device does not include a means for analyzing the encoded digital capacitance values.

5. A track pad input device consisting essentially of:

a track pad sensor having a plurality of sensing elements, each sensing element associated with a region of the track pad sensor;

a data acquisition circuit for selectively encoding a digital value representing a characteristic for each of the plurality of sensing elements; and

a communication circuit for transmitting the encoded digital values to a host processor for analysis, wherein the host processor is also at least partially responsible for executing user-level tasks.

6. The track pad input device of claim 5, wherein the sensor element comprises a resistive sensor array.

7. The track pad input device of claim 5, wherein the sensor element comprises a capacitive sensor array and each encoded digital value represents a capacitance value.

8. The track pad input device of claim 5, wherein the data acquisition circuit is adapted to repeatedly encode digital values for each of the plurality of sensing elements.

9. The track pad input device of claim 5, wherein the communication circuit is adapted to transmit the encoded digital values in accordance with a universal serial bus protocol.

10. A track pad input device comprising:

a track pad sensor having a plurality of sensing elements, each sensing element associated with a region of the track pad sensor;

means for measuring a digital value for each of the plurality of sensing elements, the measured digital value representing a characteristic of the sensing element; and

means for transmitting the plurality of measured digital values to a host processor for processing, wherein the host processor is also at least partially responsible for executing user-level tasks.

11. The track pad input device of claim 10, wherein the track pad input device does not include a means for determining a user action corresponding to manipulation of the track pad sensor.

12. The track pad input device of claim 10, wherein the track pad sensor comprises a resistive sensor array.

13. The track pad input device of claim 10, wherein the track pad sensor comprises a capacitive sensor array.

14. The track pad input device of claim 13, wherein the means for measuring comprises:

means for selectively stimulating each of the plurality of sensing elements;

means for determining a time required to stimulate each selected sensing element to a specified event; and

means for encoding the determined time into a digital value.

15. The track pad input device of claim 14, wherein the specified event comprises charging a known capacitance to a specified voltage.

16. The track pad input device of claim 10, wherein the means for transmitting comprises a means for transmitting the measured digital values to the host processor in accordance with a universal serial bus protocol.

17. A track pad input method, comprising:

stimulating a plurality of sensor elements in a track pad sensor;

measuring a characteristic for each of the stimulated sensor elements, each measurement being encoded by a digital value;

transmitting the measured digital values to a host processor wherein the host processor is responsible, at least in part, for executing user-level tasks;

analyzing, with the host processor, the measured digital values; and

generating a signal representing a track pad input action based on the measured digital values.

18. The method of claim 17, wherein the act of stimulating comprises stimulating a capacitive track pad sensor element.

19. The method of claim 18, wherein the act of measuring a characteristic comprises determining a digital value representing a capacitance value.

20. The method of claim 17, wherein the act of transmitting comprises transmitting the measured digital values in accordance with a universal serial bus protocol.

21. The method of claim 17, wherein the act of generating comprises generating a signal encoding a cursor movement action.

22. The method of claim 17, wherein the host processor is one of a plurality of processors associated with a host computer system.

23. The method of claim 22, wherein the act of analyzing is performed by one or more of the plurality of processors.

24. A computer system, comprising:

one or more host processors for executing, at least in part, user-level tasks;

a display unit operatively coupled to the host processor;

a first communication circuit operatively coupled to the host processor; and

a track pad input device comprising –

a track pad sensor having a plurality of sensing elements, each sensing element associated with a region of the track pad sensor;

a data acquisition circuit electrically coupled to the track pad sensor for selectively encoding a digital value representing a characteristic for each of the plurality of sensing elements; and

a second communication circuit for transmitting the encoded digital values to the first communication circuit, where after at least one of the one or more host determine an action corresponding to manipulation of the track pad sensor.

25. The computer system of claim 24, wherein the first and second communication circuits are adapted to operate in accordance with a universal serial bus protocol.

26. The computer system of claim 24, wherein the track pad sensor comprises a resistive sensor array.

27. The computer system of claim 24, wherein the track pad sensor comprises a capacitive sensor array.

28. The computer system of claim 27, wherein the data acquisition circuit comprises:

means for selectively stimulating each of the plurality of sensing elements;

means for determining a time required to stimulate each selected sensing element to a specified event; and

means for encoding the determined time into a digital value.

29. The computer system of claim 28, wherein the specified event comprises charging a known capacitance to a specified voltage.

30. The computer system of claim 24, wherein the data acquisition circuit is adapted to repeatedly encode digital values for each of the plurality of sensing elements.

31. The method of claim 17, wherein the act of analyzing comprises determining a single finger is manipulating the track pad sensor.

32. The method of claim 31, wherein the act of generating a signal comprises indicating a single-finger gesture.

33. The method of claim 32, wherein the single-finger gesture comprises a single click action.

34. The method of claim 32, wherein the single-finger gesture comprises a drag operation.

35. The method of claim 32, wherein the single-finger gesture comprises a select operation.

36. The method of claim 17, wherein the act of analyzing comprises determining multiple fingers are simultaneously manipulating the track pad sensor.

37. The method of claim 36, wherein the act of generating comprises generating a signal indicating a multi-finger gesture.

38. The method of claim 36, wherein the multi-finger gesture comprises a double-click operation.

39. The method of claim 36, wherein the multi-finger gesture comprises a visual zoom operation.

40. A track pad input method, comprising:

stimulating a plurality of sensor elements in a track pad sensor using a single finger;

measuring a characteristic for each of the stimulated sensor elements, each measurement being encoded by a digital value;

transmitting the measured digital values to a host processor wherein the host processor is responsible, at least in part, for executing user-level tasks;

analyzing, with the host processor, the measured digital values; and

generating a signal representing a single-finger gesture based on the measured digital values.

41. The method of claim 40, wherein the act of generating a signal representing a single-finger gesture comprises generating a signal representing a single click action.

42. The method of claim 40, wherein the act of generating a signal representing a single-finger gesture comprises generating a signal representing a drag operation.

43. The method of claim 40, wherein the act of generating a signal representing a single-finger gesture comprises generating a signal representing a select operation.

44. A track pad input method, comprising:

stimulating a plurality of sensor elements in a track pad sensor using multiple fingers simultaneously;

measuring a characteristic for each of the stimulated sensor elements, each measurement being encoded by a digital value;

transmitting the measured digital values to a host processor wherein the host processor is responsible, at least in part, for executing user-level tasks;

analyzing, with the host processor, the measured digital values; and

generating a signal representing a multi-finger gesture based on the measured digital values.

