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(54) **TOUCH PAD**
BERÜHRUNGS-PAD
PAVE TACTILE

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(73) Proprietor: **Soundtouch Limited**
Whitstable,
Kent CT5 4EG (GB)

(72) Inventor: **Hardie-Bick, Anthony Richard**
London SW1Y 6BL (GB)

(74) Representative: **Chapman, Paul Nicholas**
Atkinson & Company
Intellectual Property Limited
7 Moorgate Road
Rotherham
South Yorkshire S60 2EN (GB)

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- **PATENT ABSTRACTS OF JAPAN vol. 2000, no. 02, 29 February 2000 (2000-02-29) & JP 11 327772 A (RICOH CO LTD), 30 November 1999 (1999-11-30) & US 6 392 167 B1 (NAKAGAWA YOSHIKATSU) 21 May 2002 (2002-05-21)**

EP 1 481 359 B9

Description

Field of the Invention

[0001] The present invention relates to a touch pad for navigating a graphical user interface. In particular, the present invention relates to an acoustic touch pad, and a method for processing acoustic signals resulting from touch events in order to identify the location of a touch event.

Introduction to the Invention

[0002] The mouse, keyboard and monitor combination of the desktop computer has provided computer operators with the ability to perform complex data manipulations without needing to be aware of underlying operations. While this interface is not perfect, the success of the personal computer is largely due to this particular method of operating a computer.

[0003] It is inconvenient to operate a laptop computer with a mouse, and so a touch pad is used. While most laptop users find this comfortable, it clearly imposes restrictions upon ease of use, as otherwise a percentage of desktop users would adopt such a device in preference to the mouse. The small area of laptop touch pads imposes restrictions upon the ease with which a detailed graphical user interface can be navigated. Compared to a mouse, such small area touch pads are ineffective because the relationship between finger movement and cursor is unnatural; laptop touch pads must apply considerable cursor acceleration in order to make useful navigation possible.

[0004] The size of the laptop touch pad is partly restricted by cost. However, a more fundamental restriction is that accidental touch points from fingers or other areas of the hand prevent a larger touch pad from operating. A larger touch pad would solve the problem of cursor movement, but known low cost touch pad technologies would be unable to operate if other fingers or parts of a hand were allowed to rest anywhere on the surface. The multiplexed resistive and capacitive methods employed in most laptop computers cannot provide a solution to these problems.

[0005] A large area touch pad that is tolerant of multiple point contact is disclosed in International Patent Application WO 9938149 A1. Products using this technology are produced by Fingerworks Inc., whose website is at <http://www.fingerworks.com>. Fingerworks provides a touch pad that has a large number of individually amplified proximity sensors to construct a proximity profile of a hand and fingers. Tracking software identifies gestures for cursor movement and click events. These touch pads are very expensive, due to the complexity of the sensor circuit.

[0006] Acoustic touch sensors are known that detect the location of a tap event on a surface. A finger tap location device is disclosed in European Patent Application

EP 0474232 A2, and a stylus tap location device is disclosed in German Patent Application DE 3027923 A1. Both these disclosures use the same underlying principle. A tap on a surface generates an acoustic wavefront that moves radially away from the point of impact. An array of transducers embedded in the surface, or at its edges, receives the wavefront at different times. A pair of transducers provides a time delay of arrival (TDA), which defines a hyperbolic curve upon which the event must have occurred. A second pair of transducers provides a second time delay of arrival, thereby enabling the event to be located in two dimensions. At least three transducers are required to locate a tap event in two dimensions.

[0007] Movement of a cursor requires there to be a continuous acoustic interaction across a touch-receptive surface, enabling a continuous update of cursor location on the screen to be performed. Wavefront detection techniques cannot be used to detect continuous movement of a fingertip across a surface. Signal processing methods are known for obtaining time delay of arrival from a continuous signal. United States Patent Application US 5465302 discloses a method for locating continuous acoustic signals. In the method, a linear relationship between spectrum phase and time delay of arrival is identified, thus enabling two pairs of microphones to be used to identify the location of a person speaking in a room. However, this acoustic environment is relatively ideal, and the amount of echo and reverberation in such environments is not high enough to degrade the accuracy of speaker location. However, the sound received at a transducer in a touch pad is predominantly the result of many acoustic paths due to edge reflections and other effects. This complexity destroys the linear relationship between spectrum phase and sound source location that could otherwise be exploited to locate the source of a continuous sound.

[0008] A stylus-operated acoustic detection system is disclosed in German Patent Application DE 4143364 A1. In this system, a stylus is moved across a rippled surface. A natural resonance of the stylus combines with the waveform generated by movement across the ripples to produce sidebands. Acoustic signals containing the sidebands are received by transducers in the edges of the surface, and processed to provide velocity information for the stylus. The amplitude of the acoustic signals provides a rough estimate of location, which, in combination with the velocity and knowledge of the alignment of the ripples, can be used to facilitate continuous tracking of the stylus. The use of ripples in the surface requires that a stylus be used, so this technique cannot be used for tracking a moving fingertip.

[0009] In International Patent Application WO 01/43063 A1 by the present applicant, a method and apparatus are disclosed in which the friction resulting from the movement of a finger across a surface generates a continuous acoustic signal. This continuous friction noise is acquired by transducers embedded in a surface, and

processed to identify the fingertip location. Spectral amplitudes are examined to identify the proximity of the touch event to a transducer. A plurality of such proximity readings is generated for respective transducers, and the location of the moving finger tip is thereby resolved in two dimensions. However, spectral amplitudes are dependent upon several characteristics, of which location is only one, thereby restricting the accuracy of cursor navigation.

[0010] An acoustic touch position sensor is disclosed in US 5,591,945. A transducer of the disclosed position sensor imparts a wave to a surface which propagates along a first axis. A reflective array reflects the wave as a set of waves travelling along a different axis. The waves are partially absorbed, attenuated or perturbed by an object touching the substrate thereby creating a modified waveform having characteristics indicative of the axial displacement of the object. A reflective array redirects the modified waves to a receiving transducer to detect wave perturbation.

Summary of the invention

[0011] It is an aim of the present invention to provide an improved apparatus for controlling cursor movement in response to acoustic signals generated by a finger movement.

[0012] The object of the invention is achieved by the apparatus according to claim 1, the method of claim 12 and the medium of claim 20.

Brief Description of the Drawings

[0013] The invention will now be described by way of example only with reference to the accompanying drawings, in which:

Figure 1 shows a computer system, including a touch pad, a computer, a monitor, a CDROM containing a touch pad driver and a network over which a touch pad driver may be transmitted;

Figure 2 details physical construction of the touch pad shown in *Figure 1*;

Figure 3 shows a cross-sectional view of the touch pad shown in *Figure 1*;

Figure 4 details key components of the computer shown in *Figure 1*, including a main memory;

Figure 5 details steps performed by an operator of the computer shown in *Figure 1* in order to perform installation of the touch pad driver from CDROM or the Internet shown in *Figure 1*;

Figure 6 details contents of the main memory shown in *Figure 4* after the installation performed in *Figure 5*, including a touch pad driver including profiles and an index;

Figure 7 shows the invention, including operations of extracting phase difference information, looking up candidate locations in an index and identifying

highest scoring candidates, and calibration data including an index and phase difference profiles; *Figure 8* shows the circuit details for the touch pad shown in *Figure 1*;

Figures 9 and *10* illustrate acoustic transmission paths on the touch pad shown in *Figure 1*;

Figure 11 details the operation of extracting phase difference information shown in *Figure 7*;

Figure 12 details the phase difference profiles shown in *Figure 8*;

Figure 13 details the index shown in *Figure 6*;

Figure 14 details the operation of looking up candidate locations in an index shown in *Figure 7*, including a step of testing features;

Figure 15 details the step of testing features shown in *Figure 14*;

Figure 16 illustrates the result of looking up candidate locations in an index shown in *Figure 7*;

Figure 17 illustrates the result of identifying highest scoring candidates shown in *Figure 7*;

Figure 18 details steps performed when performing the operation of identifying highest scoring candidates shown in *Figure 7*, including steps of obtaining similarity scores;

Figure 19 details the steps of obtaining similarity scores shown in *Figure 18*;

Figures 20 and *21* illustrate alternate embodiments of the invention;

Figure 22 summarises operations for creating the calibration data shown in *Figure 7*, including a step of recording location profiles and a step of creating a location index;

Figure 23 details hardware used when calibrating the touch pad shown in *Figure 1*;

Figure 24 details the step of recording location profiles shown in *Figure 22*; and

Figure 25 details the step of creating a location index shown in *Figure 22*.

Detailed Description of The Preferred Embodiment

[0014] A personal computer system is shown in *Figure 1*. A touch pad 101 supplies signals to a computer 102 via a connecting cable 103. Signals from the touch pad 101 are generated in response to touch events 104 made on the surface 105 of the touch pad 101. Touch events include continuous movement of a fingertip 106 across the surface of the touch pad 101 and the tapping of a finger on the surface of the touch pad. The computer 102 supplies image signals to a monitor 107, thereby enabling the monitor 107 to display a graphical user interface 108 including a cursor 109 and icons 110. Instructions provided on a CDROM 111 or via the Internet 112 enable the computer to interpret signals from the touch pad thereby enabling a user to navigate the graphical user interface 108 displayed on the monitor 107. A keyboard 113 supplies additional alphanumeric input to the computer 102.

[0015] The touch pad **101** receives two types of touch event. A first type of touch event is the sliding movement of a fingertip across the surface **105** of the touch pad **101**. Such movement is interpreted by the computer **102** to result in movement of the cursor **109** in the graphical user interface **108** displayed on the monitor **107**. A second type of touch event is a tap of the fingertip **105** against the surface **105**. When the cursor **109** is located over an icon **110**, a single tap is interpreted by the computer as a request to activate a process associated with that icon. Other types of tap interpretation are possible, such as double tap, as well as taps made in particular areas of the touch pad surface **105**. In this way, a range of pointer-device activity required for navigating a graphical user interface is provided.

[0016] The touch pad **101** has an advantage over a mouse pointing device in that the mass of a mouse is absent, and muscular effort is required only for the movement of the finger **106**. This results in a reduction in operator stress during prolonged computer use. A natural relationship exists between cursor and finger movement, because of the area of the touch pad is relatively large, at 230mm wide by 180mm deep, making the touch pad **101** shown in *Figure 1* considerably easier to use than the type of touch pad commonly found in a laptop computer.

[0017] The touch pad **101** shown in *Figure 1* is detailed in *Figure 2*. The touch pad **101** contains four transducers **201**, **202**, **203** and **204**. A touch event made on the surface of the touch pad **101** results in an acoustic interaction. Interaction between a finger **106** and the surface is acoustic in nature. Two different types of touch event may occur. In the first type of touch event, continuous movement of a fingertip across the surface of the touch pad **101** generates continuous noise. For clarification, the term "noise" is intended in this context to mean a broad spectrum of random sound. Similar sound is known as "white noise". Noise is generated as a result of friction between the surface and the moving finger, and shall hereinafter be referred to as "friction noise". A second type of touch event is short duration of sound resulting from a tap of a finger, or possibly another object, against the surface at a particular fixed location.

[0018] Both types of touch event, friction noise and tap, result in sound being transmitted through the surface **105** from the location of the touch event. The surface **105** is herein considered as comprising all those parts of the touch pad **101** that are significant in the transmission of sound waves resulting from touch events. The four transducers **201** to **204** pick up acoustic signals in different parts of the surface and convert these into electrical form. The electrical signals generated by the transducers are translated from sound waves into corresponding varying electrical potentials. Representations of these acoustic signals are supplied to the computer **102** via a connecting cable **103**.

[0019] A cross sectional view of the touch pad **101** is shown in *Figure 3*, including a transducer **201**. The sur-

face **105** is rigid and acoustically conductive, and made out of high density polyethylene. The top of the surface **105** is unpolished, so that movement of a fingertip **106** across the surface **105** generates friction noise. Materials such as polyethylene, nylon and fibreglass have a natural roughness, even in an apparently smooth surface, that facilitates generation of friction noise. In alternative embodiments, the surface can be made from a different high density material, including polymers such as nylon, and composite laminate materials such as fibreglass and Formica. Furthermore, the requirements for friction noise generation and acoustic transmission characteristics may conflict, in which case some embodiments may provide a top surface layer for the creation of friction noise, and a lower surface layer for acoustic conduction.

[0020] The transducer **201** is a piezo-electric transducer of the type commonly used for producing sound in digital watches. This type of transducer is extremely low cost and can be used as a contact microphone. The piezo transducers **201** to **204** are bonded to the underside of the surface **105** by a thin layer of hard adhesive. Sound pressure waves moving through the surface **105** pass through a transducer **201**, producing a varying electrical potential in proportion to the distortion of the piezo-ceramic material in the transducer. Piezo-electric transducers have polarity. An upwards distortion of the transducer shown in cross section in *Figure 3* results in a positive electrical potential being developed across the transducer terminals. A downwards distortion of the transducer would then result in a negative potential being developed. The direction of polarisation of the piezo-ceramic material depends upon the direction of a polarising voltage that is applied during the process of transducer manufacture.

[0021] The base of the touch pad **101** is light foam rubber **301**, that supports the touch pad surface **105** away from any acoustic interference, as well as providing a protective covering to the transducers **201** to **204** and their electrical connections.

[0022] The computer **102** shown in *Figure 1* is detailed in *Figure 4*. A Pentium central processing unit (CPU) **401** executes instructions held in one hundred and twenty-eight megabytes of main memory (RAM) **402**. The main memory **402** also stores data which the processor may manipulate according to its instructions. Both data and instructions are stored on a hard disk drive **403**. The hard disk drive **403** retains its contents when the computer **102** is switched off, so contents of the main memory **402** are refreshed from the hard disk drive **403** when the computer is switched on. Instructions and or data may be installed onto the hard disk drive **403** from a variety of sources. A CDROM drive **404** reads CDROM, CDR or CDRW disks, including the CDROM **111**.

[0023] A video card **405** receives instructions and data from the processor **401** to render images on the monitor **107**, thereby providing the user with a graphical user interface **108** that can be navigated by touch events formed on the touch pad **101**. The cursor **109** is the primary signifier of navigation in such an interface. However, it is

also known to navigate three and higher dimension environments using two or less dimensions provided by a pointing device. The touch pad **101** can be used for this type of navigation also, which includes the navigation of three-dimensional computer-generated environments.

[0024] A sound card **406** receives signals from the touch pad **101**. The sound card **406** has a stereo analogue to digital converter **407**, and the transducers **201** to **204** are connected to the stereo microphone input of the sound card **406**. The analogue to digital converter **407** in the soundcard **406** is configured to operate at a sample rate of 44.1 kHz with sixteen bits of precision for each of the left and right stereo channels. The sound card **406** digitises incoming electrical signals from the touch pad **101**, and makes these digitised acoustic signals available to the processor **401**. During operation, the stream of samples is temporarily stored in main memory, awaiting a burst of processor activity during which touch events are interpreted to update the user interface **108**. This process of acquiring, storing, processing and updating is performed continuously with no apparent delay, so that movement of the user's fingertip **106** across the surface **105** of the touch pad **101** results in a substantially continuous movement of the cursor **109** on the monitor **109**. Other aspects of the user interface **108** may also be updated substantially continuously in response to user fingertip movements.

[0025] A modem **408** provides connectivity to the Internet **112**. The keyboard **113** is connected to a Universal Serial Bus (USB) port **409**. The components **401** to **409** of the computer **102** are standard components of an ordinary personal computer.

[0026] Instructions for interpreting touch pad signals also require data representing calibrated touch pad characteristics. This combination of instructions and data for interpreting touch pad signals forms a touch pad driver. The touch pad driver may be stored in volatile memory **402**, nonvolatile memory **403**, **111** or transmitted over a network **112**. Touch pad operation requires that the touch pad driver is installed on the computer **112**. A flowchart summarising user operations to install and operate the driver for the touch pad **101** are shown in *Figure 5*. At step **501** the user switches on the computer. At step **502**, a question is asked as to whether a touch pad driver is already installed. If so, control is directed to step **506**, where the user may start to navigate the graphical user interface **108** immediately. Alternatively, control is directed to step **503**, where a question is asked as to whether the touch pad driver is to be loaded from a site on the Internet **112**. If not, control is directed to step **505**.

[0027] The touch pad driver is downloaded via the Internet **112** at step **504**. In this process, instructions and data for interpreting touch pad signals are transmitted from a remote site on the Internet **112**, via the modem **408** to the main memory **402** and the hard disk drive **403** of the computer **102**. The instructions and data are transmitted in an electrical medium as an encoded stream of varying electrical potentials. During transmission over

the Internet, the instructions and data may also be encoded as serial or parallel signals and transmitted through optical fibre or an electromagnetic radio or microwave medium. The modem **408** constructs parallel signals of eight bits from the received serial stream, and these are supplied to the processor **401**, which performs additional decoding steps, including data decompression, so as to reconstruct the driver instructions and data. The touch pad driver may exist in several computer-readable forms: as intermediate serial data encoded upon a computer-readable medium such as the Internet or other network; as intermediate parallel compressed data stored temporarily in the main memory **402** or hard disk **403** of a computer **102**, or as a decoded executable set of instructions with associated data that is ready for installation or execution upon a computer with which a touch pad **101** is intended for use. It is further possible that a touch pad driver may be presented to a computer in a format that is only useful with an additional enabling sequence of codes that may be entered on the keyboard **113** or some other means of data entry.

[0028] As an alternative to installation via the Internet **112**, the touch pad driver instructions and data are encoded upon the medium of the CDROM **111** as patterns of optical pits in an aluminium layer. At step **505** the user places the CDROM disk **111** into the CDROM drive **404** and the touch pad driver is located automatically. The CDROM drive **404** reads the pattern of pits on the CDROM **111**, generating a serial stream of varying electrical potentials. Installation from the CDROM **111** results in conversion from the physical computer readable medium of the CDROM disk **111** into a serial stream of electrical pulses that are reconstructed as data, and stored in main memory **402**. Instructions executing on the processor **401** perform data decompression in order to reconstruct the driver in a form that is installable on the computer **102**.

[0029] At step **506** the touch pad driver is installed. The user initiates the installation process, resulting in installation instructions present on the computer's hard disk drive **403** being executed to install touch pad driver instructions and data. Once installed, the touch pad driver instructions are executed, and the touch pad driver thereafter exists as one of many processes that run automatically when the computer is switched on. At step **507** the user navigates the graphical user interface **108** using the touch pad **101**. The touch pad driver is an enabling set of instructions and or data that, when installed upon an ordinary personal computer **102**, enable that computer to perform steps for interpreting signals from the touch pad **101**.

