graphic display apparatus for localized sensory stimulation will be discussed. Basically, the apparatus and system includes a control unit **41** (preferably microprocessor based and including program memory), position sensing and feedback unit **43** (such as device **21** or glove **23**) used to inform the control system of which portion of the virtual surface should be displayed, energy source **25** (working fluid storage and pressurizer, for example), channels/interface **27** and/or **31** and **33** for containment of the working fluid, modulator **29** and array **15** including stimulus points **17** embedded in matrix **19**.

[**0048**] Preferably, energy source **25** is a storage and/or pressurization system utilizing working fluid such as filtered air. The advantages of air are apparent, including plentiful readily available supply and unimportance of minor leakage. Air may be used through ancillary channels at array **15** to control heating and humidity to limit perspiration. The ready compressibility of air can serve as a buffer to help regulate the pressure of the stimulus points against the finger or other body locale. Since compressibility limits the frequency response of the system, air channel design must take into account the maximum stimulus frequency that will be needed. Systems using large volumes of working fluid are made quite practical utilizing air and obviate the need for working fluid recovery. Systems could employ other fluids such as water or hydraulic fluid. Such liquid based systems have the advantage in applications employing high frequency operations, though leakage, inertia and fluid recovery must be managed. In either case, pressurization is achieved by conventional means such as a pump, and a pressurized fluid reservoir may be useful in balancing fluid delivery. Volume and pressure regulation of convention varieties may be employed, so that volume and pressure are sufficient to allow correct operation when a large percentage of the stimulus points are activated.

[**0049**] Channels/interface **27** and/or **31** and **33** for working fluid must meet the needs for positioning of components (for example, source **25** of pressurized working fluid may be some distance from fingertip stimulator array **15**), are selected to meet requirements for volume delivery while keeping pressure drop within specified bounds, and are designed for maximum volume/cross section, flexibility and durability.

[**0050**] Pressure-based stimulus at stimulus points **17** is accommodated by modulation of the flow of working fluid to the individual stimulus points **17** at modulator **29**. Utilization of an array of microvalve actuators in a one to one relation with the number of stimulus points is the now preferred implementation of this modulation function. A highly compact array of electromechanical valves (Microelectromechanical systems, or MEMS, technology, for example) may be utilized. Since the valves need only be large enough to allow passage of sufficient working fluid to operate the stimulus points, the entire microvalve array **29** can be on the order of the area of stimulus point array **15** itself using currently available technology. The simplest and most reliable implementation would be one microvalve per stimulus point **17**, with the microvalve array either placed very close to stimulus point array **15**, remotely from array **15**, or a combination thereof. The number and nature of channels/interface **27** and/or **31** and **33** will be determined by selected placement of microvalve array **29** relative to stimulus point array **15**.

[**0051**] For one to one implementation, each microvalve in array **29** is selected to handle the volume of fluid flow needed to drive one stimulus point **17** (which in turn will depend upon the type of stimulus point deployed as hereinafter detailed). Alternatively, multiple smaller microvalves could be used for each stimulus point **17**, thereby improving reliability of display array **15** by providing graceful degradation of performance in the event of failure of a single valve. Increased reliability can be further provided by use of valves that are normally closed unless activated, such valves being less likely to become jammed in the open position. As discussed further below, cost savings may be achieved using fewer valves and requiring each valve to drive several stimulus points **17** under control of a multiplex selection regime at control unit **41**.

[**0052**] If the valves of modulator array **29** feature binary operation (either fully open or fully closed, with no intermediate positions) then the degree of pressure applied at stimulus points **17** may be controlled by temporal (time-based) modulation of the valves. Modulation techniques can include adjustment of duty cycle (the percentage of the time that each valve is open) or various other techniques in which the valves are very briefly pulsed to the open position many times per second and wherein the pressure applied (or felt) at a stimulus point **17** is determined by the number of pulses per unit of time. With temporal modulation techniques, it is highly desirable that no unintended vibration be apparent to the user (the threshold of sensitivity to vibration varies from person to person and depends on display parameters, but is generally in the area of several hundred Hertz). The switching speed of the valves is not the only factor to consider in avoiding unwanted vibration. If brief pulses are used as the modulation technique, then the pulses should be distributed relatively evenly over time so that there is not a significant low frequency component to the pressure signal delivered to stimulus points **17**. The inclusion of a small storage reservoir between a valve in array **29** and a stimulus point **17** of array **15** (before lines **27** or incorporated with complex **33**, for example) would tend to smooth out high frequency vibration components, which may be desirable for display systems that do not need high frequency operation.

[**0053**] Alternatively, variable pressure valves (valves having continuously variable fluid throughput capability), while more complex to manufacture and control, could be utilized to control pressure application at stimulus points **17**. While the valves may include exhaust porting, fluid exhaust is preferably handled at stimulus points **17**.

[**0054**] Pressure-driven stimulus points **17** in array **15** may be implemented in several different ways. As shown in **FIG. 6**, plurality of pin assemblies **39** each including a cylinder **35** having a piston **47** with pin **49** mounted thereon may be used so that the working fluid (such as air) coming from modulator **29** passes into cylinder **35** through inlet **37** (from either lines **27** or at interface **33**) and pushes piston **47** (and thus pin **49**) part way out of cylinder **35**, pressing pin **49** against the skin of the user with a pressure proportional to the average pressure of the working fluid applied to cylinder **35**. When no working fluid is applied at inlet **37**, leakage in cylinder **35** (in the case of air, for example, at exhaust passage **51** formed at piston **47**, pin **49** having a diameter smaller that that of the piston), or slow return of working fluid through a control path (in the case of liquid) causes sufficient working fluid to escape cylinder **35** so that the resilience of the skin causes