45. The method of claim 44, wherein the act of generating a signal representing a multi-finger gesture comprises generating a signal representing a double-click operation.

46. The method of claim 44, wherein the act of generating a signal representing a multi-finger gesture comprises generating a signal representing a visual zoom operation.

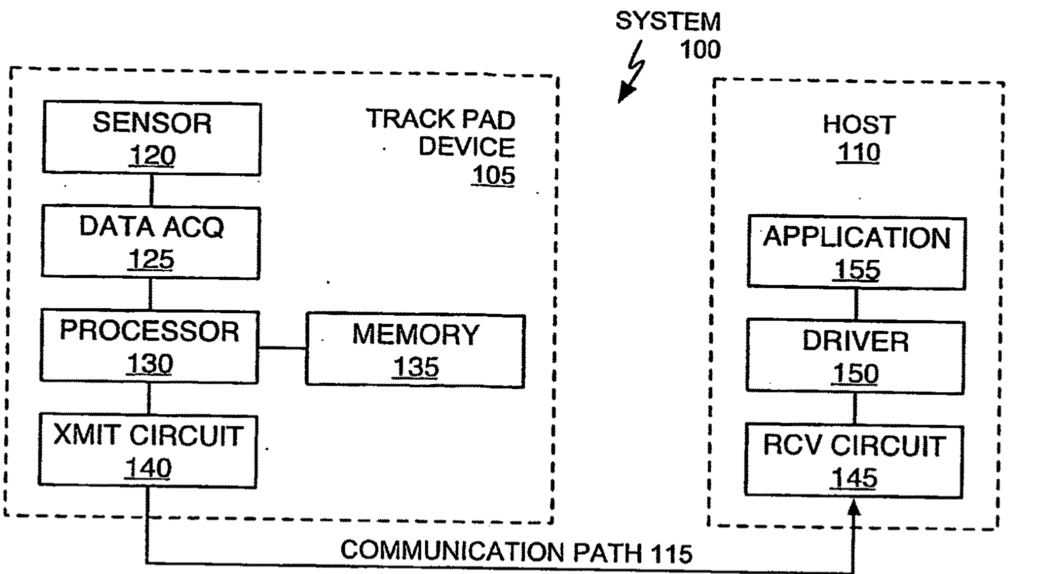

FIG. 1
(Prior Art)