[0030] Operation of the computer to install the touch pad driver requires navigation of a computer interface. Since the touch pad **101** is not operative prior to installation of its associated driver instructions and data, navigation for the installation process may be performed using the keyboard **113**.

[0031] Once the computer **102** has been switched on

and the touch pad driver has been installed, the main memory **402** may be summarised as comprising the components shown in *Figure 6*. An operating system **601** includes instructions and data structures for enabling applications, such as a web browser, word processor, email client and so on, to execute on the computer and to interact with hardware components **402** to **407** of the computer without concern for their specific characteristics. For example, a pointing device such as a mouse may be replaced with a graphics tablet or touch pad. The operating system presents pointing device information to applications in a universal pointing device format, so that application developers know in advance that their program will work with many different kinds of pointing device. The touch pad driver enables the operating system to provide this kind of device abstraction, thus enabling the operating system to present the touch pad as a generalised "input control device" that may be used equally by all programs requiring graphical navigation of some kind.

[0032] The operating system **601** includes an application installer **702**, which was used to perform the installation process initiated by the user at step **506** in *Figure 5*. As a result of installation, touch pad instructions and data are stored on the hard disk drive **403** and also in main memory **402** as shown at **603**. The touch tablet driver **603** includes instructions **604** and calibration data **605**. The calibration data **605** includes an index **606** and location profiles **607**. Other device drivers also reside in main memory, as shown at **608**. Applications are shown at **609** and **610**.

[0033] The invention is shown in *Figure 7*. The touch pad **101** has a surface **105** upon which touch events are formed. Touch events cause an acoustic interaction between the surface **105** of the touch pad **101** and an object, such as the user's finger **106**. Acoustic signals are generated as a result of an acoustic interaction of this kind, and these signals are acquired at transducer locations **201**, **202**, **203** and **204**. The transducer locations are asymmetric. Acoustic signals from transducer locations **201** and **203** are combined electrically to form one of the two stereo channels supplied to the analogue to digital converter **407** in the sound card **406** of the computer **102**. The other channel of the analogue to digital converter **407** is supplied by the electrical combination of signals from transducers **202** and **204**. Connections **103** from the electrically combined transducers supply representations of the combined acoustic signals to the analogue to digital converter **407**.

[0034] The combination of signals from multiple transducers **201**, **203** and **202**, **204** spread across the touch pad surface ensures that low level friction noise signals will be acquired at sufficient levels wherever they occur on the surface **105**. The combination of transducer signals improves the accuracy of touch event location by increasing the signal strength. However, due to the asymmetry of the combined transducer locations, acoustic signal characteristics have higher complexity than acoustic

signals acquired from individual locations on the surface. This substantially increases the ability of the touch pad driver to identify the location of a touch event.

[0035] Signals from transducers **201** and **203** are combined in antiphase, indicated by the plus (+) and minus (-) signs shown on the transducers in *Figure 7*. Combination in antiphase has the effect of reducing the amplitude of low frequency components that are present at locations **201** and **203**. The antiphase combination combines preferred high frequency components of the acoustic signals, while rejecting unwanted low frequency components. The same arrangement is provided for the wiring of transducers **202** and **204**, so that both channels contain combinations of preferred components of the acoustic signals, while significantly excluding unwanted low frequencies. Removal of unwanted acoustic signal components enables the touch pad driver **603** to reliably detect, classify and locate different types of touch event.

[0036] Acoustic signals resulting from friction noise are low in amplitude, and the component frequencies of friction noise have a relatively equal amplitude across the spectrum. However, tap events generate acoustic signals of extremely high amplitude. The high amplitudes are concentrated mostly in the low frequency part of the spectrum. By reducing the amplitude of low frequencies, it is possible to avoid overloading the analogue to digital converter **407** during tap events. The low frequencies of high amplitude contribute minimal location information to the touch pad driver **603**, and so they may be excluded without affecting the accuracy of touch event location. Use of an antiphase connection between transducers avoids the need for expensive conditioning circuitry that would otherwise be required in order to ensure that the analogue to digital converter **407** does not get overloaded by a tap event. Such overload would prevent a tap event from being correctly interpreted by the touch pad driver.

[0037] The touch pad driver instructions **604**, when executed on the processor **401**, result in operations **701** to **705**. These operations process digitised acoustic signals supplied from the analogue to digital converter **407**, and analyse them to identify the location of a touch event on the surface of the touch pad **101**. Identification of the location of a tap event is known in the art, as shown in EP 0 474 232 A2 and DE 30 27 923 A1. However, the methods and apparatus disclosed in this prior art do not facilitate the continuous tracking of a moving fingertip, and are not directed towards this aim. A method for continuous acoustic tracking of a fingertip is disclosed in WO 01/43063 A1 by the present applicant. However, this does not disclose a touch pad apparatus or method capable of locating a touch event to a high-enough level of accuracy required for navigating a graphical user interface. Furthermore, in all of the prior art, at least three channels of analogue to digital conversion are required to resolve an acoustic event location in the two dimensions of a surface, making such apparatus considerably more expensive than the present invention. The use of only two channels of analogue to digital conversion

makes it possible to connected the touch pad **101** directly to an ordinary computer, taking advantage of the standard provision of a low cost sound card having a stereo microphone input. The computer **102** is enabled for operation with the touch pad **101** by the installation of the touch pad driver **603**.

[0038] The operations of the touch pad instructions **604** are shown in *Figure 7*. The analogue to digital converter **407** generates two streams of samples, which may be considered as left and right channels, since they are ordinarily used to convey this information. In the operation **701** for extracting phase difference information, each of these channels is considered in groups of **512** samples, and the samples are processed by a windowing function, a Hanning window, in preparation for a fast fourier transform (FFT). The fast fourier transform analyses the audio samples into **256** frequencies, each defined by a complex number which defines information about the phase angle of each frequency component. Left and right fourier transformations are performed, resulting in a left-right pair of phase angles for each of **256** frequency components. Looked at in isolation, the **256** left channel phase angles are entirely random. This is also true of the right channel phase angles. However, when each of the **256** left angles is subtracted from its respective right channel phase angle, the result is a graph of phase difference information **706**, which is related to the location of the touch event. This location-related information is used to identify the location of a touch event. Each location on the surface **105** has its own unique phase difference characteristic. This uniqueness is the result of the asymmetry of the transducer locations, and the fact that signals from different asymmetric locations are combined, thereby increasing complexity and ensuring that each possible surface location is well differentiated in terms of its respective phase difference characteristic.

[0039] The calibration data **605** for the touch pad **101** includes a large number of phase difference profiles **607**, or location-related profiles **607**. These accurately store phase difference characteristics calibrated at known locations on the surface of the touch pad **101**. Each phase difference profile **707** has an associated location **708**, which defines both x and y co-ordinates on the touch pad surface **105**. The location of a touch event is defined in two dimensions by reference to phase difference profiles of known two-dimensional location. However, the number of such profile locations is very high, being in the order of several thousand. Comparing the phase difference information **706** with each such stored profile would require an excessive amount of processing to be performed.

[0040] The location of a touch event is identified by comparing phase difference information **706** with phase difference profiles **607** of known location. Because of the large number of profiles **607**, an index is used to identify candidate locations before comparisons between the phase difference information **706** and profiles **607** are performed.

[0041] Having extracted the phase difference information **706** from the digitised acoustic signals, the next operation **702** performed by the touch pad driver is to look up candidate locations in the index **606**. The indexing operation generates candidate locations, which are a subset of locations from the entire set of locations for which profiles are stored. From this short list of candidates, the next operation **703** identifies highest scoring candidate locations. This includes searching around previously identified candidate locations. In operation **703**, similarity scores are generated for each possible candidate location, resulting in identification of a small number of high scoring profiles whose location is known.

[0042] The location of a touch event is calculated in operation **704**. The similarity scores are used to determine an interpolation between respective profile locations, so as to identify the central location of a touch event, which is rarely coincident with the location of a calibrated profile.

[0043] Having identified the location of the touch event, the graphical user interface **108** is updated in operation **705**.

[0044] When the touch event is the continuous movement of a finger across the surface **105**, updating the interface is performed in the following way: The difference moved by the finger since the last measurement of its location is noted. The distance is scaled appropriately, and a corresponding pixel movement is added to the current position of the cursor **109**. A command is then issued to the operating system to refresh the graphical user interface **108**. This causes a differential movement of the cursor. The cursor is moved according to the difference between the previous fingertip position and the current fingertip position. Absolute cursor movement is also possible, where the dimensions of the touch pad **101** are mapped onto the dimensions of the screen, and the location of the cursor on the screen is in fixed relation to the location of the fingertip on the touch pad. However, this is not generally useful for cursor navigation.

[0045] When the touch event is a tap, it is interpreted as a left mouse button click event. This is convenient for most kinds of interface navigation, resulting in a point-and-tap paradigm that is inherently appealing. However, the mouse and other pointing devices have several buttons, at least some of which have important functions that must be provided by the touch pad **101**. The right button click is achieved by tapping to the right of where the user last moved their fingertip. Other tap events can be provided with a similar level of control of the familiar range of mouse operations. Tap event location is necessary information for generating such context-sensitive tap events. Tap event locations are identified in the same way as finger movement events, as described for operations **701** to **704**. A tap event is distinguished from a movement event by its duration and intensity, both of which are identified from an examination of the digitised acoustic signals supplied from the analogue to digital converter **407**.

[0046] In summary, acoustic signals arising from touch events are acquired by the touch pad **101**. Touch events are signified by an acoustic interaction between the touch pad **101** and an object **106**. The touch pad **101** has an area **105** in which such touch events may be formed. Transducers acquire the acoustic signals at a plurality of different locations **201**, **202**, **203** and **204** in the surface **105**. A connecting cable **103** supplies output signals that are representations of the said acoustic signals to an analogue to digital converter **407**. A plurality of transducers **201**, **203** is configured so as to electrically combine acoustic signals from a plurality of said different locations **201**, **203** into a combined signal for said connecting cable **103**. A second plurality of transducers **202**, **204** is similarly configured. Combined transducers are connected in antiphase **201**, **203** so as to electrically combine preferred components of the acquired acoustic signals, thereby avoiding potential analogue to digital converter overload during a tap event.

[0047] Having acquired acoustic signals from the touch pad surface **105**, representations of the said acoustic signals are digitised **407**, forming digitised acoustic signals. Phase difference information **706** is extracted from the acoustic signals by processing the digitised acoustic signals. The location of the touch event is identified on the basis of comparisons **703** between the phase difference information **706** and phase difference profiles **707** whose respective locations **708** are known. A subset of all possible locations for which profiles are stored is identified by processing the phase difference information **706** with an index **606** to identify candidate locations **702** whose respective profiles are then processed with the phase difference information **706** to identify the location of an acoustic interaction resulting from a touch event. In an alternative embodiment, the relationships between location-related profiles and their respective locations are stored, without explicit storage of the profiles and or the locations themselves. Interpolation **704** is used to refine the touch event location to a precision greater than that provided by the grid of profiles for which locations are known.

[0048] The touch pad driver **603** enables an ordinary personal computer to operate with the touch pad **101**. The touch pad driver includes instructions **604** and calibration data **605**. The instructions may be provided on a physical computer readable medium, or on a transient electrical or optical computer-readable medium such as a high speed network or the internet **112**. Instructions embodied in any such form therefore provide an ordinary computer with the enabling means to interpret signals from an acoustic touch pad, and to perform pointer actions including cursor movement. The data structures required for such usage, namely the location-related profiles **607** and an index **606** and or relationships between location-related profiles **707** and respective touch pad locations **708**, are also required for operation of the touch pad **101**, and these data structures may be encoded on a computer-readable medium such as a CDROM **111** or

transmitted over a network **112** either with or without the touch pad driver instructions **604**. It is advantageous for the user of the touch pad **101** to have the data **605** and the instructions **604** presented together on the same medium **111** or **112**. In an alternate embodiment, the touch pad driver **603**, or parts of it, are stored on a read only memory, and are accessed directly by a processor without intermediate storage in random access memory. That processor may be a digital signal processor configured supply signals to a computer system, that performs ordinary computer application and operating system processing.

[0049] The circuit diagram for the touch pad **101** is shown in *Figure 8*. Each piezo-electric transducer **201** to **204** comprises a brass disc **801** upon which a piezo-ceramic layer is deposited. A conductive metallic surface is deposited on the exposed piezo-ceramic material, and wires are soldered to the two conductive outer layers of the device. When the transducer is manufactured, a high voltage is applied to establish alignment of the crystalline structure in the piezo-ceramic material. The polarity of this voltage determines whether a concave or convex flexing of the transducer disk shall result in a positive or negative voltage being developed across its terminals. Concave flexing will be considered as an expansion of the brass plate side of the device. For convenience in the circuit description, the brass plate side will be considered as the negative terminal of the device.

[0050] In the circuit diagram, transducer pairs **201**, **203** and **202**, **204** are connected in series with their polarities reversed. This achieves an antiphase combination of their respective acoustic signals. The transducers could also be connected in parallel, but the series connection is preferred in order to supply a higher voltage signal to the analogue to digital converter **407**. The antiphase arrangement reduces the amplitudes of low frequency components of the acoustic signals, because these components are in phase at most points on the touch pad surface **105**. Further reduction of low frequencies is achieved by a single pole high pass filter formed by a resistor **803** in parallel with the transducers **201** and **203**. The transducers have an intrinsic capacitance, which, in conjunction with the resistor, forms a high pass filter. A second resistor **804** is connected across transducers **202** and **204** to achieve the same high pass filtering effect. The high pass filters perform signal conditioning so as to emphasise preferred components of the acoustic signals. In an alternate embodiment a different signal conditioning circuit may be used, such as a passive inductive filter, an active filter or a compressor or limiting circuit. In the preferred embodiment, however, signal conditioning is achieved by the combination of the antiphase connection between transducers and the high pass filter implemented by the addition of a resistor across transducer outputs as shown in *Figure 8*. The signals from the transducers are supplied to the output cable **103**, which is terminated in a 3.5mm stereo jack plug **805**. The jack plug **805** connects directly to the stereo microphone input

of the sound card **406**.

[0051] Characteristics, of the acoustic signals are explained with reference to *Figure 9* and *Figure 10*. In *Figure 9*, a touch event **901** generates sound waves that spread out through the surface **105** of the touch pad **101**. A few of these waves reach the transducer at location **201**. A direct path **902** provides the loudest signal. Other paths **903** and **904** are indirect, and reflect once or several times from the edges of the touch pad **101**. However, the indirect paths are numerous, and so their combined energy is greater than that of the single direct path **902**. The acoustic signals transformed into electrical signals by the transducer at location **201** are therefore different from the sound at location of the touch event **901** itself. *Figure 10* shows a touch event at a slightly different location. Here the paths **1002**, **1003**, **1004** are of different length and have different amplitudes. The paths are generally longer, but their ratios are slightly different from those shown in *Figure 9*. As a result, the transformation of the acoustic signal between its source, at **1001**, and its destination is different from the transformation that occurs in *Figure 9*. The transformation of the acoustic signal is location-dependent.

[0052] It is impossible to know the precise sound that occurs at the location of the touch event **901**. Therefore, knowledge of the acoustic signals at transducer **201** cannot provide sufficient information to identify the location of a touch event **901**. A different set of transformations is inherent in the acoustic signals generated by transducer **202**. A comparison of the two transformed sets of acoustic signals does provide information related to the location of a touch event. In order to ensure that these relationships are unique to each possible location on the surface **105**, the transducers are located asymmetrically. Furthermore, in order to increase the complexity of relationships, pairs of transducer outputs are combined. Transducers **201** and **203** are connected so as to electrically combine acoustic signals. Signals from transducers **202** and **204** are also combined in this way. The relationships between the combined transducer outputs provide an ideal level of complexity for identifying the touch event location. Having several transducers spread out over the surface has the added beneficial effect of ensuring that weak friction noise signals can be picked up well at all locations in the surface. Combined transducers **201**, **203** are located diagonally from each other so as to ensure that any touch event location is as close as possible to transducers of both channels. Furthermore, by connecting the transducers in antiphase, preferred components of the acoustic signals are combined, while unwanted low frequency components are cancelled out or attenuated.

[0053] Signals relating to touch event location are illustrated in *Figure 11*. Acoustic signals at the transducers **201**, **202**, **203** and **204** are transformed into electrical analogue signals whose variation over time is illustrated by the graphs shown in *Figure 11*. The signals from transducers **201** and **203** are combined electrically and sup-

plied to the analogue to digital converter **407**, resulting in left digitised acoustic signals **1101**. Signals from transducers **202** and **204** are similarly digitised, resulting in right digitised acoustic signals **1102**. Each of the left and right digitised acoustic signals is independently transformed, in operation **701**, by a fast fourier transform (FFT). This generates independent phase angle information for left and right channels. The phase angle information comprises **256** frequencies each of which has a phase angle defined by a complex number having a real and an imaginary component.

[0054] For the purposes of the preferred embodiment, frequency amplitude information is discarded. However, in an alternative embodiment, phase difference information is represented by complex numbers that include amplitude information that is not discarded, and is used as an additional characteristic for locating a touch event or for other purposes.

[0055] The phase angle information of an individual channel is random, and conveys no useful information. Random phase angle graphs are shown at **1103**, for the left channel, and **1104** for the right. Phase differences between respective phase angles are calculated by multiplying a complex number from one channel by the complex conjugate of the respective complex number from the other channel. The resulting complex number is converted into a phase angle. The resulting phase difference information **706** is unique to the touch event location on the surface **105**. The graph of phase difference information generated from the transducer signals is noisy, but is sufficiently clear to enable it to be used in matching with profiles **707** whose locations **708** are known. In this way it is possible to identify the location of a touch event.

[0056] Phase difference profiles **607** shown in *Figure 6* are detailed in *Figure 12*. Each profile **1201**, **1202**, **1203** has an associated location. Neighbouring locations **1201**, **1202** have similar profiles. The profile locations are spaced 4mm apart from each other, in both dimensions of the touch pad surface **105**.

[0057] The index **606** shown in *Figure 6* is detailed in *Figure 13*. The index comprises a number of index tests **1301**, **1302** and **1303**. There is a total of sixty-four index tests. Each index test **1301** comprises two parts: a set of features **1304** and a set of location group scores **1305**.

