

another embodiment, some exotic fluids such as electrorheological and/or magnetorheological fluid can be used in place of thermal fluid in thermal fluid pockets 504. Thermal fluid pockets 504 filled with electrorheological fluid can be stimulated by a local or remote electrical field, while thermal fluid pockets 504 filled with magnetorheological fluid can be stimulated by a local or remote magnetic field.

[0068] FIG. 5(b) is a side view diagram for an interface device 550 illustrating an array of haptic cells 502 using thermal fluid pockets 554 in accordance with one embodiment of the present invention. Device 550 also shows an activated thermal fluid pocket 554 and an activated activating cell 560. During the operation, thermal fluid pocket 554 increases its physical volume (or size) from its original state 556 to expanded thermal fluid pocket 554 when activating cell 560 is activated. When activating cell 560 is activated, it provides heat 562 to thermal fluid pocket 554 or 556 to expand the size of thermal fluid pocket 554 or 556. Due to the expansion of thermal fluid pocket 554, a localized portion 552 of insulated layer 506 is created. As soon as the temperature of the fluid in the thermal fluid pocket 554 cools down, the size of thermal fluid pocket 554 returns to its original state 556. The change of size between original size of a thermal fluid pocket 556 and expanded size of thermal fluid pocket 554 generates a haptic effect. It should be noted that activating cell 560 could be an electric heater or an optical heater such as an infrared simulator. As such, an array of haptic cells using thermal fluid pockets 552 may be used to control the surface texture of touch-sensitive surface of the interface device.

[0069] FIG. 6(a) is a side view diagram of an interface device 600 illustrating an array of MEMS pumps 602 in accordance with one embodiment of the present invention. The array of MEMS pumps 602 can be used to implement tactile regions for controlling surface textures. Diagram 600 includes an insulated layer 606 and a haptic layer 612. While the top surface of insulated layer 606 is configured to receive a touch or touches from a user, the bottom surface of insulated layer 606 is placed adjacent to the top surface of haptic layer 612. The bottom surface of haptic layer 612 is, in one embodiment, placed adjacent to a display (not shown in FIG. 6(a)), wherein haptic layer 612 and insulated layer 606 may be substantially transparent thereby objects or images displayed in the display can be seen through haptic layer 612 and insulated layer 606. It should be noted that display is not a necessary component in order for the interface device to function.

[0070] Haptic layer 612, in one embodiment, includes a grid of MEMS pumps 602, which further includes at least one pocket 604. Each MEMS pump 602 includes a pressurized valve 608 and a depressurized valve 610. Pressurized valve 608 is coupled to an inlet tube 614 while depressurized valve 610 is coupled to an outlet tube 616. In one embodiment, inlet tube 614, which is under high liquid pressure, is used to pump liquid through pressurized valve 608 to expand pocket 604. Similarly, outlet tube 616, which is under low pressure, is used to release the liquid through depressurized valve 610 to release the pressure from pocket 604. It should be noted that MEMS pumps 602 can be coupled to the same pressurized liquid reservoir. It should be further noted that pressurized valve 608 and depressurized valve 610 can be combined into one single valve for both inlet tube 614 and outlet tube 616. It should be further noted that inlet tube 614 and outlet tube 616 can also be combined into one tube.

[0071] A grid of MEMS pumps 602 includes an array of pressurized valves 608 and depressurized valves 610, wherein pressurized valves 608 are coupled with a rear or a side mounted liquid reservoir under pressure while depressurized valves 610 are coupled to a rear or a side mounted depressurized liquid reservoir with low pressure. Valves 608-610 control the filling and emptying the liquid pockets 604 in MEMS pumps 602 to produce localized strain. An advantage of using pressurized liquid reservoir is to quickly deform the surface of insulated layer 606 and to maintain the deformation with minimal or no energy consumption (or expenditure). It should be noted that MEMS pump 602 can also use pressurized air or other gases to achieve similar results as liquid.

[0072] Device 600 further includes a set of control wires 617-618, which can be used to control pressurized valve 608 and depressurized valve 610, respectively. It should be noted that each valve in haptic layer 612 is addressable using electrical signals transmitted from wires or wireless network.

[0073] FIG. 6(b) illustrates two diagrams of an interface device 620 and 650 having an array of MEMS pumps 604 in accordance with one embodiment of the present invention. Device 620 illustrates an activated pocket 623, which includes an activated inlet valve 630 and a deactivated outlet valve 632. During an operation, pocket 623 increases its physical volume (or size) from its original state 624 to its expanded pocket 623 when inlet valve 630 is activated. When inlet valve 630 is activated (or open) in response to electrical signal from wire 628, inlet tube 625 pumps liquid 626 from pressurized reservoir to pocket 623. Due to the expansion of pocket 623, a localized strain 622 of insulated layer 606 is created.

[0074] Device 650 illustrates an activated MEMS pump returns from its expanded state of pocket 623 to the original state of pocket 653. When depressurized valve 660 is activated, depressurized valve 660 releases liquid 656 from pocket 653 to low pressurized outlet 654. It should be noted that depressurized valve 660 is controlled by at least one control signal via wire 658. The change in volume between original size of pocket 604 and expanded size of pocket 623 generates haptic effects. As such, an array of MEMS pumps 602 may be used to control the surface texture of touch-sensitive surface of the interface device.

[0075] FIG. 7 illustrates a side view diagram for an interface device 700 having an array of haptic cells 702 using variable porosity membrane 710 in accordance with one embodiment of the present invention. The porosity membrane 710 can be used to implement tactile regions for controlling surface textures. Device 700 includes an insulated layer 706 and a haptic layer 712. While the top surface of insulated layer 706 is configured to receive inputs from a user, the bottom surface of insulated layer 706 is placed adjacent to the top surface of haptic layer 712. The bottom surface of haptic layer 712 is, in one embodiment, placed adjacent to a display (not shown in FIG. 7), wherein haptic layer 712 and insulated layer 706 may be substantially transparent thereby objects or images displayed in the display can be seen through haptic layer 712 and insulated layer 706. It should be noted that display is not a necessary component in order for the interface device to function.

[0076] Haptic layer 712, in one embodiment, includes a grid of haptic cells 702, inlet valves 703, and outlet valves 704. Haptic cells 702, in one embodiment, are pockets capable of containing fluid. Haptic layer 712 is similar to haptic layer 612 as shown in FIG. 6(a) except that haptic layer