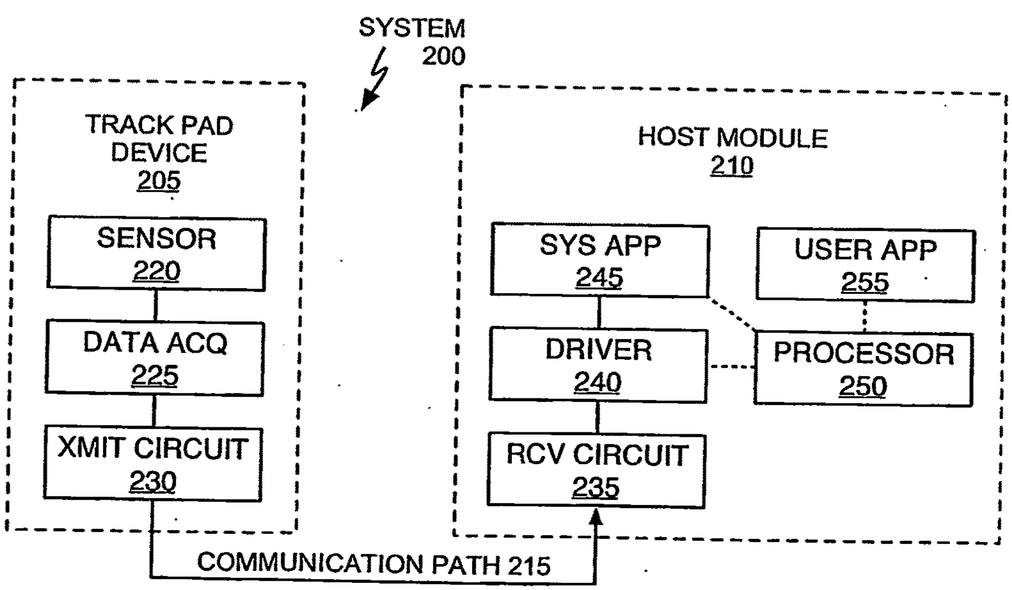

FIG. 2

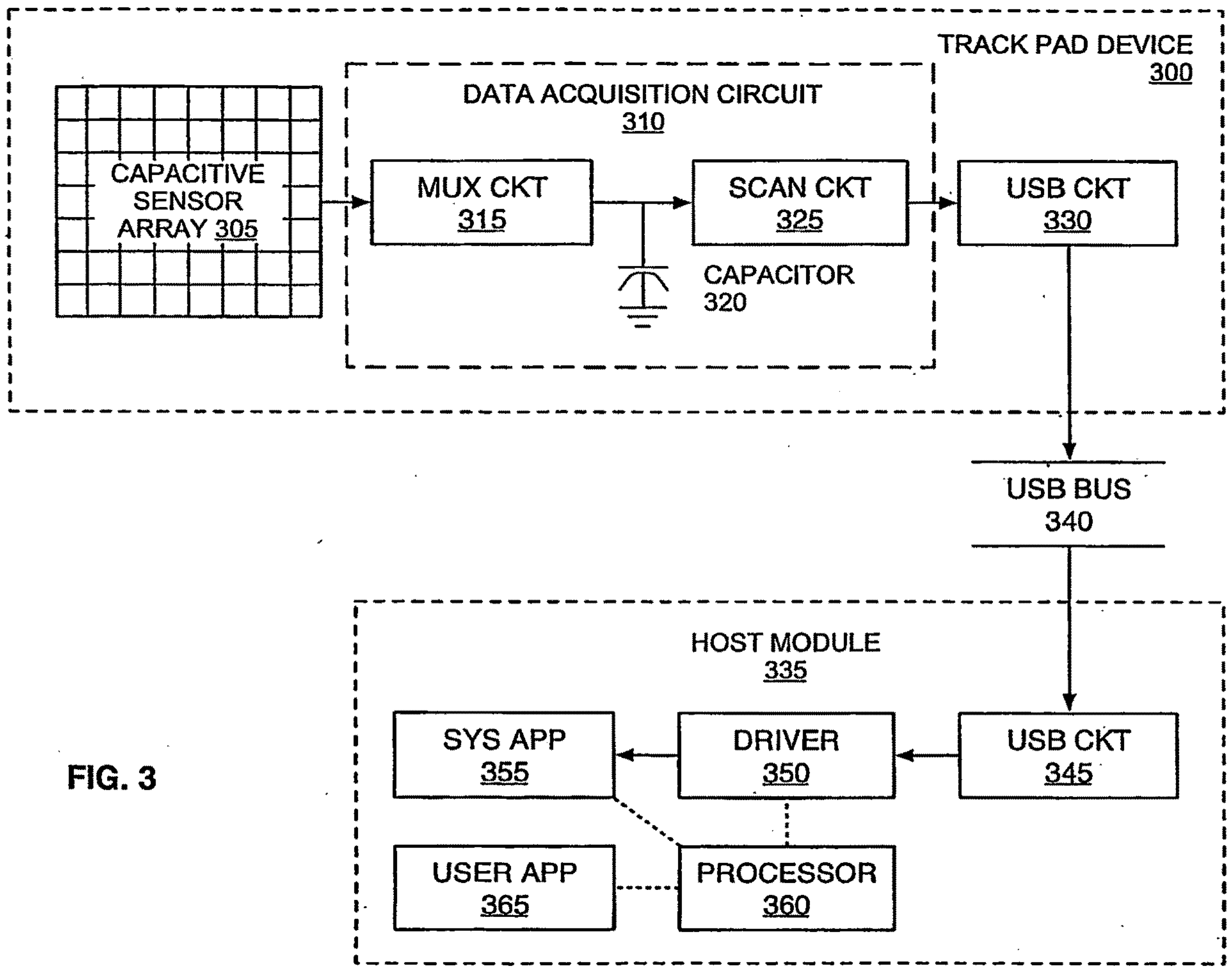
TRACK PAD DEVICE 300
DATA ACQUISITION CIRCUIT 310
CAPACITIVE SENSOR ARRAY 305
MUX CKT 315
SCAN CKT 325
USB CKT 330
CAPACITOR 320
USB BUS 340
HOST MODULE 335
SYS APP 355
DRIVER 350
USB CKT 345
USER APP 365
PROCESSOR 360

FIG. 3

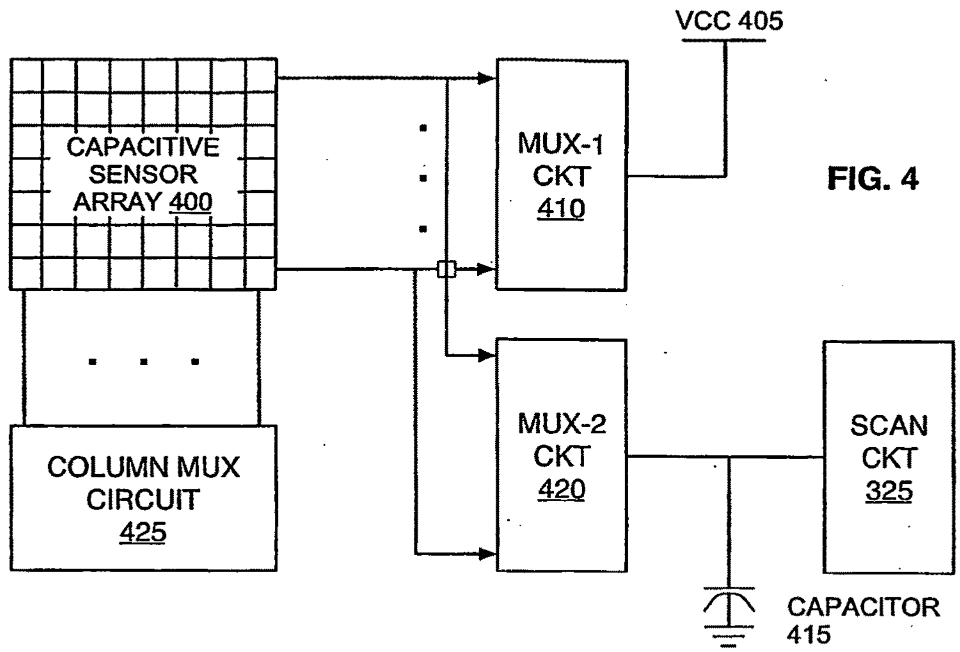
VCC 405
CAPACITIVE SENSOR ARRAY 400
MUX-1 CKT 410
COLUMN MUX CIRCUIT 425
MUX-2 CKT 420
SCAN CKT 325
CAPACITOR 415

FIG. 4

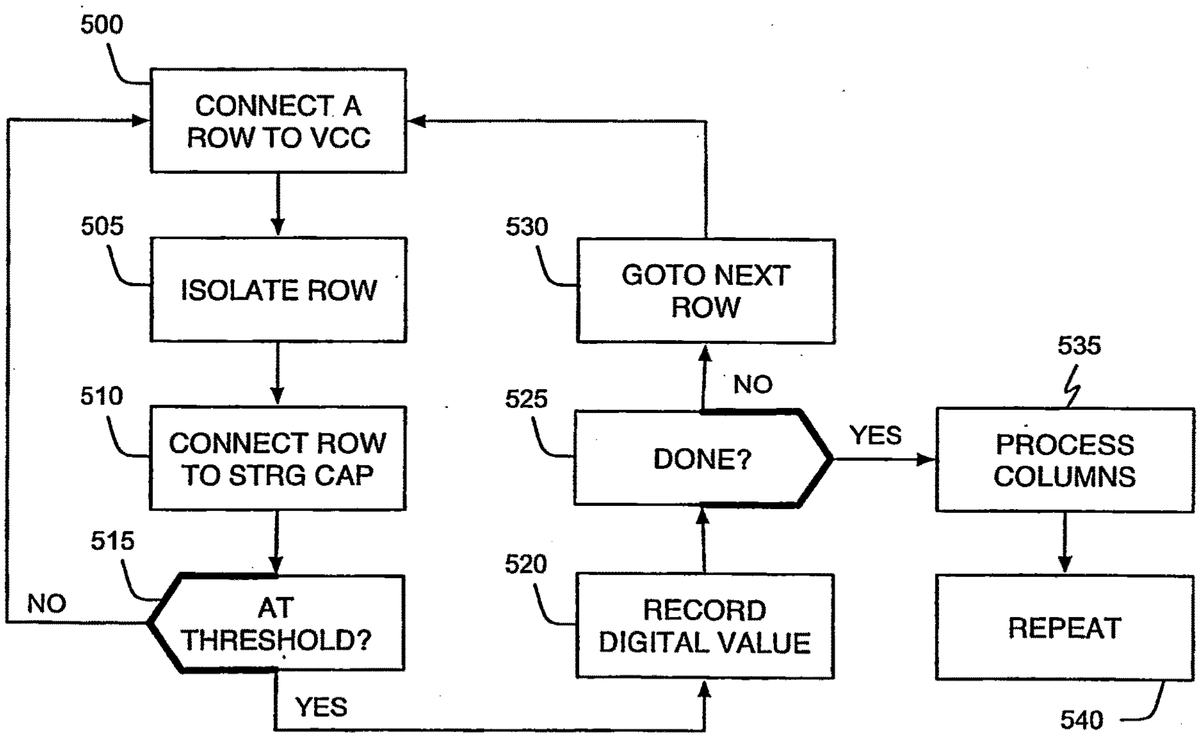
500
CONNECT A ROW TO VCC
505
ISOLATE ROW
510
CONNECT ROW TO STRG CAP
515
AT THRESHOLD?
NO
YES
520
RECORD DIGITAL VALUE
525
DONE?
NO
YES
530
GOTO NEXT ROW
535
PROCESS COLUMNS
REPEAT
540