[0058] There are four features **1304** in each index test. Each feature **1306** has a frequency value **1307** and a phase angle value **1308**. There are **256** frequencies in the phase difference information. The feature frequency **1307** specifies one of the **256** frequencies. The phase angle **1308** specifies the preferred value of the phase at that frequency. The phase values range from **-128** to **+127**, which correspond to phase angles in the range $-\pi$ to $+\pi$. An eight-bit integer representation is used for speed of processing. In combination, the four features specify preferred phase angle values at specified frequencies. A proportion of phase difference profiles **607** will match the feature set well. Coincidence between matching phase difference profiles **607** and phase differ-

ence information **706** that also matches the feature set, indicates a high probability that the phase difference profile closely matches the phase difference information. Applying all sixty-four index tests in this way results in set of probability scores for profile locations, enabling candidate locations to be identified.

[0059] The location group scores **1305** for index test **1 1301** are also detailed in *Figure 13*. Calibrated locations are grouped together in groups of four. Features **1304** for the test are then compared with each of the four grouped locations and the average similarity score is stored in association with that group. There is a total of **610** location groups, resulting from a total of **2440** calibrated location profiles. Each group has its own index number **1309**, from which the grouped locations may easily be identified by multiplying by four and adding 0, 1, 2 or 3. The associated score is expressed as a floating point value in the range -1 to +1. A score of zero indicates that the location group, on average, has no correlation with the features of the test. A negative score indicates a negative correlation, and a positive score **1310** indicates a positive correlation. Correlation is the measure of similarity between patterns.

[0060] The operation **702** of looking up candidate locations in the index **606** shown in *Figure 7* is detailed in *Figure 14*. At step **1401** a set of group score accumulators is set to zero. There are **610** group score accumulators - one for each location group. At step **1402** the first index test **1301** is selected. At step **1403** the features **1304** of the test are applied to the phase difference information in order to identify an information score value **S**. **S** is a measure of the similarity between the phase difference information **706** and the specified features of the test. Up to this point, the location group scores **1305** have not been consulted. At step **1404** the first location group **1309** is selected. At step **1405** the score accumulator for the group is updated by adding the product of the group score **1310** and **S**. If both of these are positive, this indicates a degree of similarity between the profiles of the grouped locations and the phase difference information **706**. If both **S** and the group score are negative, this also indicates a degree of similarity, indicated by the product of these two negative values being positive. If **S** and the group score have different signs, this indicates a non-similarity between the phase difference information **706** and the profiles of the location group. The purpose of the indexing process is to gather information that results in the identification of profiles of known location having a strong similarity to the phase difference information **706**. As the steps of *Figure 14* are repeated, the group score accumulators are updated at step **1405**. At the end of the process, the highest scoring location groups are identified as the candidate locations.

[0061] At step **1406** a question is asked as to whether another location group is to be selected. If all **610** location groups have not been considered, control is directed back to step **1404**. Alternatively, control is directed to step **1407**, where a question is asked as to whether an-

other index test can be selected. If so, control is directed back to step **1402**. Alternatively, if all sixty-four index tests have been processed, control is directed to step **1408**. At step **1408** the location groups are sorted into order according to their accumulated scores. At step **1409** the eight best scoring location groups are identified. At step **1410** the individual thirty-two candidate locations are identified from the indices of the location groups.

[0062] The step **1403** of applying test features to the phase difference information to obtain the information score **S** is detailed in *Figure 15*. At step **1501** a variable **D** is set to zero. At step **1502** the first feature is selected, and a variable **n** is set to indicate the feature number. At step **1503** the array of phase difference information, **PDI**, is indexed at the frequency **1307** specified by the current feature to identify the phase angle at that frequency in the phase difference information. This is indicated by the term **PDI[Freq[n]]**. The phase angle **1308**, **Phase[n]**, specified by the feature, is subtracted from this value, to provide a phase difference. Negative values are converted to positive, giving an absolute difference between the two phase angle values. A small difference indicates the phase difference information **706** matches the feature **1306** well.

[0063] At step **1504** a question is asked as to whether another feature is to be considered. If so, control is directed to step **1502**, and step **1503** is repeated four times, once for each feature. After all features for the test have been processed, control is directed to steps **1505** and **1506**, where the integer score **D** accumulated at step **1503** is re-ranged to provide a similarity score between -1 and +1.

[0064] The result of the operation **702** of looking up candidate locations in the index is illustrated in *Figure 16*. Eight location groups **1601** to **1608** have been identified, and their positions on the surface of the touch pad **101** are shown. These location groups are detailed in *Figure 17*. Each location group contains four candidate locations. The highest scoring candidate locations, identified in operation **703**, are likely to be those in close proximity to the location of the touch event. Similarity between the phase difference information **706** and profiles for the candidate locations is measured by a similarity score, or correlation, that is shown just below each of the candidate locations that are shown in *Figure 17*. The true location of the touch event is shown at **1701**. Calculation of the location of the touch event is done by a cubic spline interpolation in two dimensions, constructed according to the similarity scores. Iterative interpolation is then done to find the peak score to a fine level of resolution, resulting in a fractional offset between calibrated locations, as shown by the location of the touch event **1701**.

[0065] The operation **703** of identifying the highest scoring candidate locations shown in *Figure 7* is detailed in *Figure 18*. At step **1801** the first candidate location is selected. At step **1802** the candidate location's phase difference profile **1201** is correlated with the phase difference information **706** to obtain a correlation score for

the candidate location. This correlation score is in the range -1 to +1. At step **1803** a question is asked as to whether another candidate location needs to be scored. If so, control is directed back to step **1801**. Alternatively, once all thirty-two candidate locations have been scored, control is directed to step **1804**, where the highest scoring candidate locations are identified. This reduces the number of candidate locations to twenty, as illustrated in *Figure 17*. At step **1805** a search is performed around the highest scoring locations to see if any high scoring locations have been missed by the indexing process **702**. At step **1806** similarity scores are obtained for the additional locations identified in step **1805**.

[**0066**] The steps **1802** and **1806** for correlating location profiles **1201**, **1202**, **1203** with phase difference information **706** are performed in the same way, as shown in the flowchart in *Figure 19*. At step **1901** the next location is selected for correlation. At step **1902** a variable D is set to zero. At step **1903** the first frequency in the spectrum is selected. At step **1904** a calculation is made of the phase difference between the phase angles of the location profile and the phase difference location at the selected frequency. This phase difference is added to variable D. At step **1905** a question is asked as to whether another frequency is to be considered. Step **1904** is repeated for all **256** frequencies in the spectrum, resulting in a total accumulated phase difference, D, representative of the difference between the characteristics of the phase difference information **706** and the profile for the selected location. At steps **1906** and **1907** a correlation or similarity score S is calculated by re-ranging of the value D, and stored with respect to the selected location. The values shown at each location in *Figure 17*, are the values calculated at step **1907**. At step **1908** a question is asked as to whether another location is to be correlated. The steps of *Figure 19* are repeated for each location for which a similarity score is required.

[**0067**] The operations shown in *Figure 7* may be considered in the following way: Acoustic signals resulting from an acoustic interaction between an object and a surface are acquired at a plurality of locations **201**, **202**, **203** and **204** in the surface of the touch pad **101**. Phase difference information **706** is extracted from digitised acoustic signals **1101**, **1102**. The acoustic interaction is then located in two dimensions of the touch pad surface by comparing **703** phase difference information **706** with a plurality of phase difference profiles **607** whose respective locations are known. In order to minimise the amount of processing required for comparing profiles **607** with phase difference information **706**, the phase difference information **706** is first processed **702** with an index **606** to identify groups of candidate locations **1601** to **1608**. The acoustic interaction is then located by processing of the phase difference information with phase difference profiles of the individual candidate locations.

[**0068**] The touch pad **101** shown in *Figure 1* is a stand-alone input device used to replace the mouse and achieve advantages of speed of use and reduction in

operator stress. In an alternative embodiment, a touch pad according to the invention is provided in a laptop computer. This is illustrated in *Figure 20*. The laptop computer **2000** has a large area acoustic touch pad **2001**, taking up the entire width of the computer **2000**. While typing on the keyboard **2002**, the operator's wrists may rest upon the touch pad surface without false triggering of cursor movement or tap events. The touch pad driver only tracks localised points of friction noise or taps, and so the large indistinct areas of the wrist, or non-moving fingers, do not affect operation. Movement of the cursor on the screen is considerably eased, due to the large area over which finger movements may be made.

[**0069**] In a further alternative embodiment, illustrated in *Figure 21*, an acoustic touch pad **101** includes a digital radio link to a computer system. Analogue to digital conversion circuitry is included in the base of the touch pad, and the digitised acoustic signals are transmitted over the digital radio link to a computer system. In other embodiments, the two-dimensional surface of the acoustic touch pad is curved in a third dimension. The touch pad may be wrapped into curved shapes of any kind, including a sphere, the entire surface of which can be made touch-sensitive.

[**0070**] The calibration data **605** that is used by the driver instructions **604** includes profiles for each of several thousand locations on the surface **105** of the touch pad **101**. Calibration data is generated by the operations shown in *Figure 22*. At step **2201** location profiles **607** are recorded. At step **2202** a location index **606** is created by processing the recorded location profiles. Apparatus used to perform the profile recording operation **2201** is shown in *Figure 23*. A transducer **2301** supplies random noise, similar to friction noise, to the surface **105** of the touch pad **101** at different locations. The transducer **2301** supplies sound to the surface via a pointed tip **2303**. This simulates the effect of friction noise being generated continuously at a particular location. Each of the **2440** locations to be calibrated are supplied with random noise in this manner. Acoustic signals from the touch pad **101** are processed to generate calibration profiles **607** and an index **606**.

[**0071**] The operation **2201** of recording location profiles shown in *Figure 22* and illustrated in *Figure 23* is detailed in *Figure 24*. At step **2401** the first location is selected. At this time, the random noise transducer **2301** is moved to the first location on the touch pad surface **105**. At step **2402** phase difference information is recorded for several seconds. The phase difference angles, expressed as complex numbers, are accumulated. Once sufficient accumulation has taken place, the accumulated complex numbers are converted into phase angles. This accumulation process has the effect of recording the location profile with high precision, and with low noise. At step **2403** the location profile is stored as part of calibration data **605** for the touch pad **101**. At step **2404** a question is asked as to whether another location is to be calibrated. The steps of *Figure 24* are repeated until all

locations on the surface have been calibrated in this way.

[0072] The operation **2202** of creating a location index, shown in *Figure 22* is detailed in *Figure 25*. At step **2501** the first of sixty-four index tests is selected. At step **2502** a set of random test features is created. This involves selecting a random frequency value **1307** and a random phase angle **1308** for each of the four test features **1304**. At step **2503** location group scores are calculated for the set of features created at step **2502**. The location group scores are calculated by the steps shown in *Figure 15* applied to each of the locations in the group, resulting in four values for score S, which are then averaged to produce a single value for S for each location group. There are **610** location groups, and **610** score values are generated in step **2503**. At step **2504** a question is asked as to whether the location group scores have a wide range of values. The **610** scores generated at step **2503** are analysed to see whether their range is high or not. A wide range of scores indicates that the features generated at step **2502** have a strong ability to differentiate between location profiles, which is a required characteristic. If the range of values is not sufficiently high, control is directed to step **2502** and a different set of test features is created. Alternatively, the index test, including features **1304** and group scores **1305**, is stored at **2505**. At step **2506** a question is asked as to whether all sixty-four index tests have been created. If not, control is directed to step **2501**. Alternatively, all tests have been created, and the index **606** is complete. Steps **2502**, **2593** and **2504** may be considered as having the effect of classifying locations in terms of the similarity of their respective location-related profiles.

Claims

1. Apparatus (102) for processing electrical signals generated by a plurality of transducer means (201, 202, 203, 204) in response to sound generated by an interaction between an object and a surface (105) for generating computer input data, comprising:

an analogue to digital converter (407) for digitising said electrical signals;
processing means (401) configured to process said digitised electrical signals;
instruction storage means (402) storing instructions (604) for said processing means (401); and
calibration storage means (402) storing calibration data (605) for said surface; wherein
said instructions (604) are executed by said processing means (401) to perform the steps of:

- a) acquiring digitised acoustic signals from said analogue to digital converter (407);
- b) extracting phase difference information (706) from frequency components of said digitised acoustic signals;

- c) locating said interaction by comparing said phase difference information (706) with a plurality of phase difference profiles (607) for which surface locations are known; and
- d) generating computer input data in response to said location.

2. Apparatus according to claim 1, wherein said interaction is located by interpolating between the surface locations of phase difference profiles most similar to said extracted phase difference information.
3. Apparatus according to claim 1 or claim 2, wherein said calibration data (605) includes phase difference profiles (607) and an index (606) of phase difference profiles for said surface and said plurality of phase difference profiles compared at step (c) is selected from a larger plurality by processing said phase difference information with said index.
4. Apparatus according to claim 3, wherein said index (606) comprises a plurality of index tests which are processed with said phase difference information (706) to generate test scores.
5. Apparatus according to claim 4, wherein said test scores are processed with test scores for known locations to accumulate index scores for known locations on said surface.
6. Apparatus according to claim 5, wherein said test scores of known locations are associated with groups of known locations.
7. Apparatus according to claim 5 or claim 6, wherein said phase difference profiles compared at step (c) are selected by identifying phase difference profiles having high accumulated index scores.
8. A touch-operable input device (101) for generating input data comprising the apparatus (102) according to any of claims 1 to 7, said device further comprising:

a surface (105) capable of generating a broad spectrum of sound by frictional interaction with a finger moving across it; and
a plurality of asymmetrically located transducer means (201, 202, 203, 204) arranged to generate electrical signals from sound waves conducted via a sound-conductive substrate from touch events made upon said surface,

wherein said electrical signals are supplied to said analogue to digital converter (407) of said apparatus for converting said electrical signals into digitised acoustic signals.
9. A touch operable input device (101) according to

claim 8, comprising:

at least four asymmetrically located transducer means (201, 202, 203, 204) arranged to generate electrical signals from sound waves conducted via a sound-conductive substrate (105) from touch event locations on said surface;

characterised in that:

a first grouping (201, 203) of said transducer means is electrically connected in anti-phase to generate a first channel of said electrical signals; a second grouping (202, 204) of said transducer means is electrically connected in anti-phase to generate a second channel of said electrical signals; and said first and said second channels have connecting means (103) for connecting to said apparatus (102).

10. A touch operable input device (101) according to claim 9, wherein a said transducer grouping is connected in series.

11. A touch operable input device according to any of claims 8 to 10, wherein resistance means (803, 804) is connected in parallel with one or a plurality of said transducer means in order to attenuate low frequency components of said electrical signals.

12. A method of generating input data for a computer (102), in which an interaction between an object (106) and a surface (105) generates sound by friction between said surface and said object, the method comprising the steps of

- converting sound into electrical signals by at least two transducer means (201, 202, 203, 204),
- processing said electrical signals to extract phase difference information (706) from frequency components of said signals.
- identifying the location of said interaction by comparisons between said phase difference information (706) and a plurality of phase difference profiles (607) for which surface locations are known; and
- generating input data for said computer in response to said identified location of interaction.

13. A method according to claim 12, wherein said location of interaction is identified by interpolating between the surface locations of phase difference profiles (607) most similar to said phase difference information (706).

14. A method according to claim 12 or claim 13, wherein

said plurality of phase difference profiles is selected from a larger plurality by processing said phase difference information with an index (606) of phase difference profiles for said surface.

15. A method according to claim 14, wherein said index comprises a plurality of index tests that are processed with said phase difference information to generate test scores.

16. A method according to claim 15, wherein said test scores are processed with test scores for known locations to accumulate index scores for locations on said surface.

17. A method according to claim 16, wherein said test scores of known locations include groups of known locations for which phase difference profiles are known.

18. A method according to claim 16 or claim 17, wherein said selection of phase difference profiles for comparison with said phase difference information includes identifying phase difference profiles associated with high index scores.

19. A method according to any of claims 11 to 18, wherein electrical signals from a plurality of said transducer means are combined in anti-phase to reduce the amplitude of unwanted low frequency components.

20. A computer-readable medium (111) having program instructions (604) encoded upon it for causing a computer to process electrical signals generated by a plurality of transducer means (201, 202, 203, 204) in response to sound generated by an interaction between an object (106) and a surface (105) by executing the steps of:

- a) acquiring the digitised acoustic signals from an analogue to digital converter (407);
- b) extracting phase difference information (706) from frequency compounds of said digitised acoustic signals;
- c) locating said interaction by comparing said phase difference information (706) with a plurality of phase difference profiles (607) for which surface locations are known; and
- d) generating input data in response to said locations.

21. A computer-readable medium (111) according to claim 20, including additional instructions for locating said interaction by interpolating between the surface locations of phase difference profiles most similar to said extracted phase difference information.

22. A computer-readable medium (111) according to

claim 20 or claim 21, including instructions for selecting said plurality of phase difference profiles compared at step (c) from a larger plurality by processing said phase difference information with an index (606) of phase difference profiles.

23. A computer-readable medium (111) according to claim 22, including additional instructions for generating test scores by processing a plurality of index tests with said phase difference information.

24. A computer-readable medium (111) according to claim 23, wherein said test scores are processed with fixed test scores for known locations to accumulate index scores for known locations on said surface.

25. A computer-readable medium (111) according to claim 24, wherein said test scores of known locations are associated with groups of known locations.

26. A computer-readable medium (111) according to claim 24 or claim 25, wherein said phase difference profiles compared at step (c) are selected by identifying phase difference profiles having high index scores.

Patentansprüche

1. Vorrichtung (102) zum Verarbeiten elektrischer Signale, die durch mehrere Messwandlerrmittel (201, 202, 203, 204) in Reaktion auf Schall erzeugt werden, der durch eine Wechselwirkung zwischen einem Objekt und einer Oberfläche (105) erzeugt wird, um Computereingangsdaten zu erzeugen, umfassend:

einen Analog-Digital-Wandler (407) zum Digitalisieren der elektrischen Signale;
ein Verarbeitungsmittel (401), das dafür konfiguriert ist, die digitalisierten elektrischen Signale zu verarbeiten;
ein Instruktionsspeichermittel (402), das Instruktionen (604) für das Verarbeitungsmittel (401) speichert; und
ein Kalibrierungsspeichermittel (402), das Kalibrierungsdaten (605) für die Oberfläche speichert;

wobei

die Instruktionen (604) durch das Verarbeitungsmittel (401) ausgeführt werden, um folgende Schritte auszuführen:

- a) Erfassen digitalisierter akustischer Signale von dem Analog-Digital-Wandler (407);
- b) Extrahieren von Phasendifferenzinformatio-

nen (706) aus Frequenzkomponenten der digitalisierten akustischen Signale;

c) Lokalisieren der Wechselwirkung durch Vergleichen der Phasendifferenzinformationen (706) mit mehreren Phasendifferenzprofilen (607), für die Oberflächenpositionen bekannt sind; und

d) Erzeugen von Computereingangsdaten in Reaktion auf die Lokalisierung.

