be utilized and this work has begun. For example, fixed displacement-based technology by Orbital Research uses microvalves that direct air to inflate small elastic balloons intended for use in an extended display for display of Braille (in a fairly low-density array). The display would, of course, remain static as the user reads it.

[0009] Johns Hopkins University has constructed a refreshable fingertip tactile graphic display for research on the sense of touch. The display uses a 20 by 20 pin array of stimulus points at 0.5 mm spacing, with a large multi-position linear actuator for each pin, and mechanical concentrator (linkages) to direct the activity of all 400 actuators into a small area (approximately 1 cm square, the entire device being several feet on each side). The action of the display is based upon controlled displacements of the pins at selected heights. The motors used to drive the pins have optical feedback to determine position, but this is mechanically linked to the driving source. The design is bulky and expensive, with pin operation based on fixed displacement.

[0010] Devices intended for accessibility applications have also been heretofore suggested and/or utilized. The VIRTOUCH VIRTUAL MOUSE uses three fixed displacement-based (4-level selection) 8×4 actuator fingertip arrays mounted on a computer mouse device. The arrays are driven by piezoelectric actuators, and while a user can learn to interpret tactile information (such as the tracking of the cursor across a virtual line), the spacing of the pins is several times too large to permit it to create detailed tactile sensations that would be needed for a general-purpose tactile display. Likewise, the OPTACON by Telesensory produces low resolution images using an optical scanner and a low-density array of vibrating pins to permit blind and visually impaired users to read printed or displayed text scanned by the device. The user must learn to interpret the vibration of the pins as image information (i.e., the pins do not change elevation). The use of fairly large electromechanical actuators and mechanical linkages limits the resolution of images achievable by the device.

[0011] Thus there remains a need for affordable refreshable tactile graphics for use by blind and visually impaired users, and particularly in a relatively portable and less cumbersome deployment. If the technology could also be used to improve the sense of touch in virtual reality and other related mainstream applications, this would increase the market size for the technology and drive further commercial development that would improve quality and lower the cost for both mainstream and accessibility applications.

SUMMARY OF THE INVENTION

[0012] This invention provides a refreshable scanning tactile graphic display apparatus and method for localized sensory stimulation designed so that the number of stimulus points needed is reduced from the thousands that would be needed for an extended array of conventional design, thereby lowering the cost of production of apparatus in accord with the invention. Further savings are achieved by reducing the ratio of actuators to stimulus points. Actuators disclosed herein will further reduce the cost per actuator, compared to discrete piezoelectric actuators currently in use.

[0013] The refreshable scanning tactile graphic display apparatus and system of this invention includes a display array having pressure responsive stimulus points embedded in a matrix, an energy source applied at the stimulus points through a modulator, a control unit, and, preferably, a position sensing and feedback unit.

[0014] More particularly, the apparatus for localized sensory stimulation of this invention to tactilely simulate a virtual display includes a high density array of stimulus points each capable of delivering different pressure variable stimulus at a selected body location of a user. An energy source and delivery system provide activation energy to the stimulus points, a modulator selectively activating, including varying pressure applied at, the stimulus points. A control unit controls the operation of the modulator, and a position sensing and feedback unit is preferably connected with the control unit to inform the control unit which portion of the virtual display should be tactilely simulated at the stimulus points.

[0015] The stimulus points are preferably fluid actuated and are held at a matrix for stimulating a localized area of a user's body. The modulator preferably provides an actuator array operatively associated with the stimulus points for selected application of working fluid thereto to both actuate and modulate body applied pressure at the stimulus points. The energy source and delivery system provides, in such case, for working fluid pressurization, containment and delivery.

[0016] The array of stimulus points covers only the surface of a localized area of the body (such as a fingertip, for example) for selectively stimulating the area. The individual stimulus points do not move laterally with respect to the skin at the area, and any given stimulus point always stimulates approximately the same spot on the skin. A pattern is selectively impressed on these stimulus points, and the pattern is caused to move across the surface of the skin in a uniform manner by the selective activation and deactivation of particular stimulus points in the array responsive to feedback. This stimulation of the sensors in the skin is comparable to a real patterned surface moving laterally across the skin's surface thereby creating the mental impression for the user of a real patterned surface moving across the skin.

[0017] The method of this invention for localized sensory stimulation to tactilely simulate a virtual display includes providing for delivery of stimulus at a high density set of points at a selected body location of a user. Stimulus delivery is modulated at different ones of the points for selective actuation including applying variable differential pressure stimulus at the points. Modulation is controlled responsive to selected input to control which portion of the virtual display should be tactilely simulated at the points.

[0018] It is therefore an object of this invention to provide improved graphic tactile display apparatus and methods.

[0019] It is another object of this invention to provide refreshable scanning tactile graphic display apparatus and methods.

[0020] It is still another object of this invention to provide pressure responsive refreshable scanning tactile graphic display apparatus including a display array with stimulus points embedded in a matrix, an energy source applied at the stimulus points through a modulator, a control unit, and, preferably, a position sensing and feedback unit.