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2005/033255

A. CLASSIFICATION OF SUBJECT MATTER
G06F3/038 G06F3/044

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97/18547 A (URE, MICHAEL, J) 22 May 1997 (1997-05-22) page 6, line 15 - page 7, line 15; figure 3 page 9, line 18 - page 10, line 23; figure 4 page 11, line 8 - page 12, line 2; figure 6	1-46
A	US 5 825 352 A (BISSET ET AL) 20 October 1998 (1998-10-20) column 5, line 6 - column 8, line 45; figures 1-5 column 11, line 56 - column 15, line 11; figures 7,8	3,7,8, 13,18, 19,21, 27,30-45

-/--

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 February 2006	03/03/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Legrand, J-C

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2005/033255

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/098858 A1 (PERSKI HAIM ET AL) 29 May 2003 (2003-05-29) paragraph '0105! - paragraph '0106!; figure 1 paragraph '0121! - paragraph '0131!; figures 7-11	3,6,8, 12,26,30
A	DE 102 51 296 A1 (TRACHTE, RALF) 19 May 2004 (2004-05-19) paragraph '0002! - paragraph '0004! paragraphs '0009!, '0015!	3,8,30, 35,39, 43,46

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2005/033255

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9718547	A	22-05-1997	EP	0861485	A1	02-09-1998
			JP	2000501526	T	08-02-2000
US 5825352	A	20-10-1998	NONE			
US 2003098858	A1	29-05-2003	AU	2002356407	A1	10-06-2003
			WO	03046882	A1	05-06-2003
			JP	2005510814	T	21-04-2005
DE 10251296	A1	19-05-2004	NONE			

IFW

Appl. No.	:	10/840,862 Confirmation No. 8470
Applicant	:	Steven P. Hotelling; Joshua A. Strickon; Brian Q. Huppi / Apple Computer
Filed	:	May 6, 2004
TC/A.U.	:	2673
Examiner	:	Edouard Patrick Nestor
Docket No.	:	119-0093US (P3266US1)
Customer No.	:	61947
Title	:	MULTIPOINT TOUCHSCREEN

INFORMATION DISCLOSURE STATEMENT

Commissioner for Patents
P.O. Box 1450
Alexandria VA, 22313-1450.

Sir:

In compliance with the duty of disclosure under 37 C.F.R. § 1.56, it is respectfully requested that this Information Disclosure Statement be entered and the documents listed on attached Form PTO-1449 be considered by the Examiner and made of record. Copies of the listed documents required by 37 C.F.R. § 1.98(a)(2) are enclosed for the convenience of the Examiner.

In accordance with 37 C.F.R §§ 1.97(g),(h), this Information Disclosure Statement is not to be construed as a representation that a search has been made, and is not to be construed to be an admission that the information cited is, or is considered to be, material to patentability as defined in 37 C.F.R. § 1.56(b), or that such information constitutes prior art.

The present Information Disclosure Statement is being filed prior to the receipt of a first Official Action reflecting an examination on the merits, and hence is believed to be timely filed in accordance with 37 C.F.R § 1.97(b). No fees are believed to be due in connection with the filing of this Information Disclosure Statement. However, the Commissioner is authorized to deduct any necessary fees from Deposit Account No. 501922/119-0093US (P3266US1).

Applicants respectfully request that the listed documents be considered and made of record in the present case, and that the Examiner initial the appropriate spaces on the Form 1449 to evidence the same.

Respectfully submitted,

Nov. 10, 2006
Date

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CERTIFICATE OF MAILING
37 § C.F.R. 1.8

I hereby certify that this correspondence is being deposited with the U.S. Postal Service with sufficient postage as First Class Mail in an envelope addressed to Commissioner for Patents, P.O. Box 1450, Alexandria VA, 22313-1450, on the date below.

11·10·06
Date

Rebecca R. Ginn

Form PTO-1449 (modified)	Atty. Docket No. 119-0093US	Serial No. 10/840,862
List of Patents and Publications for Applicant's **INFORMATION DISCLOSURE STATEMENT**	Applicant(s): **Steven P. Hotelling; Joshua A. Strickon; Brian Q. Huppi** Title: **MULTIPOINT TOUCHSCREEN**	
(Use several sheets if necessary)	Filing Date: **May 6, 2004**	Group: **2673**