2. Vorrichtung nach Anspruch 1, wobei die Wechselwirkung durch Interpolieren zwischen den Oberflächenpositionen von Phasendifferenzprofilen lokalisiert wird, die den extrahierten Phasendifferenzinformationen am ähnlichsten sind.

3. Vorrichtung nach Anspruch 1 oder Anspruch 2, wobei die Kalibrierungsdaten (605) Phasendifferenzprofile (607) und einen Index (606) von Phasendifferenzprofilen für die Oberfläche enthalten und die mehreren Phasendifferenzprofile, die in Schritt c) verglichen wurden, aus einer größeren Mehrzahl durch Verarbeiten der Phasendifferenzinformationen mit dem Index ausgewählt werden.

4. Vorrichtung nach Anspruch 3, wobei der Index (606) mehrere Indextests umfasst, die mit den Phasendifferenzinformationen (706) verarbeitet werden, um Testwertungen zu erzeugen.

5. Vorrichtung nach Anspruch 4, wobei die Testwertungen mit Testwertungen für bekannte Positionen verarbeitet werden, um Indexwertungen für bekannte Positionen auf der Oberfläche zu akkumulieren.

6. Vorrichtung nach Anspruch 5, wobei die Testwertungen bekannter Positionen Gruppen bekannter Positionen zugeordnet werden.

7. Vorrichtung nach Anspruch 5 oder Anspruch 6, wobei die Phasendifferenzprofile, die in Schritt c) verglichen wurden, durch Identifizieren von Phasendifferenzprofilen ausgewählt werden, die hohe akkumulierte Indexwertungen haben.

8. Durch Berührung bedienbares Eingabegerät (101) zum Erzeugen von Eingabedaten, das die Vorrichtung (102) nach einem der Ansprüche 1 bis 7 umfasst, wobei das Gerät des Weiteren Folgendes umfasst:

eine Oberfläche (105), die in der Lage ist, ein breites Schallspektrum durch Reibungswechselwirkung mit einem Finger, der sich über die Oberfläche hinweg bewegt, zu erzeugen; und mehrere asymmetrisch angeordnete Messwandlerrmittel (201, 202, 203, 204), die dafür konfiguriert sind, elektrische Signale aus Schall-

- wellen zu erzeugen, die über ein Schall leitendes Substrat geleitet werden und von Berührungseignissen herrühren, die auf der Oberfläche stattfinden,
- wobei die elektrischen Signale in den Analog-Digital-Wandler (407) der Vorrichtung zum Umwandeln der elektrischen Signale in digitalisierte elektrische Signale eingespeist werden.
9. Durch Berührung bedienbares Eingabegerät (101) nach Anspruch 8, das Folgendes umfasst:
- mindestens vier asymmetrisch angeordnete Messwandlermittel (201, 202, 203, 204), die dafür konfiguriert sind, elektrische Signale aus Schallwellen zu erzeugen, die über ein Schall leitendes Substrat (105) geleitet werden und von Berührungseignissen herrühren, die auf der Oberfläche stattfinden;
- dadurch gekennzeichnet, dass:**
- eine erste Gruppierung (201, 203) der Messwandlermittel gegenphasig elektrisch verbunden ist, um einen ersten Kanal der elektrischen Signale zu erzeugen;
- eine zweite Gruppierung (202, 204) der Messwandlermittel gegenphasig elektrisch verbunden ist, um einen zweiten Kanal der elektrischen Signale zu erzeugen; und
- der erste und der zweite Kanal ein Verbindungsmittel (103) zum Verbinden mit der Vorrichtung (102) aufweisen.
10. Durch Berührung bedienbares Eingabegerät (101) nach Anspruch 9, wobei die Messwandlergruppierung in Reihe geschaltet ist.
11. Durch Berührung bedienbares Eingabegerät nach einem der Ansprüche 8 bis 10, wobei ein Widerstandsmittel (803, 804) parallel mit einem oder mehreren der Messwandlermittel verbunden ist, um Niederfrequenzkomponenten der elektrischen Signale zu dämpfen.
12. Verfahren zum Erzeugen von Eingabedaten für einen Computer (102), wobei eine Wechselwirkung zwischen einem Objekt (106) und einer Oberfläche (105) Schall durch Reibung zwischen der Oberfläche und dem Objekt erzeugt, wobei das Verfahren folgende Schritte umfasst:
- Umwandeln von Schall in elektrische Signale durch mindestens zwei Messwandlermittel (201, 202, 203, 204),
 - Verarbeiten der elektrischen Signale, um Phasendifferenzinformationen (706) aus Frequenzkomponenten der Signale zu extrahieren,
 - Identifizieren der Position der Wechselwirkung durch Vergleiche zwischen den Phasendifferenzinformationen (706) und mehreren Phasendifferenzprofilen (607), für die Oberflächenpositionen bekannt sind; und
 - Erzeugen von Eingabedaten für den Computer in Reaktion auf die identifizierte Position der Wechselwirkung.
13. Verfahren nach Anspruch 12, wobei die Position der Wechselwirkung durch Interpolieren zwischen den Oberflächenpositionen von Phasendifferenzprofilen (607) identifiziert wird, die den Phasendifferenzinformationen (706) am ähnlichsten sind.
14. Verfahren nach Anspruch 12 oder Anspruch 13, wobei die mehreren Phasendifferenzprofile aus einer größeren Vielzahl durch Verarbeiten der Phasendifferenzinformationen mit einem Index (606) von Phasendifferenzprofilen für die Oberfläche ausgewählt werden.
15. Verfahren nach Anspruch 14, wobei der Index mehrere Indextests umfasst, die mit den Phasendifferenzinformationen verarbeitet werden, um Testwertungen zu erzeugen.
16. Verfahren nach Anspruch 15, wobei die Testwertungen mit Testwertungen für bekannte Positionen verarbeitet werden, um Indexwertungen für Positionen auf der Oberfläche zu akkumulieren.
17. Verfahren nach Anspruch 16, wobei die Testwertungen bekannter Positionen Gruppen bekannter Positionen enthalten, für die Phasendifferenzprofile bekannt sind.
18. Verfahren nach Anspruch 16 oder Anspruch 17, wobei die Auswahl von Phasendifferenzprofilen zum Vergleich mit den Phasendifferenzinformationen, das Identifizieren von Phasendifferenzprofilen enthält, die hohen Indexwertungen zugeordnet sind.
19. Verfahren nach einem der Ansprüche 11 bis 18, wobei elektrische Signale von mehreren der Messwandlermittel gegenphasig kombiniert werden, um die Amplitude unerwünschter Niederfrequenzkomponenten zu verringern.
20. Computerlesbares Medium (111), auf dem Programmstrukturen (604) codiert sind, um einen Computer zu veranlassen, elektrische Signale zu verarbeiten, die durch mehrere Messwandlermittel (201, 202, 203, 204) in Reaktion auf Schall erzeugt werden, der durch eine Wechselwirkung zwischen einem Objekt (106) und einer Oberfläche (105) erzeugt wird, indem folgende Schritte ausgeführt werden:

- a) Erfassen der digitalisierten akustischen Signale von einem Analog-Digital-Wandler (407);
 b) Extrahieren von Phasendifferenzinformationen (706) aus Frequenzkomponenten der digitalisierten akustischen Signale;
 c) Lokalisieren der Wechselwirkung durch Vergleichen der Phasendifferenzinformationen (706) mit mehreren Phasendifferenzprofilen (607), für die Oberflächenpositionen bekannt sind; und
 d) Erzeugen von Eingangsdaten in Reaktion auf die Lokalisierung.
21. Computerlesbares Medium (111) nach Anspruch 20, das zusätzliche Instruktionen zum Lokalisieren der Wechselwirkung durch Interpolieren zwischen den Oberflächenpositionen von Phasendifferenzprofilen enthält, die den extrahierten Phasendifferenzinformationen am ähnlichsten sind.
22. Computerlesbares Medium (111) nach Anspruch 20 oder Anspruch 21, das Instruktionen zum Auswählen der mehreren Phasendifferenzprofile, die in Schritt c) verglichen wurden, aus einer größeren Mehrzahl durch Verarbeiten der Phasendifferenzinformationen mit einem Index (606) von Phasendifferenzprofilen enthält.
23. Computerlesbares Medium (111) nach Anspruch 22, das zusätzliche Instruktionen zum Erzeugen von Testwertungen durch Verarbeiten mehrerer Indextests mit den Phasendifferenzinformationen enthält.
24. Computerlesbares Medium (111) nach Anspruch 23, wobei die Testwertungen mit festen Testwertungen für bekannte Positionen verarbeitet werden, um Indexwertungen für bekannte Positionen auf der Oberfläche zu akkumulieren.
25. Computerlesbares Medium (111) nach Anspruch 24, wobei die Testwertungen bekannter Positionen Gruppen bekannter Positionen zugeordnet sind.
26. Computerlesbares Medium (111) nach Anspruch 24 oder Anspruch 25, wobei die Phasendifferenzprofile, die in Schritt c) verglichen wurden, durch Identifizieren von Phasendifferenzprofilen ausgewählt werden, die hohe Indexwertungen haben.
- un convertisseur analogique-numérique (407) pour numériser lesdits signaux électriques ;
 un moyen de traitement (401) configuré pour traiter lesdits signaux électriques numérisés ;
 un moyen de stockage d'instruction (402) stockant des instructions (604) pour ledit moyen de traitement (401) ; et
 un moyen de stockage de calibrage (402) stockant des données de calibrage (605) pour ladite surface, dans lequel lesdites instructions (604) sont exécutées par ledit moyen de traitement (401) pour réaliser les étapes de :
- a) acquisition des signaux acoustiques numérisés à partir dudit convertisseur analogique-numérique (407) ;
 b) extraction des informations de différence de phase (706) à partir des composantes de fréquence desdits signaux acoustiques numérisés ;
 c) localisation de ladite interaction en comparant lesdites informations de différence de phase (706) à une pluralité de profils de différence de phase (607) pour lesquels des emplacements de surface sont connus ; et
 d) génération de données d'entrée d'ordinateur en réponse audit emplacement.
2. Appareil selon la revendication 1, dans lequel ladite interaction est localisée par interpolation entre les emplacements de surface des profils de différence de phase les plus similaires auxdites informations de différence de phase extraites.
3. Appareil selon la revendication 1 ou la revendication 2, dans lequel lesdites données de calibrage (605) comprennent des profils de différence de phase (607) et un index (606) des profils de différence de phase pour ladite surface et ladite pluralité de profils de différence de phase comparés à l'étape c) est sélectionné à partir d'une plus grande pluralité par traitement desdites informations de différence de phase avec ledit index.
4. Appareil selon la revendication 3, dans lequel ledit index (606) comprend une pluralité de tests d'index qui sont traités avec lesdites informations de différence de phase (706) pour générer des indices de pertinence de test.
5. Appareil selon la revendication 4, dans lequel lesdits indices de pertinence de test sont traités avec des indices de pertinence de test pour des emplacements connus pour accumuler des indices de pertinence d'index pour des emplacements connus sur ladite surface.

Revendications

1. Appareil (102) pour traiter des signaux électriques générés par une pluralité de moyens transducteurs (201, 202, 203, 204) en réponse à un son généré par une interaction entre un objet et une surface (105) pour générer des données d'entrée d'ordinateur, comprenant :

6. Appareil selon la revendication 5, dans lequel lesdits indices de pertinence de test des emplacements connus sont associés aux groupes d'emplacements connus.

7. Appareil selon la revendication 5 ou la revendication 6, dans lequel lesdits profils de différence de phase comparés à l'étape c) sont sélectionnés en identifiant des profils de différence de phase ayant des indices de pertinence d'index accumulés élevés.

8. Dispositif d'entrée exploitable tactilement (101) pour générer des données d'entrée comprenant l'appareil (102) selon l'une quelconque des revendications 1 à 7, ledit dispositif comprenant en outre :

une surface (105) capable de générer un spectre large de son par interaction frictionnelle avec un doigt se déplaçant sur la surface ; et une pluralité de moyens transducteurs situés asymétriquement (201, 202, 203, 204) configurés pour générer des signaux électriques à partir des ondes sonores conduites via un substrat conducteur de son à partir des événements tactiles faits sur ladite surface, dans lequel lesdits signaux électriques sont fournis audit convertisseur analogique-numérique (407) dudit appareil pour convertir lesdits signaux électriques en signaux acoustiques numérisés.

9. Dispositif d'entrée exploitable tactilement (101) selon la revendication 8, comprenant :

au moins quatre moyens transducteurs situés asymétriquement (201, 202, 203, 204) disposés pour générer des signaux électriques à partir des ondes sonores conduites via un substrat conducteur de son (105) à partir des emplacements d'événement tactiles sur ladite surface ; **caractérisé en ce que :**

un premier groupement (201, 203) dudit moyen transducteur est électriquement raccordé en opposition de phase pour générer un premier canal desdits signaux électriques ; un second groupement (202, 204) dudit moyen transducteur est électriquement raccordé en opposition de phase pour générer un second canal desdits signaux électriques ; et ledit premier et ledit second canaux ont un moyen de connexion (103) pour la connexion audit appareil (102).

10. Dispositif d'entrée exploitable tactilement (101) selon la revendication 9, dans lequel un dit groupement

transducteur est monté en série.

11. Dispositif d'entrée exploitable tactilement selon l'une quelconque des revendications 8 à 10, dans lequel un moyen de résistance (803, 804) est monté en parallèle avec un ou une pluralité de dits moyens transducteurs afin d'atténuer des composantes basse fréquence desdits signaux électriques.

12. Procédé de génération de données d'entrée pour un ordinateur (102), dans lequel une interaction entre un objet (106) et une surface (105) génère un son par friction entre ladite surface et ledit objet, le procédé comprenant les étapes de :

- conversion de son en signaux électriques par au moins deux moyens transducteurs (201, 202, 203, 204) ;
- traitements desdits signaux électriques pour extraire des informations de différence de phase (706) à partir des composants de fréquence desdits signaux ;
- identification de l'emplacement de ladite interaction par comparaisons entre lesdites informations de différence de phase (706) et une pluralité de profils de différence de phase (607) pour lesquels des emplacements de surface sont connus ; et
- génération de données d'entrée pour ledit ordinateur en réponse audit emplacement identifié d'interaction.

13. Procédé selon la revendication 12, dans lequel ledit emplacement d'interaction est identifié en interpolant entre les emplacements de surface des profils de différence de phase (607) les plus similaires auxdites informations de différence de phase (706).

14. Procédé selon la revendication 12 ou la revendication 13, dans lequel ladite pluralité de profils de différence de phase sont sélectionnés à partir d'une pluralité plus grande par traitement desdites informations de différence de phase avec un index (606) de profils de différence de phase pour ladite surface.

15. Procédé selon la revendication 14, dans lequel ledit index comprend une pluralité de tests d'index qui sont traités avec lesdites informations de différence de phase pour générer des indices de pertinence de test.

16. Procédé selon la revendication 15, dans lequel lesdits indices de pertinence de test sont traités avec des indices de pertinence de test pour des emplacements connus pour accumuler des indices de pertinence d'index pour des emplacements sur ladite surface.

17. Procédé selon la revendication 16, dans lequel lesdits indices de pertinence de test des emplacements connus comprennent des groupes d'emplacements connus pour lesquels des profils de différence de phase sont connus. 5
18. Procédé selon la revendication 16 ou la revendication 17, dans lequel ladite sélection de profils de différence de phase pour comparaison avec lesdites informations de différence de phase comprend l'identification des profils de différence de phase associés aux indices de pertinence d'index élevés. 10
19. Procédé selon l'une quelconque des revendications 11 à 18, dans lequel des signaux électriques à partir d'une pluralité desdits moyens transducteurs sont combinés en opposition de phase pour réduire l'amplitude des composantes basse fréquence indésirés. 15
20. Support lisible par ordinateur (111) ayant des instructions de programme (604) codées sur lui pour conduire un ordinateur à traiter des signaux électriques générés par une pluralité de moyens transducteurs (201, 202, 203, 204) en réponse au son généré par une interaction entre un objet (106) et une surface (105) en exécutant les étapes de : 20
- a) acquisition des signaux acoustiques numérisés à partir d'un convertisseur analogique-numérique (407) ; 30
 - b) extraction des informations de différence de phase (706) à partir des composantes de fréquence desdits signaux acoustiques numérisés ; 35
 - c) localisation de ladite interaction en comparant lesdites informations de différence de phase (706) avec une pluralité de profils de différence de phase (607) pour lesquels des emplacements de surface sont connus ; et 40
 - d) génération de données d'entrée en réponse auxdits emplacements.
21. Support lisible par ordinateur (111) selon la revendication 20, comprenant des instructions supplémentaires pour localiser lesdites interactions par interpolation entre les emplacements de surface des profils de différence de phase les plus similaires auxdites informations de différence de phase extraites. 45
22. Support lisible par ordinateur (111) selon la revendication 20 ou la revendication 21, comprenant des instructions pour sélectionner ladite pluralité de profils de différence de phase comparées à l'étape c) à partir d'une pluralité plus grande par traitement desdites informations de différence de phase avec un index (606) de profils de différence de phase. 50
23. Support lisible par ordinateur (111) selon la revendication 22, comprenant des instructions supplémentaires pour générer des indices de pertinence de test par traitement d'une pluralité de tests d'index avec lesdites informations de différence de phase. 5
24. Support lisible par ordinateur (111) selon la revendication 23, dans lequel lesdits indices de pertinence de test sont traités avec des indices de pertinence de test fixes pour des emplacements connus pour accumuler des indices de pertinence d'index pour des emplacements connus sur ladite surface. 10
25. Support lisible par ordinateur (111) selon la revendication 24, dans lequel lesdits indices de pertinence de test des emplacements connus sont associés à des groupes d'emplacement connus. 15
26. Support lisible par ordinateur (111) selon la revendication 24 ou la revendication 25, dans lequel lesdits profils de différence de phase comparés à l'étape c) sont sélectionnés en identifiant des profils de différence de phase ayant des indices de pertinence d'index élevés. 20

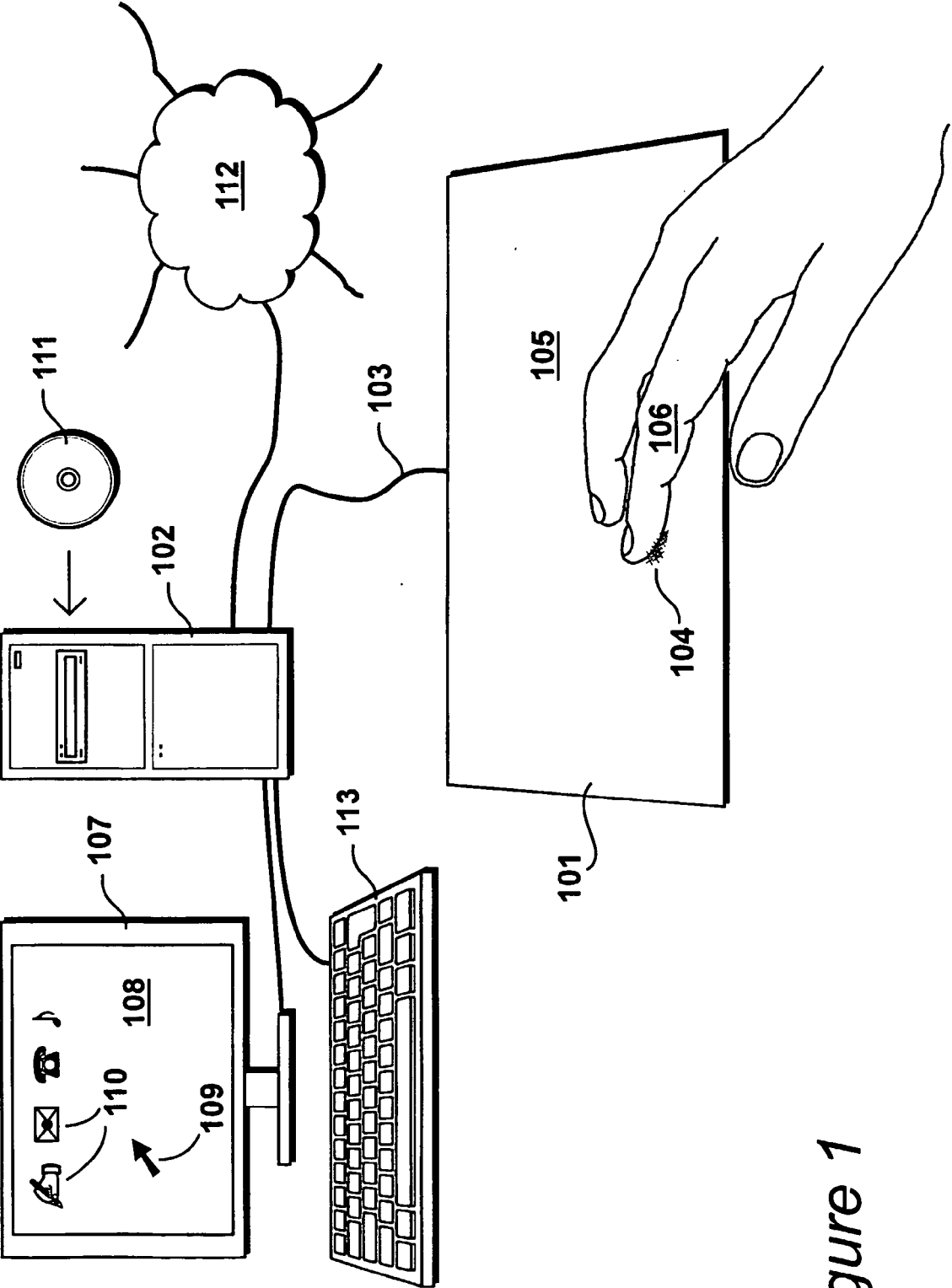


Figure 1

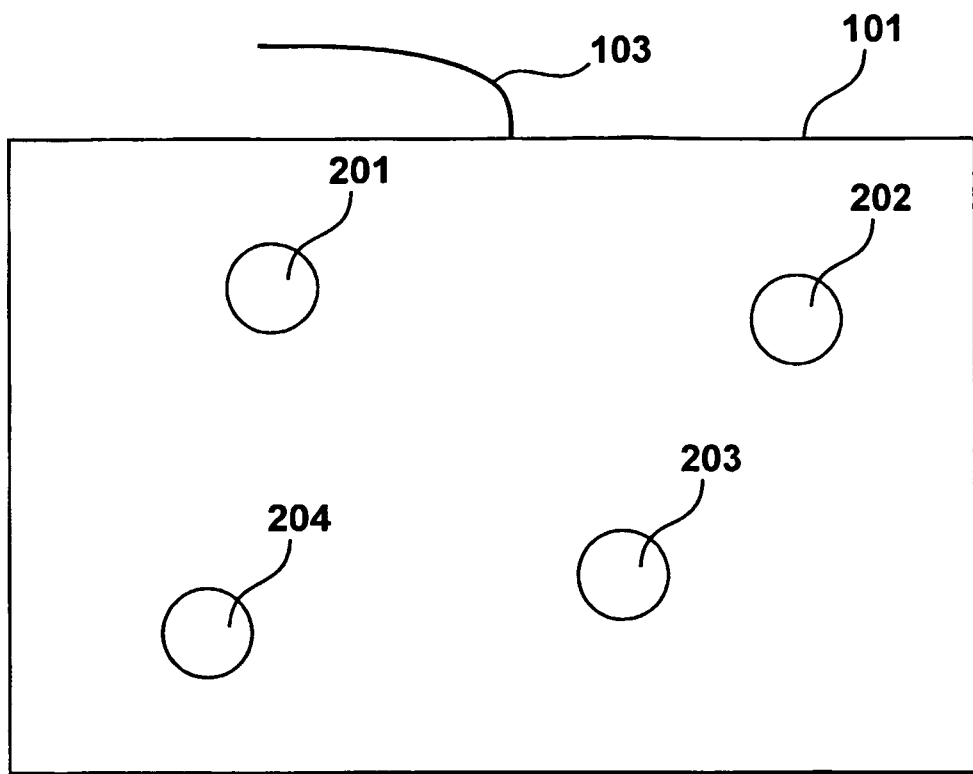


Figure 2

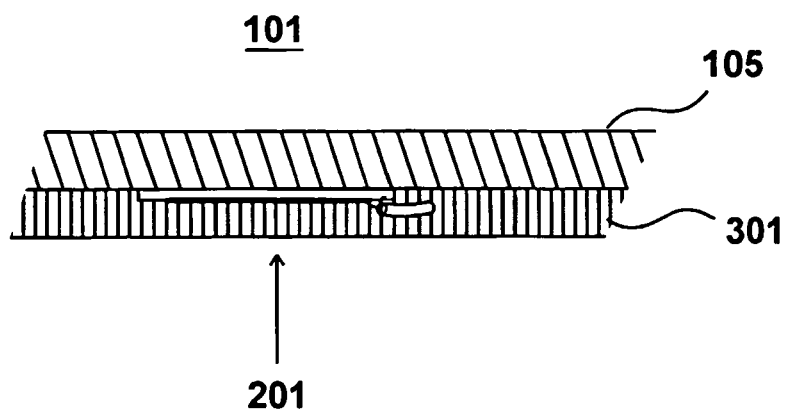


Figure 3

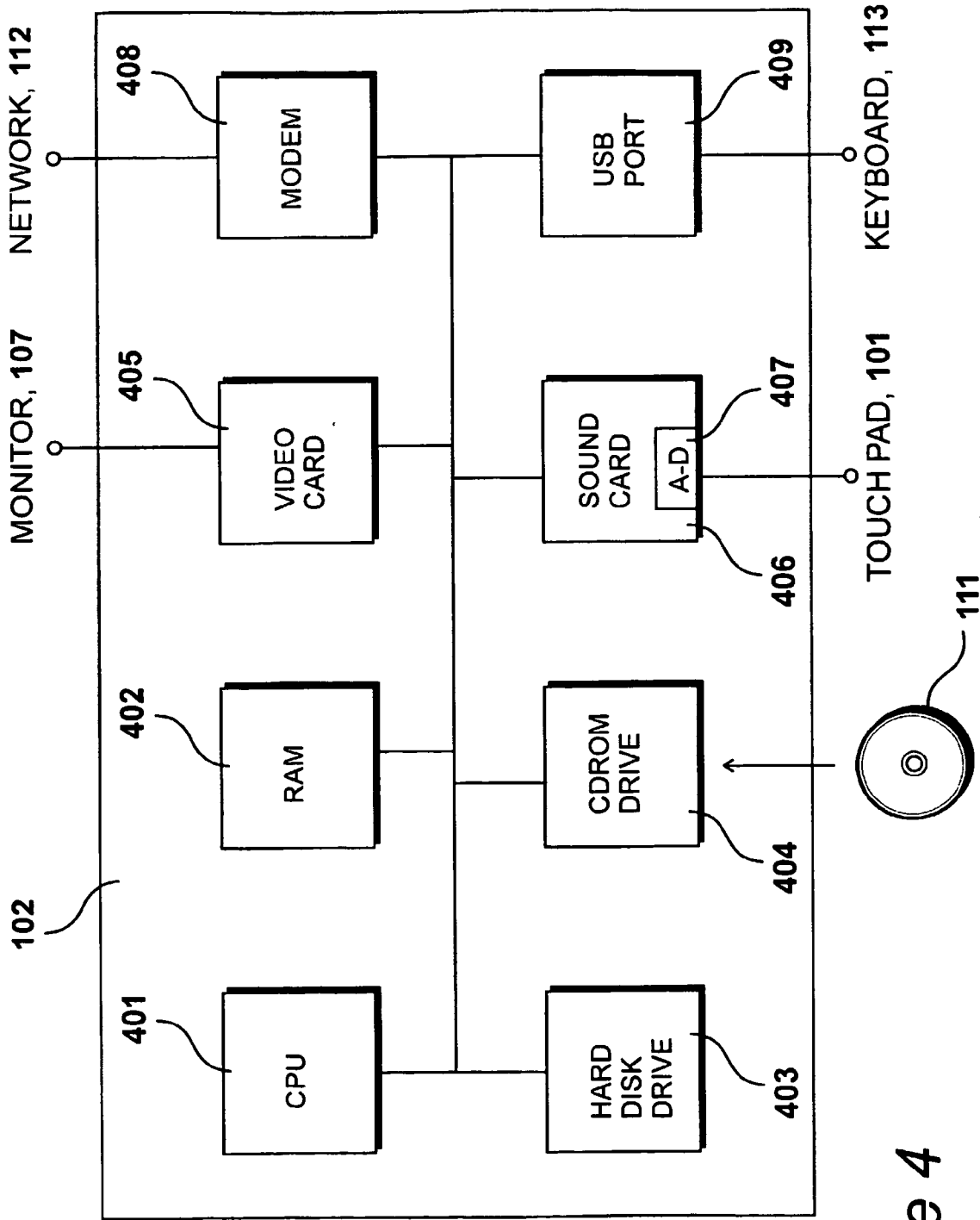


Figure 4

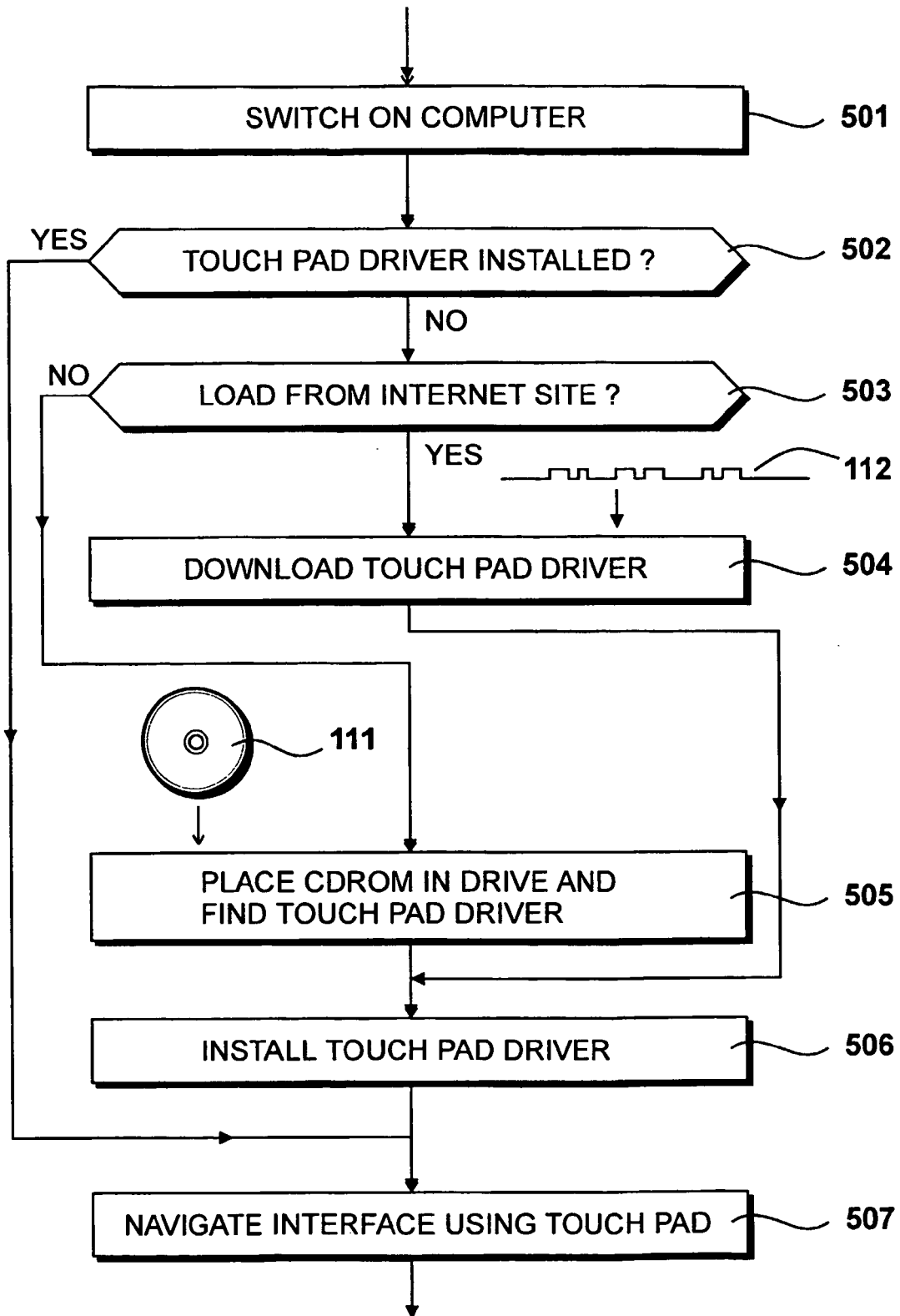


Figure 5

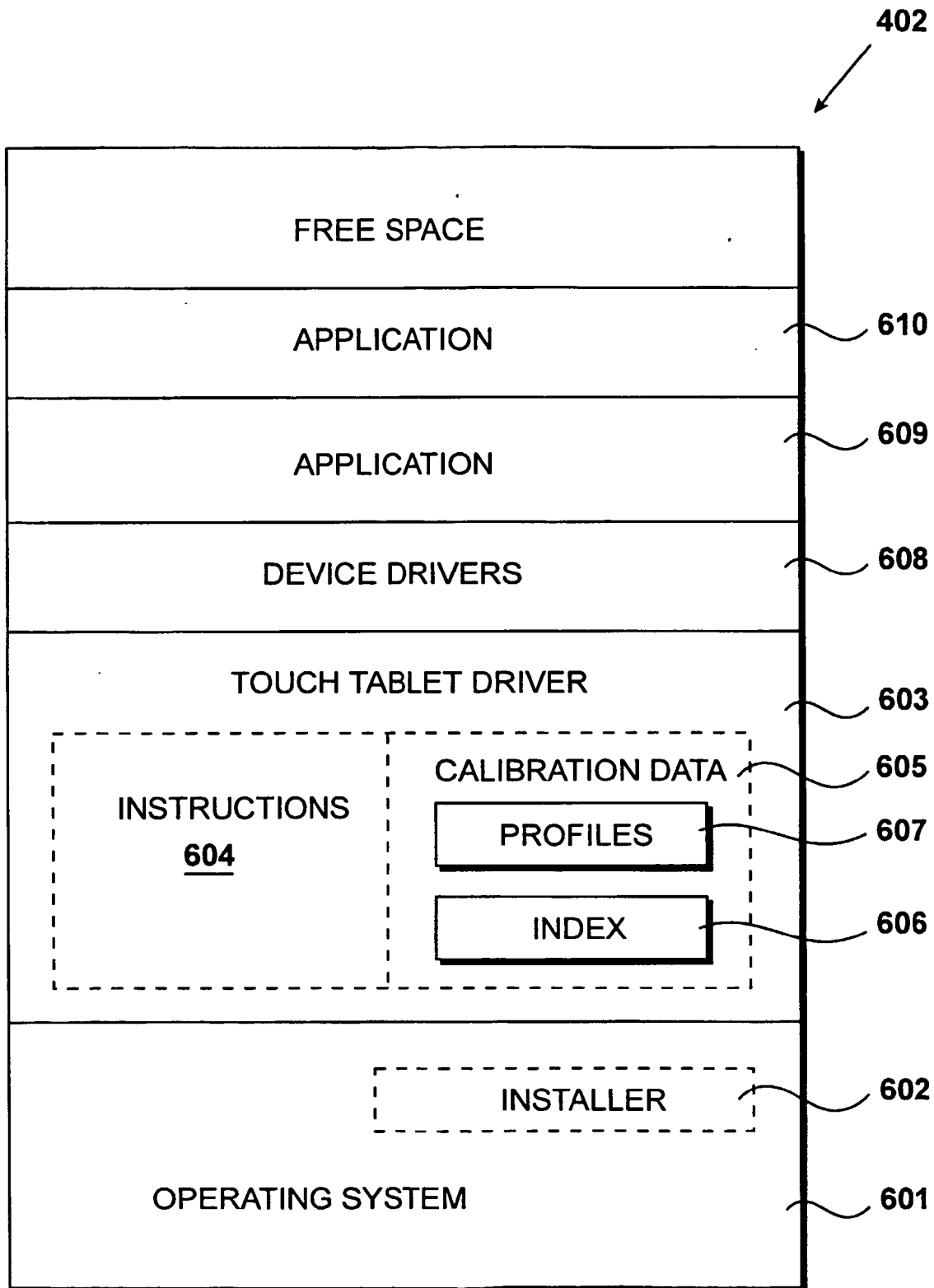


Figure 6

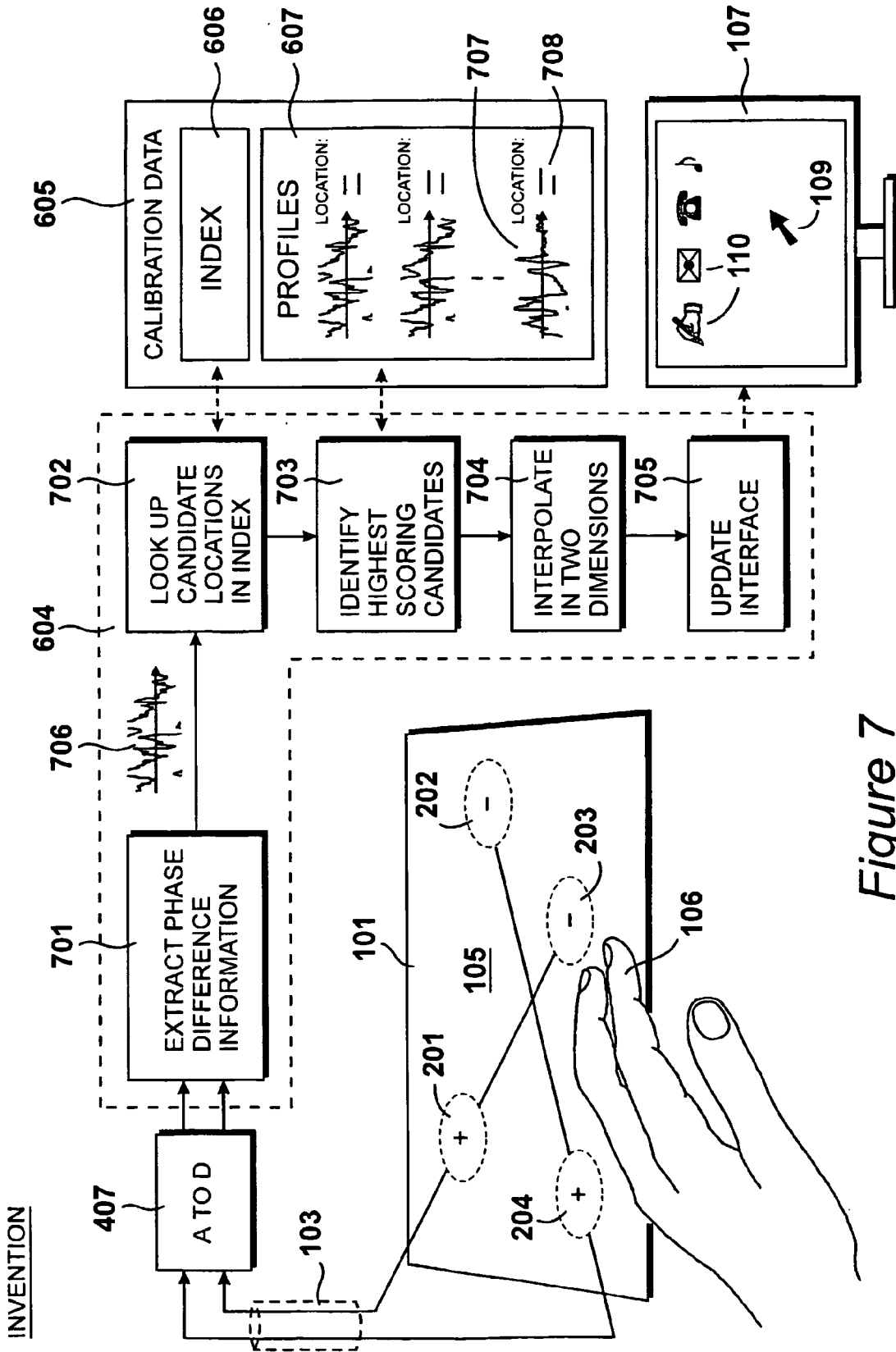


Figure 7

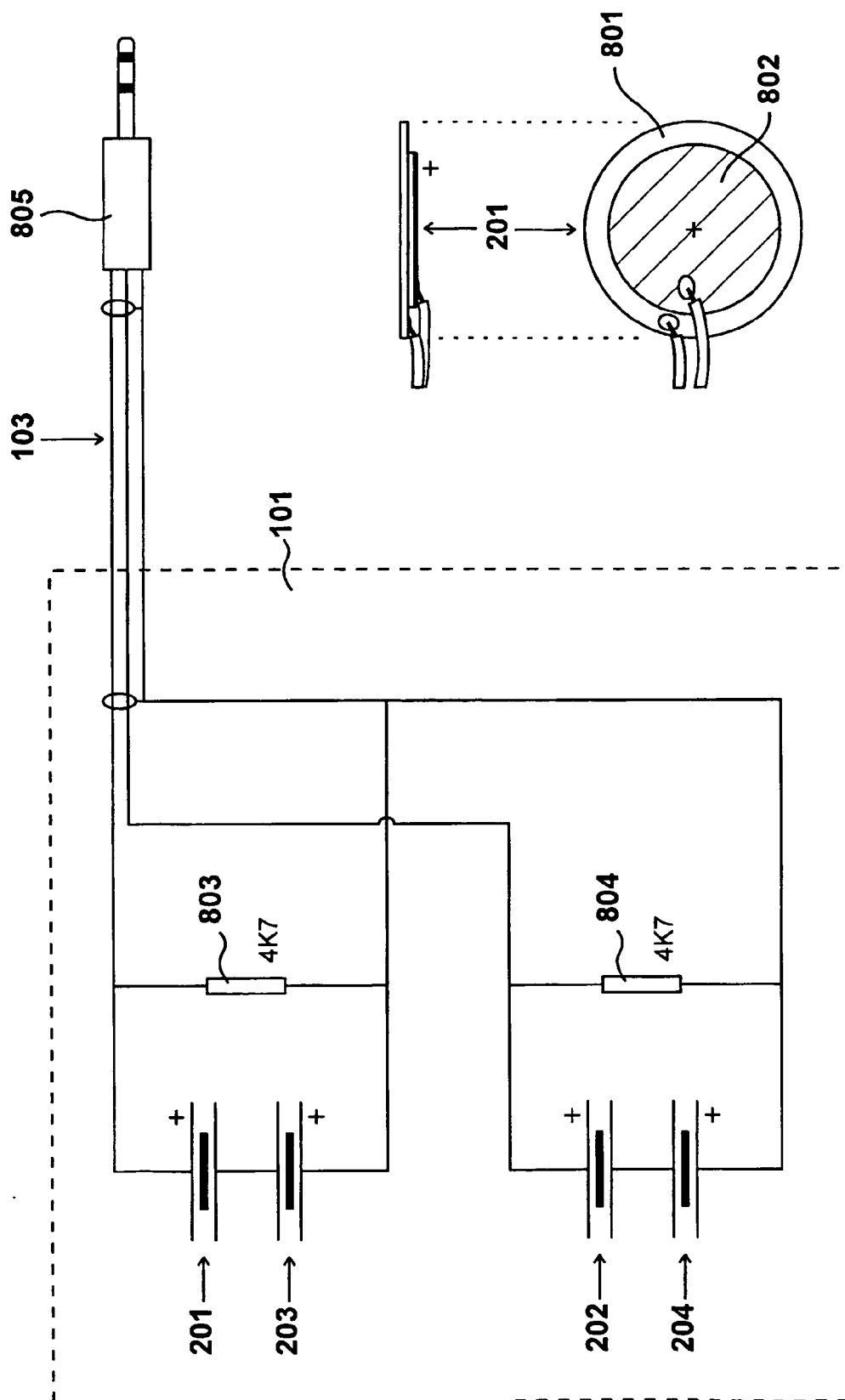


Figure 8

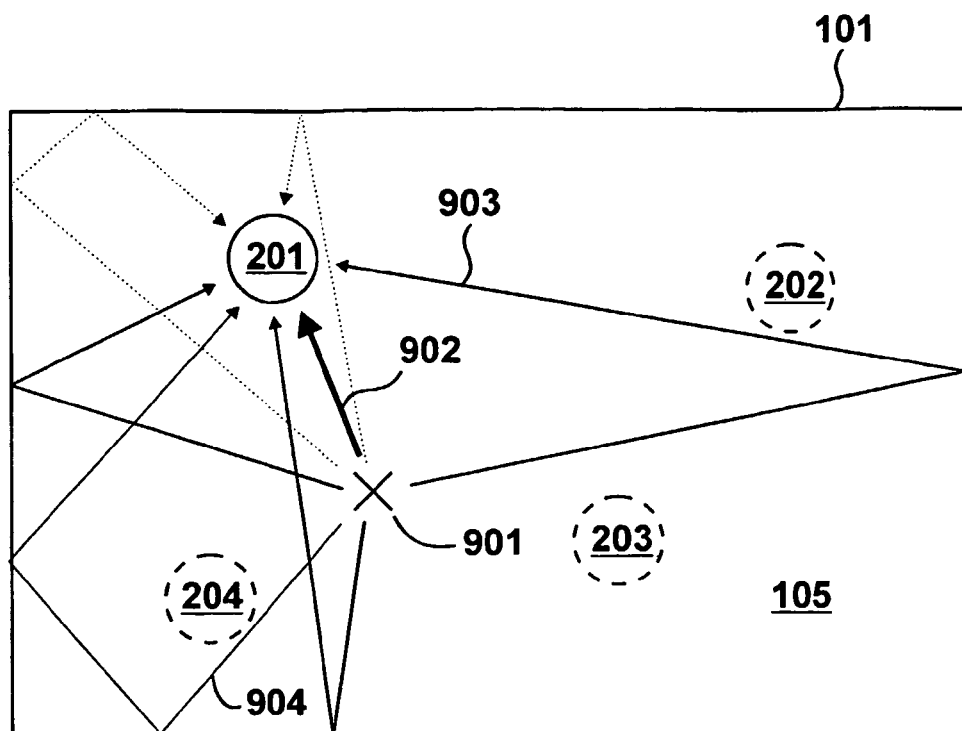