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

U.S. Patent Documents

Exam. Init.	Ref. Des.	Document Number	Date	Name	Class	Sub Class	Filing Date of App.
	A1	2002/0118848	08/29/2002	Karpenstein	381	119	02/27/2001
	A2	2003/0076301	04/24/2003	Tsuk et al.	345	159	09/26/2002
	A3	2003/0076303	04/24/2003	Huppi	345	163	02/07/2002
	A4	2003/0076306	04/24/2003	Zadesky et al.	345	173	07/01/2002
	A5	2003/0095096	05/22/2003	Robbin et al.	345	156	09/26/2002
	A6	2003/0098858	05/29/2003	Perski et al.	345	173	10/15/2002
	A7	2005/0012723	01/20/2005	Pallakoff	345	173	07/14/2004
	A8	2005/0052425	03/10/2005	Zadesky et al.	345	173	08/18/2003
	A9	2005/0110768	05/26/2005	Marriott et al.	345	173	11/25/2003
	A10	2006/0022955	02/02/2006	Kennedy	345	173	08/26/2004
	A11	2006/0022956	02/02/2006	Lengeling et al.	345	173	12/17/2004
	A12	2006/0026521	02/02/2006	Hotelling et al.	715	702	07/30/2004
	A13	2006/0026535	02/02/2006	Hotelling et al.	715	863	01/18/2005
	A14	2006/026536	02/02/2006	Hotelling et al.	715	863	01/31/2005
	A15	2006/0032680	02/16/2006	Elias et al.	178	18.06	08/15/2005
	A16	2006/0066582	03/30/2006	Lyon et al.	345	173	09/24/2004
	A17	2006/0097991	05/11/2006	Hotelling et al.	345	173	05/06/2004
	A18	3,333,160	07/25/1967	A. Gorski			02/24/1964
	A19	3,541,541	11/17/1970	D.C. Englebart			06/21/1967
	A20	3,662,105	05/09/1972	Hurst et al.	178	18	05/21/1970
	A21	3,798,370	03/19/1974	Hurst	178	18	04/17/1972
	A22	4,246,452	01/20/1981	Chandler	200	5	01/05/1979
	A23	4,550,221	10/259/1985	Mabusth	178	18	10/07/1983
	A24	4,672,364	06/09/1987	Lucas	340	365 P	06/18/1984
	A25	4,672,558	06/09/1987	Beckes et al.	364	518	09/25/1984

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Form PTO-1449 (modified)	Atty. Docket No. 119-0093US	Serial No. 10/840,862
List of Patents and Publications for Applicant's **INFORMATION DISCLOSURE STATEMENT**	Applicant(s): **Steven P. Hotelling; Joshua A. Strickon; Brian Q. Huppi** Title: **MULTIPOINT TOUCHSCREEN**	
(Use several sheets if necessary)	Filing Date: May 6, 2004	Group: 2673

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

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Exam. Init.	Ref. Des.	Document Number	Date	Name	Class	Sub Class	Filing Date of App.
	A26	4,692,809	09/08/1987	Beining et al.	358	247	11/20/1984
	A27	4,695,827	09/22/1987	Beining et al.	340	365 P	11/20/1984
	A28	4,733,222	03/22/1988	Evans	340	365 C	04/18/1986
	A29	4,734,685	03/29/1988	Watanabe	340	710	07/18/1984
	A30	4,746,770	05/24/1988	McAvinney	178	18	02/17/1987
	A31	4,771,276	09/13/1988	Parks	340	712	04/15/1985
	A32	4,788,384	11/29/1988	Bruere-Dawson et al.	178	18	12/17/1987
	A33	4,806,846	02/21/1989	Kerber	324	60 CD	07/06/1987
	A34	4,898,555	02/06/1990	Sampson	445	22	03/23/1989
	A35	4,968,877	11/06/1990	McAvinney et al.	250	221	09/14/1988
	A36	5,003,519	03/26/1991	Noirjean	368	73	05/25/1989
	A37	5,017,030	05/21/1991	Crews	400	485	07/07/1986
	A38	5,178,477	01/12/1993	Gambaro	400	489	06/06/1991
	A39	5,189,403	02/23/1993	Franz et al.	340	711	02/01/1991
	A40	5,194,862	03/16/1993	Edwards	341	20	06/07/1991
	A41	5,224,861	07/06/1993	Glass et al.	434	35	09/17/1990
	A42	5,241,308	08/31/1993	Young	341	34	07/23/1992
	A43	5,252,951	10/12/1993	Tannenbaum et al.	345	156	10/21/1991
	A44	5,281,966	01/25/1994	Walsh	341	22	01/31/1992
	A45	5,305,017	04/19/1994	Gerpheide	345	174	07/13/1992
	A46	5,345,543	09/06/1994	Capps et al.	395	137	11/16/1992
	A47	5,376,948	12/27/1994	Roberts	345	173	04/22/1994
	A48	5,398,310	03/14/1995	Tchao et al.	395	144	04/13/1992
	A49	5,442,742	08/15/1995	Greyson et al.	395	146	10/14/1993

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	Filing Date: **May 6, 2004**	Group: **2673**

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

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	A50	5,463,388	10/31/1995	Boie et al.	341	33	01/29/1993
	A51	5,463,696	10/31/1995	Beernink et al	382	186	07/05/1994
	A52	5,483,261	01/09/1996	Yasutake	345	173	10/26/1993
	A53	5,488,204	01/30/1996	Mead et al.	178	18	10/17/1994
	A54	5,495,077	02/27/1996	Miller et al.	178	18	06/02/1994
	A55	5,513,309	04/30/1996	Meier et al.	395	155	05/08/1995
	A56	5,523,775	06/04/1996	Capps	345	179	06/08/1994
	A57	5,530,455	06/25/1996	Gillick et al.	345	163	08/10/1994
	A58	5,543,590	08/06/1996	Gillespie et al.	178	18	09/02/1994
	A59	5,543,591	08/06/1996	Gillespie et al.	178	18	10/07/1994
	A60	5,563,632	10/08/1996	Roberts	345	173	04/30/1993
	A61	5,563,996	10/08/1996	Tchao	395	144	09/24/1993
	A62	5,565,658	10/15/1996	Gerpheide et al.	178	19	12/07/1994
	A63	5,579,036	11/26/1996	Yates, IV	345	173	04/28/1994
	A64	5,581,681	12/03/1996	Tchao et al.	395	804	06/07/1995
	A65	5,583,946	12/10/1996	Gourdol	382	187	09/30/1993
	A66	5,590,219	12/31/1996	Gourdol	382	202	03/16/1995
	A67	5,592,566	01/07/1997	Pagallo et al.	382	187	06/01/1995
	A68	5,594,810	01/14/1997	Gourdol	382	187	06/05/1995
	A69	5,596,694	01/21/1997	Capps	395	152	04/08/1996
	A70	5,612,719	03/18/1997	Beernink et al.	345	173	04/15/1994
	A71	5,631,805	05/20/1997	Bonsall	361	681	09/27/1995
	A72	5,633,955	05/27/1997	Bozinovic et al.	381	187	05/31/1995
	A73	5,634,102	05/27/1997	Capps	395	334	08/07/1995
	A74	5,636,101	06/03/1997	Bonsall et al.	361	681	09/27/1995