Figure 9

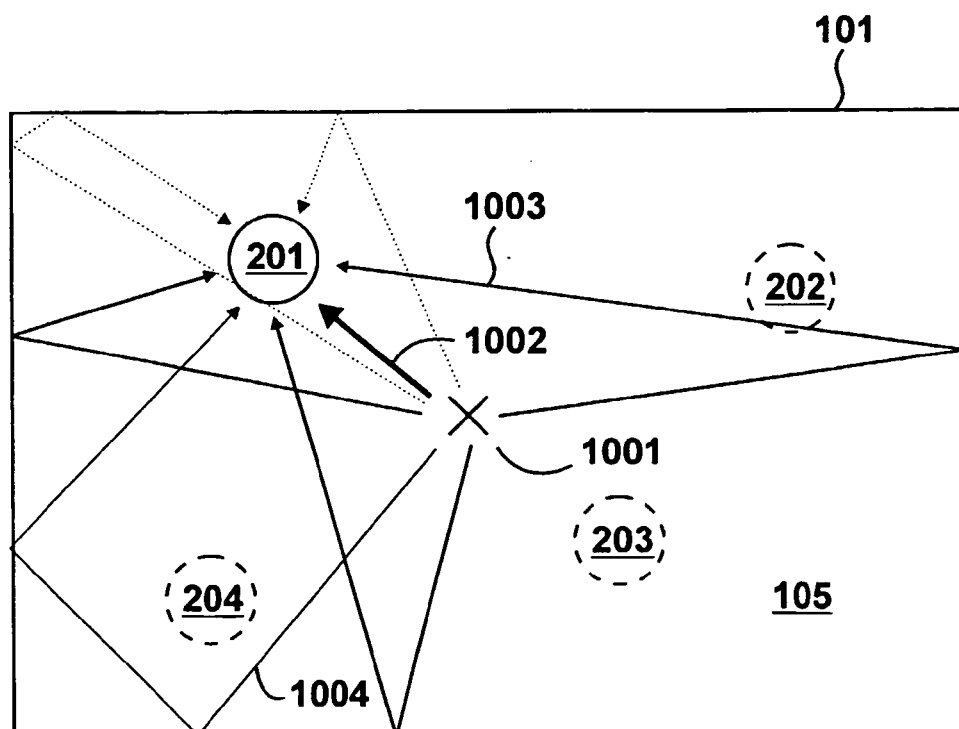


Figure 10

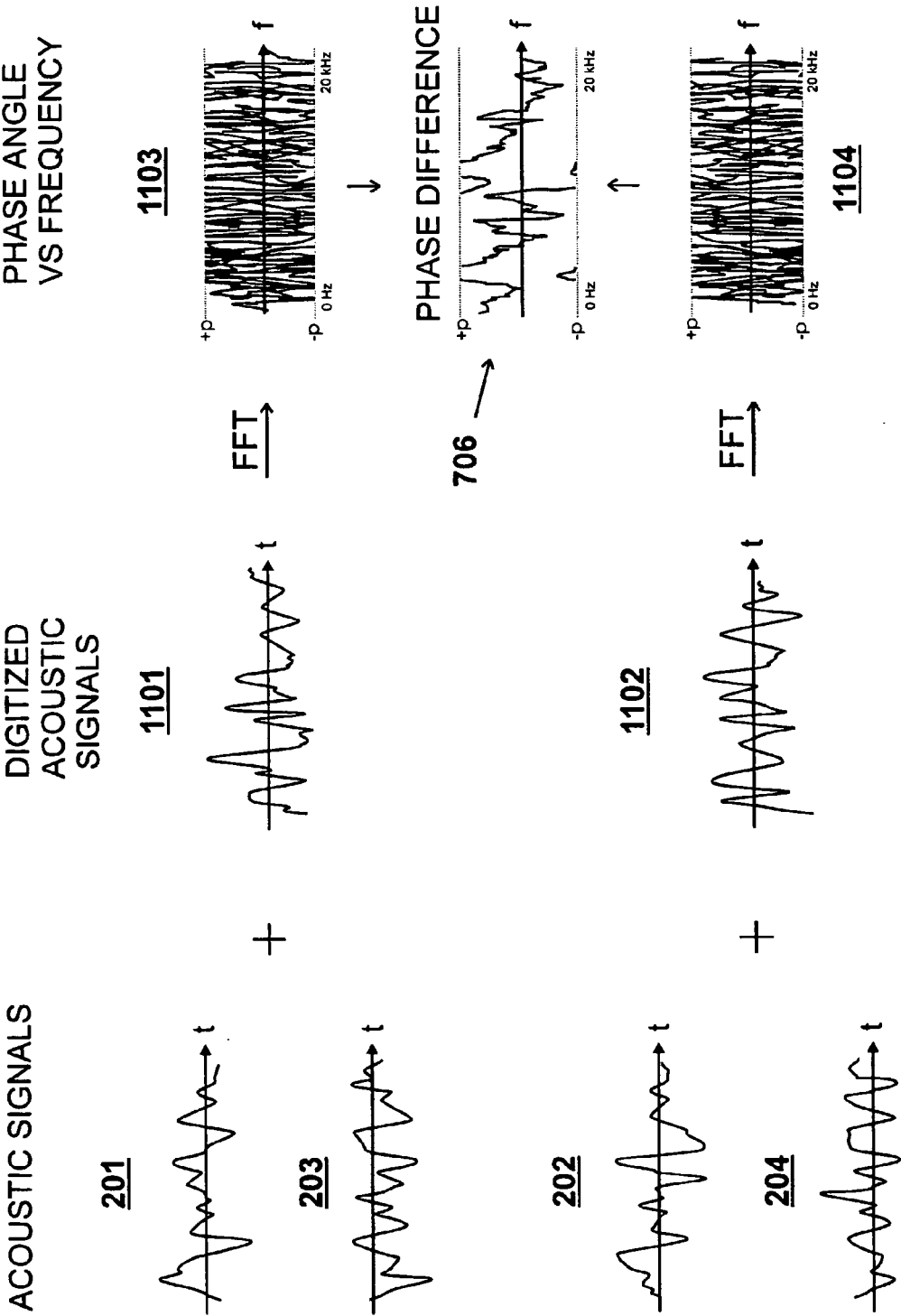


Figure 11

607

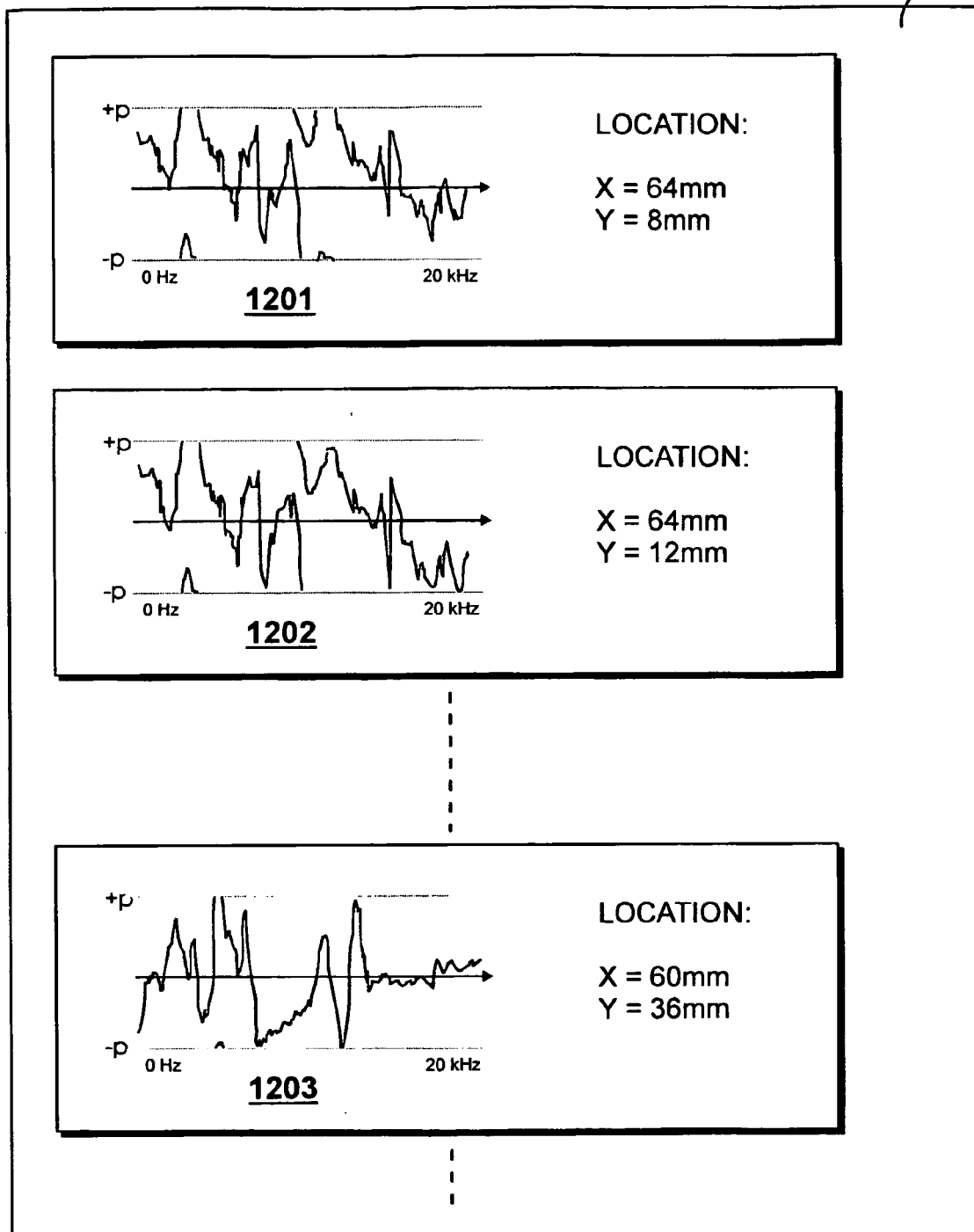


Figure 12

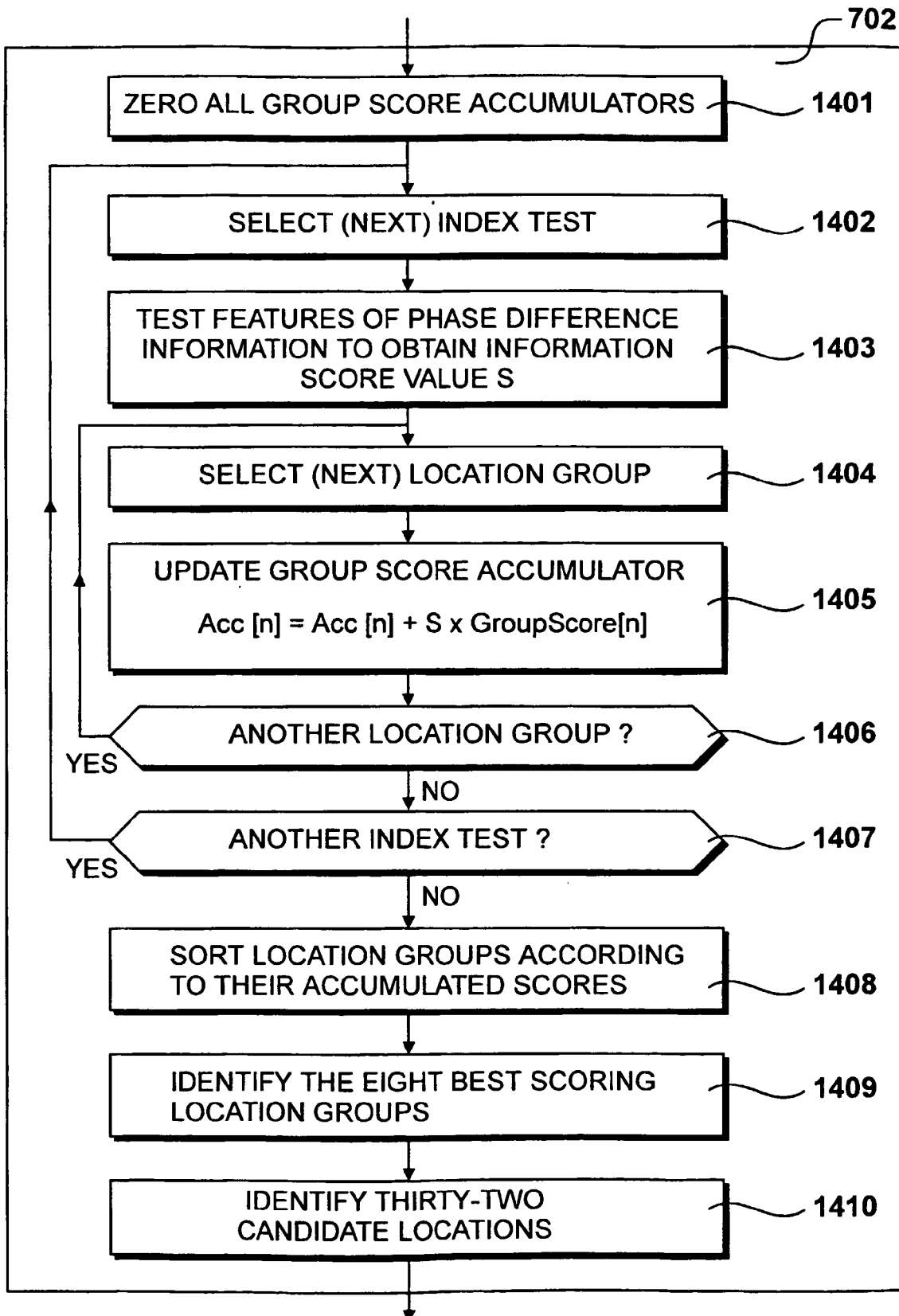
LOCATION GROUP	SCORES FOR TEST 1
GROUP	SCORE
1	0.29
2	-0.1
3	0.1
4	0.21
5	0.123
6	0.21
7	-0.78
8	-0.89
9	-0.32
.	.
.	.
103	0.34
104	0.67
105	-0.64
106	0.9
107	-0.1
108	-0.32
109	-0.104
110	-0.9
.	.
610	0.82
1305	

Figure 13

INDEX TEST 1			1301
FEATURE	FREQUENCY	PHASE	LOCATION GROUP SCORES FOR TEST 1
1	52	78	
2	102	23	
3	189	100	
4	207	-50	

INDEX TEST 2			1302
FEATURE	FREQUENCY	PHASE	LOCATION GROUP SCORES FOR TEST 2
1	38	38	
2	57	3	
3	79	-30	
4	102	-152	

INDEX TEST 64			1303
FEATURE	FREQUENCY	PHASE	LOCATION GROUP SCORES FOR TEST 64
1	41	-100	
2	95	-126	
3	109	-10	
4	235	13	

*Figure 14*

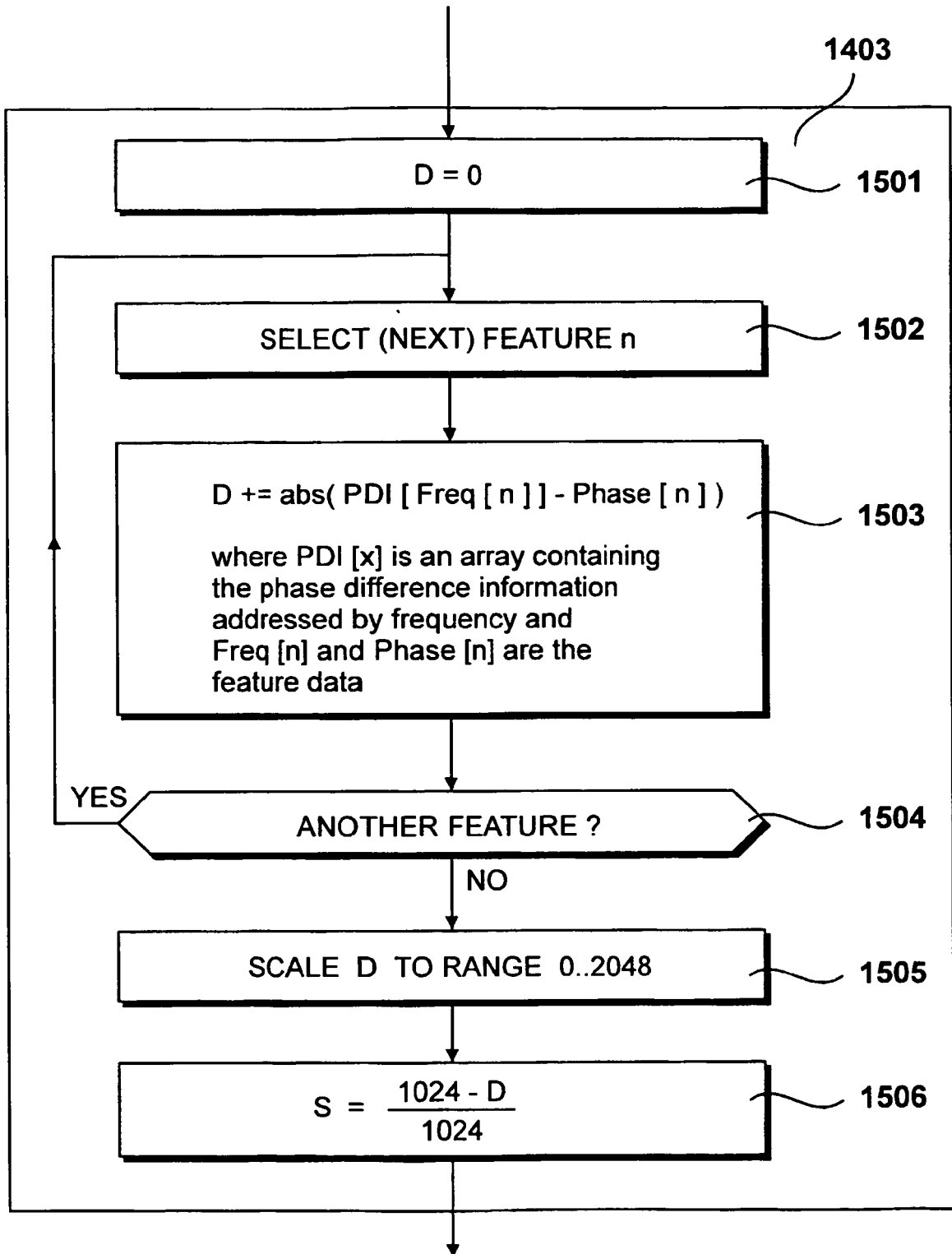


Figure 15

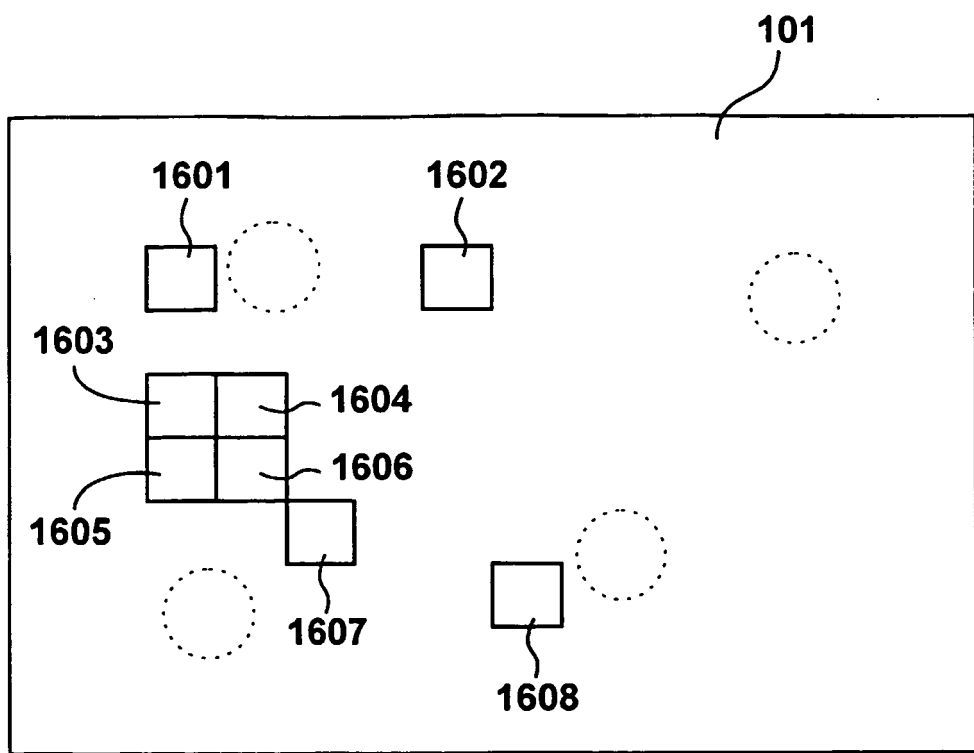


Figure 16

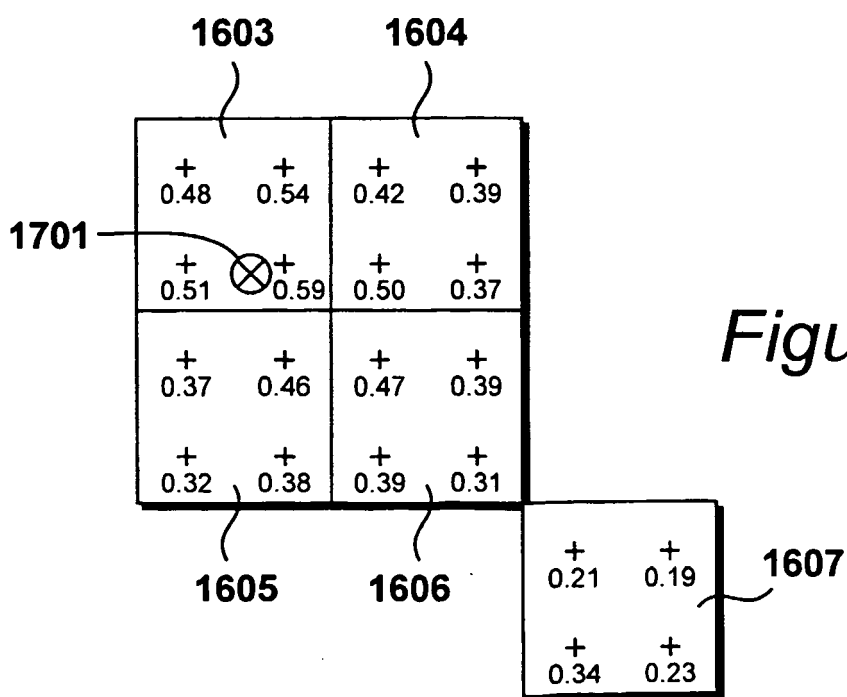