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	Filing Date: May 6, 2004	Group: 2673

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

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	A75	5,642,108	06/24/1997	Gopher et al.	341	22	12/29/1994
	A76	5,644,657	07/01/1997	Capps et al.	382	229	06/01/1995
	A77	5,666,113	09/09/1997	Logan	341	34	09/05/1995
	A78	5,666,502	09/09/1997	Capps	345	352	08/07/1995
	A79	5,666,552	09/09/1997	Grayson et al.	395	802	06/01/1995
	A80	5,675,361	10/07/1997	Santilli	345	168	08/23/1995
	A81	5,677,710	10/14/1997	Thompson-Rohrlich	345	173	05/10/1993
	A82	5,689,253	11/18/1997	Hargreaves et al	341	22	04/09/1993
	A83	5,710,844	01/20/1998	Capps et al.	382	317	05/27/1992
	A84	5,729,250	03/17/1998	Bishop et al.	345	175	05/08/1995
	A85	5,730,165	03/24/1998	Philipp	137	1	12/26/1995
	A86	5,736,976	04/07/1998	Cheung	345	168	02/13/1995
	A87	5,741,990	04/21/1998	Davies	84	423 R	01/25/1997
	A88	5,745,116	04/28/1998	Pisutha-Arnond	345	358	09/19/1996
	A89	5,745,716	04/28/1998	Tchao et al.	395	350	08/07/1995
	A90	5,748,269	05/05/1998	Harris et al.	349	58	11/21/1996
	A91	5,764,222	06/09/1998	Shieh	345	173	05/28/1996
	A92	5,746,818	05/05/1998	Yatake	106	31.86	08/29/1996
	A93	5,767,457	06/16/1998	Gerpheide et al.	178	18	11/13/1995
	A94	5,767,842	06/16/1998	Korth	345	168	04/21/1995
	A95	5,790,104	08/04/1998	Shieh	345	173	06/25/1996
	A96	5,790,107	08/04/1998	Kasser et al	345	174	06/07/1995
	A97	5,802,516	09/01/1998	Shwarts et al.	707	6	05/30/1995
	A98	5,808,567	09/15/1998	McCloud	341	20	05/17/1993

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(Use several sheets if necessary)	Filing Date: May 6, 2004	Group: 2673

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

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	A99	5,809,267	09/15/1998	Moran et al.	395	358	03/18/1996
	A100	5,821,690	10/13/1998	Martens et al.	313	506	04/22/1996
	A101	5,821,930	10/13/1998	Hansen	345	340	05/30/1996
	A102	5,823,782	10/20/1998	Marcus et al.	434	156	07/09/1997
	A103	5,825,351	10/20/1998	Tam	345	173	11/15/1995
	A104	5,825,352	10/20/1998	Bisset et al	345	173	02/18/1996
	A105	5,854,625	12/29/1998	Frisch et al.	345	173	11/06/1996
	A106	5,880,411	03/09/1999	Gillespie et al.	178	18.01	03/28/1996
	A107	5,898,434	04/27/1999	Small et al.	345	348	08/22/1994
	A108	5,920,309	07/06/1999	Bisset et al.	345	173	01/04/1996
	A109	5,923,319	07/13/1999	Bishop et al.	345	175	11/07/997
	A110	5,933,134	08/03/1999	Shieh	345	173	06/25/1996
	A111	5,943,044	08/24/1999	Martinelli et al.	345	174	05/15/1997
	A112	6,002,389	12/14/1999	Kasser	345	173	09/23/1997
	A113	6,002,808	12/14/1999	Freeman	382	288	07/26/1996
	A114	6,020,881	02/01/2000	Naughton et al.	345	327	02/18/1997
	A115	6,031,524	02/29/2000	Kunert	345	173	06/18/1997
	A116	6,037,882	03/14/2000	Levy	341	20	09/30/1997
	A117	6,050,825	04/18/2000	Nichol et al.	434	227	05/08/1998
	A118	6,052,339	04/18/2000	Frenkel et al.	368	230	06/01/1998
	A119	6,072,494	06/06/2000	Nguyen	345	358	10/15/1997
	A120	6,084,576	07/04/2000	Leu et al.	345	168	03/04/1998
	A121	6,107,997	08/222/2000	Ure	345	173	06/27/1996
	A122	6,128,003	10/03/2000	Smith et al.	345	157	12/22/1997
	A123	6,131,299	10/17/2000	Raab et al.	33	503	07/01/1998

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U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

U.S. Patent Documents

Exam. Init.	Ref. Des.	Document Number	Date	Name	Class	Sub Class	Filing Date of App.
	A124	6,135,958	10/24/2000	Mikula-Curtis et al.	600	443	08/06/1998
	A125	6,144,380	11/07/2000	Schwarts et al.	345	350	02/19/1997
	A126	6,188,391	02/13/2001	Seely et al.	345	173	07/09/1998
	A127	6,198,515	03/06/2001	Cole	348	836	03/16/1998
	A128	6,208,329	03/27/2001	Ballare	345	173	08/13/1996
	A129	6,222,465	04/24/2001	Kumar et al.	341	20	12/09/1998
	A130	6,239,790	05/29/2001	Martinelli et al.	345	174	08/17/1999
	A131	6,243,071	06/05/2001	Shwarts et al.	345	146	11/03/1993
	A132	6,246,862	06/12/2001	Grivas et al.	455	90	02/03/1999
	A133	6,249,606	06/19/2001	Kiraly et al.	382	195	02/19/1998
	A134	6,288,707	09/11/2001	Philipp	345	168	01/25/1999
	A135	6,289,326	09/11/2001	LaFleur	705	702	06/04/1997
	A136	6,292,178	09/18/2001	Bernstein et al.	345	173	10/19/1998
	A137	6,323,849	11/27/2001	Westerman et al	345	173	01/25/1999
	A138	6,347,290	02/12/2002	Bartlett	702	150	06/24/1998
	A139	6,377,009	04/23/2002	Philipp	318	468	09/07/2000
	A140	6,380,931	04/30/2002	Gillespie et al.	345	173	05/18/2001
	A141	6,411,287	06/25/2002	Scharff et al.	345	177	09/08/1999
	A142	6,414,671	07/02/2002	Gillespie et al.	345	157	03/24/1998
	A143	6,421,234	07/16/2002	Ricks et al.	361	683	01/10/2000
	A144	6,452,514	09/17/2002	Philipp	341	33	01/26/2000
	A145	6,457,355	10/01/2002	Philipp	73	304	08/24/2000
	A146	6,466,036	10/15/2002	Philipp	324	678	09/07/1999
	A147	6,515,669	02/04/2003	Mohri	345	474	10/06/1999