Figure 17

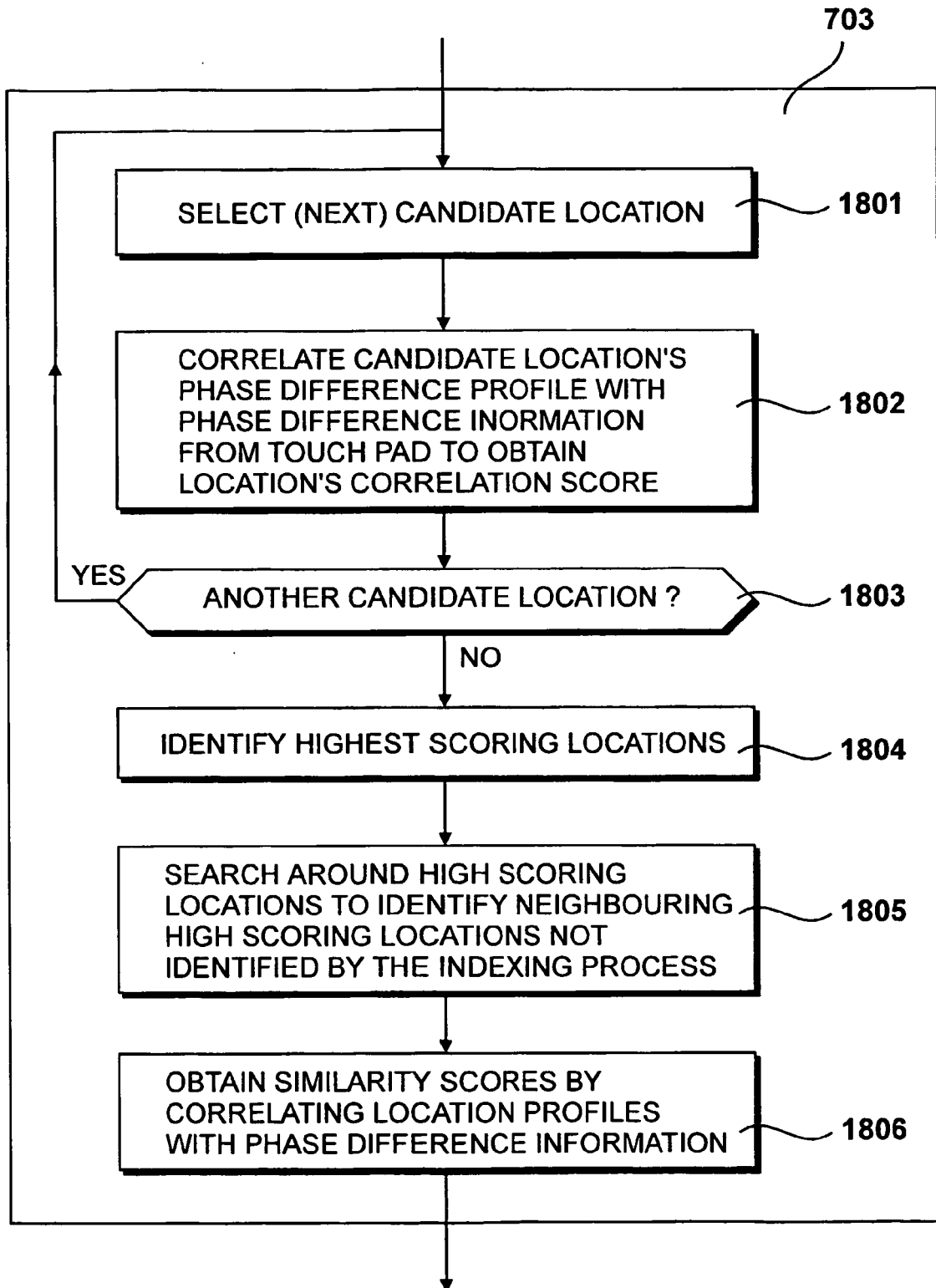


Figure 18

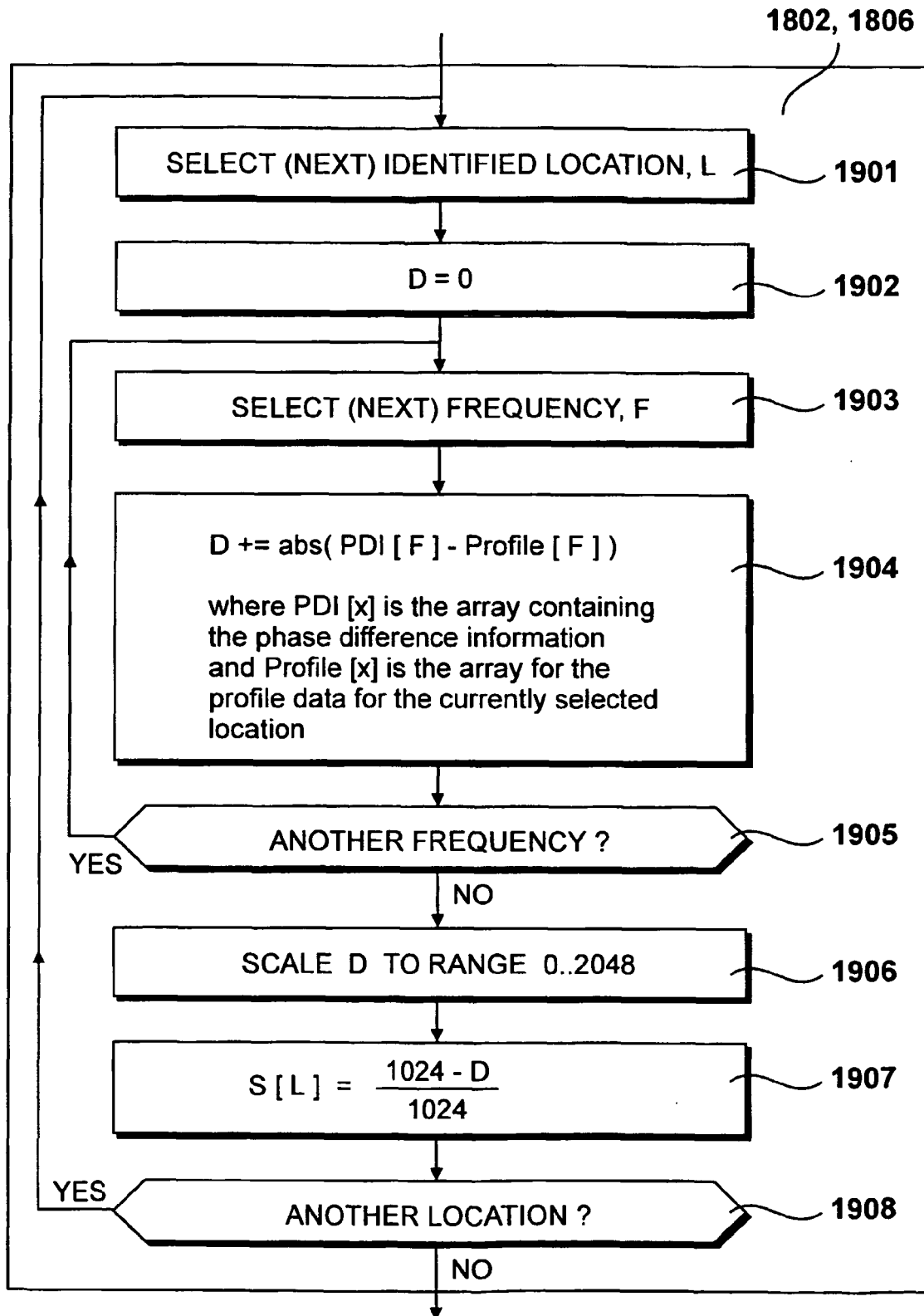


Figure 19

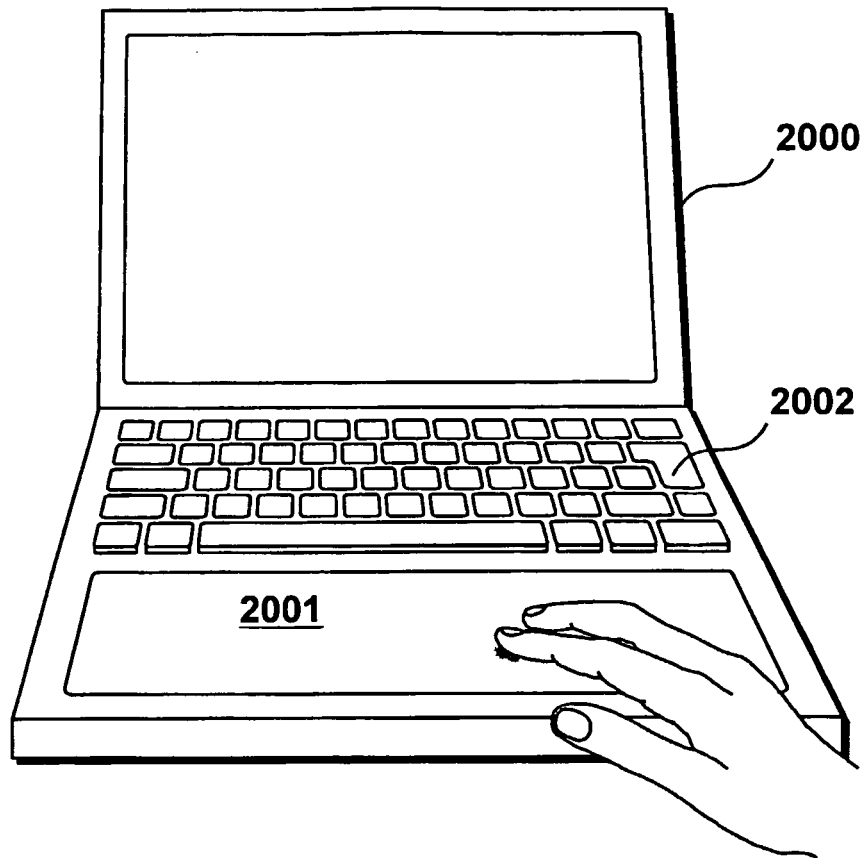


Figure 20

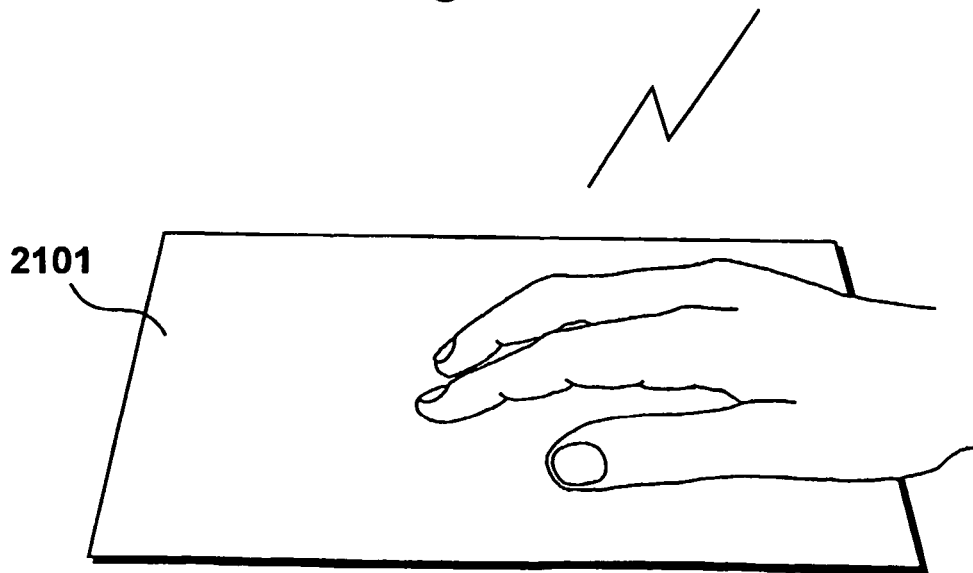


Figure 21

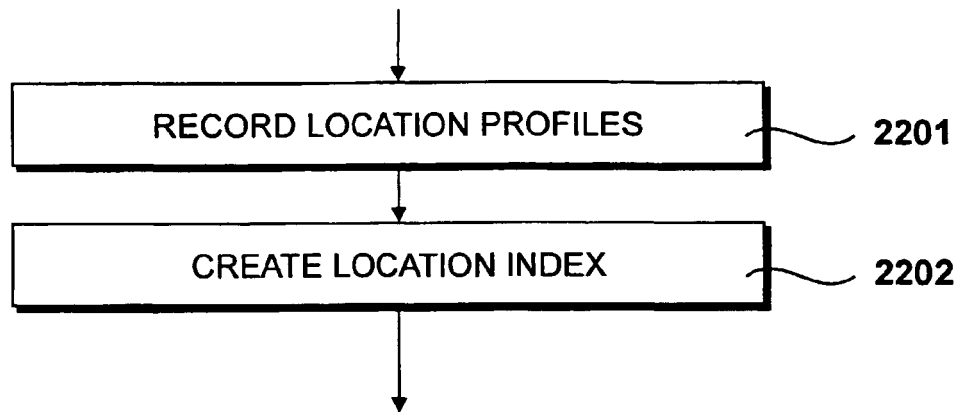


Figure 22

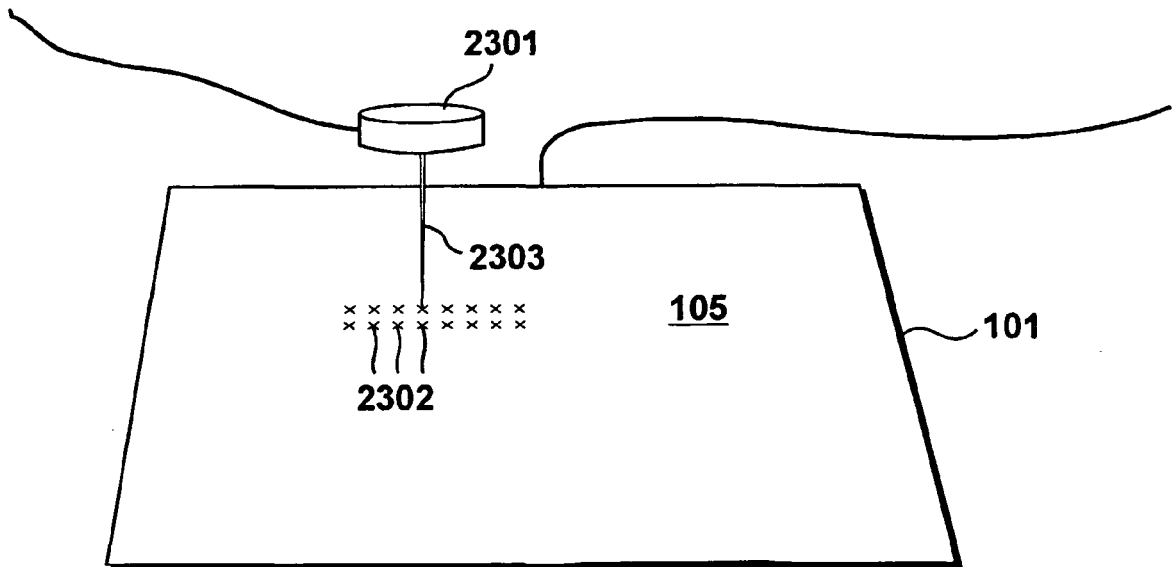


Figure 23

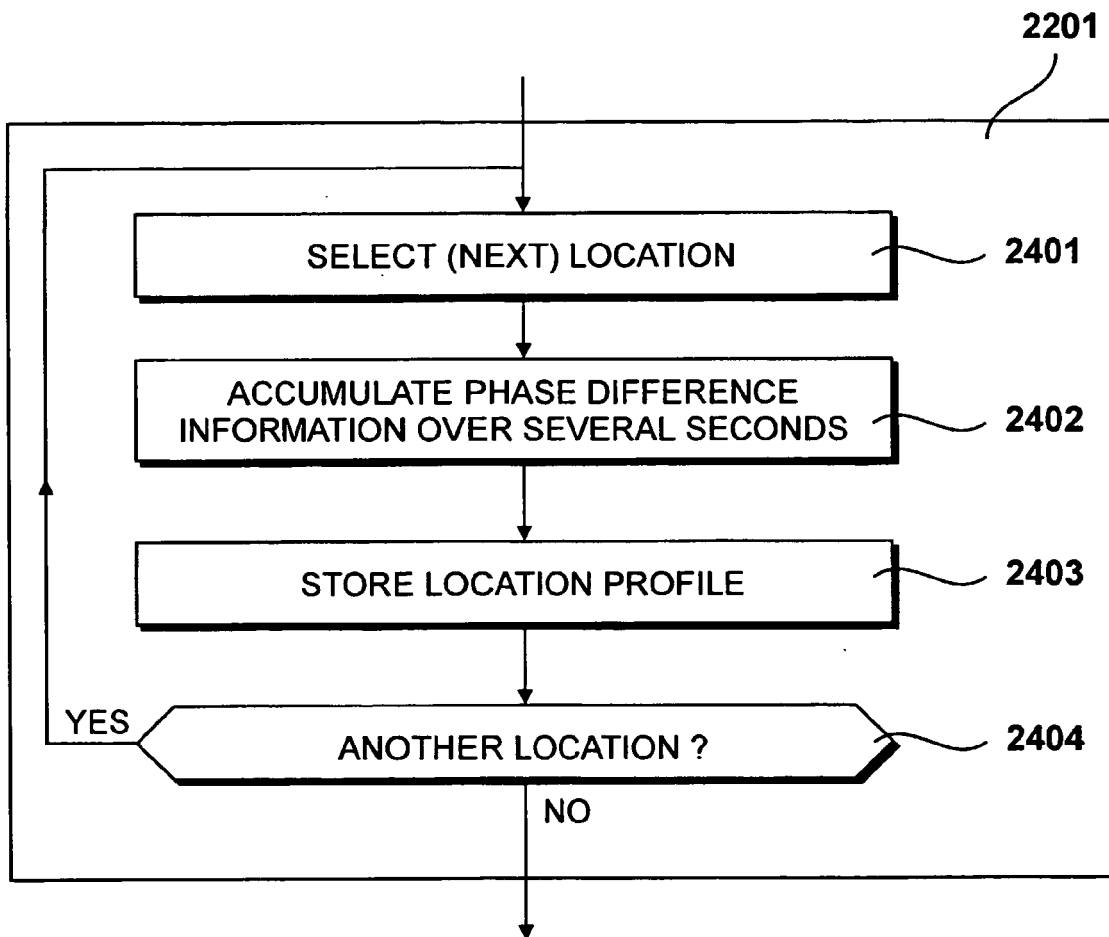


Figure 24

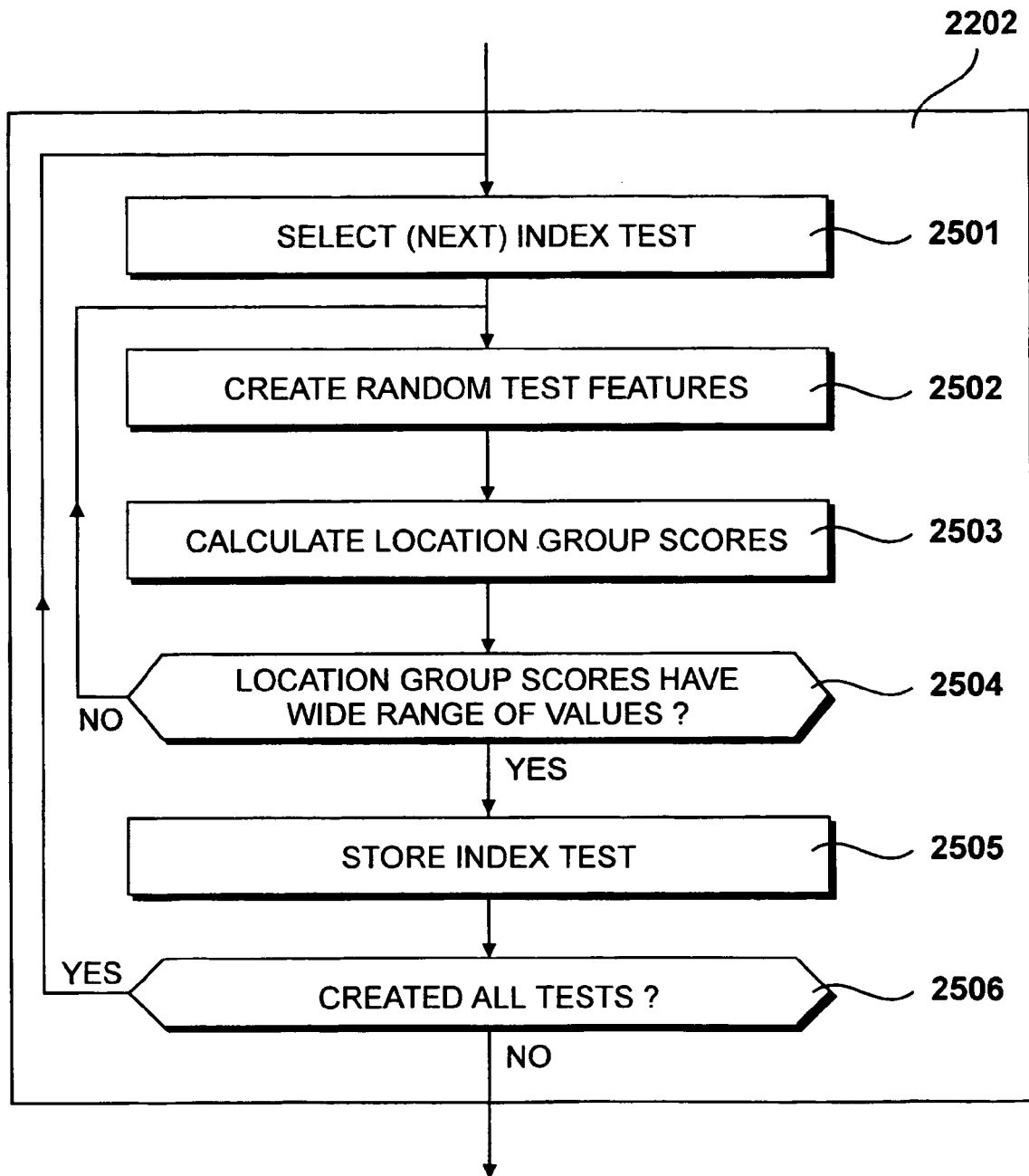


Figure 25

REFERENCES CITED IN THE DESCRIPTION

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