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(Use several sheets if necessary)	Filing Date: **May 6, 2004**	Group: **2673**

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

U.S. Patent Documents

Exam. Init.	Ref. Des.	Document Number	Date	Name	Class	Sub Class	Filing Date of App.
	A148	6,525,749	02/25/2003	Moran et al.	345	863	10/25/1996
	A149	6,535,200	03/18/2003	Philipp	345	168	08/27/2001
	A150	6,543,684	04/08/2003	White et al.	234	379	03/28/2000
	A151	6,543,947	04/08/2003	Lee	400	489	03/14/2001
	A152	6,570,557	05/27/2003	Westerman et al	345	173	02/10/2001
	A153	6,593,916	07/15/2003	Aroyan	345	173	11/03/2000
	A154	6,610,936	08/26/2003	Gillespie et al.	178	18.01	08/12/1997
	A155	6,624,833	09/23/2003	Kumar et al.	345	863	04/17/2000
	A156	6,639,577	10/28/2003	Eberhard	345	102	05/28/1998
	A157	6,650,319	11/18/2003	Hurst et al.	345	173	03/05/1999
	A158	6,658,994	12/09/2003	McMillan	99	468	03/31/2003
	A159	6,670,894	12/30/2003	Mehring	341	22	02/01/2002
	A160	6,677,932	01/13/2004	Westerman	345	173	01/28/2001
	A161	6,677,934	01/13/2004	Blanchard	345	173	07/30/1999
	A162	6,724,366	04/20/2004	Crawford	345	157	04/03/2001
	A163	6,757,002	06/29/2004	Oross et al.	345	864	11/04/1999
	A164	6,803,906	10/12/2004	Morrison et al.	345	173	07/05/2000
	A165	6,842,672	01/11/2005	Straub et al.	701	3	02/24/2004
	A166	6,856,259	02/15/2005	Sharp	341	5	02/06/2004
	A167	6,888,536	05/03/2005	Westerman et al	345	173	07/31/2001
	A168	6,900,795	05/31/2005	Knight, III et al.	345	173	02/27/2002
	A169	6,927,761	08/09/2005	Badaye et al.	345	173	03/29/2002
	A170	6,942,571	09/13/2005	McAllister et al.	463	20	10/16/2000
	A171	6,965,375	11/15/2005	Gettemy et al.	345	173	04/27/2004
	A172	6,972,401	12/06/2005	Akitt et al.	250	221	01/30/2003

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U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

U.S. Patent Documents

Exam. Init.	Ref. Des.	Document Number	Date	Name	Class	Sub Class	Filing Date of App.
	A173	6,977,666	12/20/2005	Hedrick	345	690	09/03/1999
	A174	6,985,801	01/10/2006	Straub et al.	701	3	11/12/2004
	A175	6,992,659	01/31/2006	Gettemy	345	173	05/22/2001
	A176	7,031,228	04/18/2006	Born et al.	368	69	09/02/2003
	A177	2005/0104867	05/19/2005	Westerman et al	345	173	12/17/2004
	A178	2006/0033724	02/16/2006	Chaudhri et al	345	173	09/16/2005
	A179	2006/0053387	03/09/2006	Ording	715	773	03/09/2006
	A180	2006/0085757	04/20/2006	Andre et al.	715	771	09/16/2005
	A181	2006/0197753	09/07/2006	Hotelling	345	173	03/03/2006
	A182	2003/0234768	12/25/2003	Rekimoto et al	345	169	05/14/2003
	A183	2003/0206202	11/06/2003	Moriya	345	846	11/06/2003
	A184	2004/0263484	12/30/2004	Mantysalo et al.	345	173	06/25/2003
	A185	2003/0095095	05/22/2003	Pihlaja	345	156	11/20/2001
	A186	2003/0006974	01/09/2003	Clough et al.	345	179	07/03/2001

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	B2	102 51 296	05/19/2004	DE	G06F	3/023	No
	B3	0 288 692	07/14/1993	EPO	G06K	11/06	Yes
	B4	0 464 908	09/04/1996	EPO	G06K	11/16	Yes
	B5	0 664 504	01/24/21995	EPO	G06F	3/033	Yes
	B6	1 014 295	01/09/2002	EPO	G06K	11/06	Yes
	B7	2003/088176	10/23/2003	WIPO	G08C	21/00	Yes
	B8	2006/023569	03/02/2006	WIPO	G06F	3/044	Yes

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(Use several sheets if necessary)	Filing Date: May 6, 2004	Group: 2673

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

Foreign Patent Documents

Exam. Init.	Ref. Des.	Document Number	Date	Country	Class	Sub Class	Translation Yes/No
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	B10	1997/023738	07/03/1997	WIPO	F16K	31/06	Yes
	B11	1998/14863	04/09/1998	WIPO	G06F	3/14	Yes

Other Art (Including Author, Title, Date Pertinent Pages, Etc.)

Exam. Init.	Ref. Des.	Citation
	C1	US Patent Application No. 10/654,108 filed on September 2, 2003 entitled "Ambidextrous Mouse"
	C2	US Patent Application No. 10/789,676 filed on February 27, 2004 entitled "Shape Detecting Input Device"
	C3	"4-Wire Resistive Touchscreens" obtained from http://www.touchscreens.com/intro-touchtypes-4resistive.html generated August 5, 2005
	C4	"5-Wire Resistive Touchscreens" obtained from http://www.touchscreens.com/intro-touchtypes-resistive.html generated August 5, 2005
	C5	"A Brief Overview of Gesture Recognition" obtained from http://www.dai.ed.ac.uk/Cvonline/LOCA_COPIES/COHEN/gesture_overview.html, generated April 20, 2004
	C6	"Capacitive Touchscreens" obtained from http://www.touchscreens.com/intro-touchtypes-capacitive.html generated August 5, 2005
	C7	"Capacitive Position Sensing" obtained from http://www.synaptics.com/technology/cps.cfm generated August 5, 2005
	C8	"Comparing Touch Technologies" obtained from http://www.touchscreens.com/intro-touchtypes.html generated October 10, 2004
	C9	"Gesture Recognition" http://www.fingerworks.com/gesture_recognition.html

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Form PTO-1449 (modified)	Atty. Docket No. 119-0093US	Serial No. 10/840,862
List of Patents and Publications for Applicant's **INFORMATION DISCLOSURE STATEMENT** (Use several sheets if necessary)	Applicant(s): Steven P. Hotelling; Joshua A. Strickon; Brian Q. Huppi Title: MULTIPOINT TOUCHSCREEN	
	Filing Date: May 6, 2004	Group: 2673

U.S. Patent Documents	Foreign Patent Documents	Other Art
Beginning on Page 1	*See Page 8*	*Beginning on Page 8*

Other Art (Including Author, Title, Date Pertinent Pages, Etc.)

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	C10	"GlidePoint®" obtained from http://www.cirque.com/technology/technology_gp.html generated August 5, 2005
	C11	"How do touchscreen monitors know where you're touching?" obtained from http://www.electronics.howstuffworks.com/question716.html generated August 5, 2005
	C12	"How does a touchscreen work?" obtained from http://www.touchscreens.com/intro-anatomy.html generated August 5, 2005
	C13	"iGesture Products for Everyone (learn in minutes) Product Overview" FingerWorks.com
	C14	"Infrared Touchscreens" obtained from http://www.touchscreens.com/intro-touchtypes-infrared.html generated August 5, 2005
	C15	"Mouse Emulation" FingerWorks obtained from http://www.fingerworks.com/gesture_guide_mouse.html generated August 30, 2005
	C16	"Mouse Gestures in Opera" obtained from http://www.opera.com/products/desktop/mouse/index.dml generated August 30, 2005
	C17	"Mouse Gestures," Optim oz, May 21, 2004
	C18	"MultiTouch Overview" FingerWorks obtained from http://www.fingerworks.com/multoverview.html generated August 30, 2005
	C19	"Near Field Imaging Touchscreens" obtained from http://www.touchscreens.com/intro-touchtypes-nfi.html generated August 5, 2005
	C20	"PenTouch Capacitive Touchscreens" obtained from http://www.touchscreens.com/intro-touchtypes-pentouch.html generated August 5, 2005

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List of Patents and Publications for Applicant's **INFORMATION DISCLOSURE STATEMENT** (Use several sheets if necessary)	Applicant(s): **Steven P. Hotelling; Joshua A. Strickon; Brian Q. Huppi** Title: **MULTIPOINT TOUCHSCREEN**	
	Filing Date: **May 6, 2004**	Group: **2673**

U.S. Patent Documents	Foreign Patent Documents	Other Art
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	C27	"FingerWorks – Gesture Guide – Application Switching," obtained from http://www.fingerworks.com/gesture_guide_apps.html, generated on 08/27/2004, 1-pg
	C28	"FingerWorks – Gesture Guide – Editing," obtained from http://www.fingerworks.com/gesure_guide_editing.html, generated on 08/27/2004, 1-pg
	C29	"FingerWorks – Gesture Guide – File Operations," obtained from http://www.fingerworks.com/gesture_guide_files.html, generated on 08/27/2004, 1-pg
	C30	"FingerWorks – Gesture Guide – Text Manipulation," obtained from http://www.fingerworks.com/gesture_guide_text_manip.html, generated on 08/27/2004, 2-pg

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	C33	"FingerWorks – Guide to Hand Gestures for USB Touchpads," obtained from http://www.fingerworks.com/igesture_userguide.html, generated 08/27/2004, 1-pg
	C34	"FingerWorks – iGesture – Technical Details," obtained from http://www.fingerworks.com/igesture_tech.html, generated 08/27/2004, 1-pg
	C35	"FingerWorks – The Only Touchpads with Ergonomic Full-Hand Resting and Relaxation!" obtained from http://www.fingerworks.com/resting.html, Copyright 2001, 1-pg
	C36	"FingerWorks – Tips for Typing on the Mini," obtained from http://www.fingerworks.com/mini_typing.html, generated on 08/27/2004, 2-pgs
	C37	"iGesture Pad – the MultiFinger USB TouchPad with Whole-Hand Gestures," obtained from http://www.fingerworks.com/igesture.html, generated 08/27/2004, 2-pgs
	C38	Bier, et al., "Toolglass and Magic Lenses: The see-through interface" In James Kijiya, editor, Computer Graphics (SIGGRAPH '93 Proceedings), volume 27, pages 73-80, August 1993
	C39	Douglas et al., *The Ergonomics of Computer Pointing Devices* (1997)
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Beginning on Page 1	***See Page 8***	***Beginning on Page 8***

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	C43	Fukumoto, et al., "ActiveClick: Tactile Feedback for Touch Panels," In CHI 2001 Summary, pages 121-122, 2001
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	C45	Hardy, "Fingerworks" March 7, 2002; BBC World On Line
	C46	Hillier and Gerald J. Lieberman, *Introduction to Operations Research* (1986)
	C47	International Search Report dated March 3, 2006 (PCT/US 05/03325; 119-0052WO)
	C48	Jacob et al., "Integrality and Separability of Input Devices," *ACM Transactions on Computer-Human Interaction*, 1:3-26 (Mar. 1994)
	C49	Kinkley et al., "Touch-Sensing Input Devices," in CHI '99 Proceedings, pp 223-230, 1999
	C50	KIONX "KXP84 Series Summary Data Sheet" copyright 2005,dated 10/21/2005, 4-pgs
	C51	Lee et al., "A Multi-Touch Three Dimensional Touch-Sensitive Tablet," in CHI '85 Proceedings, pages 121-128, 2000
	C52	Lee, "A Fast Multiple-Touch-Sensitive Input Device," Master's Thesis, University of Toronto (1984)
	C53	Matsushita et al., "HoloWall: Designing a Finger, Hand, Body and Object Sensitive Wall," In Proceedings of UIST '97, October 1997
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	C55	Quek, "Unencumbered Gestural Interaction," *IEEE Multimedia*, 3:36-47 (Winter 1996)

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	C63	Wellner, "The Digital Desk Calculators: Tangible Manipulation on a Desk Top Display" IN ACM UIST '91 Proceedings, Pages 27-34, November 1991
	C64	Williams, "Applications for a Switched-Capacitor Instrumentation Building Block" Linear Technology Application Note 3, July 1985, pp. 1-16
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	C66	Yeh et al., "Switched Capacitor Interface Circuit for Capacitive Transducers" 1985 IEEE
	C67	Zhai et al., "Dual Stream Input for Pointing and Scrolling," *Proceedings of CHI '97 Extended Abstracts* (1997)

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