ing is not inhibited to the degree that it would interfere with positions and angles of the fingers. When creating a mental model of the dimensions of an object being grasped, the user may learn to ignore the thickness of the display apparatus at the body locale and concentrate on the differential signal provided by the display apparatus.

[0070] It is important to note that the output of the pressure-based tactile display apparatus of this invention is effectively a differential signal, whether or not it is combined with a haptic system. If the same force is applied to all the stimulus points **17**, the perceived sensation will be much the same as when no force is applied to any of the stimulus points. This is a good match for detailed sense of touch in humans, which depends on differences in pressure and changes over time to collect tactile information. A display driving algorithm should, therefore, concentrate on such differentials applied at array **15** thereby minimizing power consumption while producing a useful tactile signal and providing a differential signal margin adequate to allow reasonable changes in what is being displayed over a short time interval. The driving algorithm must also take into account the maximum frequency and other capabilities of the apparatus, the degree of realism needed, and the texture and rate of change in motion of the virtual surface being displayed. The modulation frequency needed is increased by higher density of stimulus points **17**, by increases in the number of intensity levels needed, by increases in the velocity of the virtual surface being displayed, and by the effort to avoid the unintended perception of vibration.

[0071] Methods that may be used in the display driving algorithm include implementation of multiple pressure levels by rapid sequencing of pseudorandom patterns so that each stimulus point is driven the correct fraction of the time, while any unintended vibration or motion felt by the user is minimized. For representation of very rapid lateral motion, the performance bandwidth of the tactile display may not be adequate to recreate the motion of a detailed surface with complete accuracy. However, the human sense of touch is unable to maintain full detail spatial resolution during rapid motion. The driving algorithm can take advantage of this limitation in human perception and produce a stimulus that, while lacking in the full detail and motion, conveys to the user enough information to produce a realistic sensation. Specific techniques may include driving only a subset of the total collection of tactile stimulus points **17** during rapid motion and skipping steps in the lateral propagation of patterns.

[0072] The refreshable scanning tactile graphic display apparatus and methods for localized sensory stimulation of this invention can be used in many applications. The display apparatus provides much of the functionality of a large-area refreshable tactile display in a smaller package and with a greatly reduced number of stimulus points. By integrating one or more fingertip arrays **15** into data glove **23**, a detailed sense of touch can be added to the virtual environment, and integrated with existing haptic technology. The tactile display apparatus can be included in an augmented reality system that combines elements of the real world and virtual reality (for example, a robot manipulator device that is operated by remote control (teleoperation) can be equipped with pressure sensor arrays to give it a "sense of touch", signals from the arrays being relayed to a human operator using the apparatus of this invention, who then has tactile input, not merely sight, to guide operation of the manipulator). Fingertip tactile display apparatus of this invention can be put into the fingers of a protective suit, with sensors or mechanical linkages on the outside of the fingers of the suit to direct the driving of the display arrays, thereby providing the users of such suits with a more effective sense of touch for improved ergonomic design and more effective operation (many environmental isolation suits or pressure suits have gloves that protect the user from a hostile environment but that also significantly limit the sense of touch in the fingers). Other applications will be apparent from those disclosed hereinabove.

What is claimed is:

1. A refreshable scanning tactile graphic display apparatus for localized sensory stimulation comprising:

a high density array of stimulus points each capable of delivering different pressure variable stimulus at a selected body location of a user;

means for applying activation energy from an energy source to said stimulus points;

a modulator for selective activation including pressure variation of said stimulus points utilizing said means for applying activation energy; and

a control unit for controlling said modulator operation.

2. The refreshable scanning tactile graphic display apparatus of claim 1 further comprising a body position sensing and feedback unit having said high density array of stimulus points mounted therewith and providing body position information to said control unit.

3. The refreshable scanning tactile graphic display apparatus of claim 2 wherein said body position sensing and feedback unit is one of mouse-type tracking device, a data glove, and a lateral pressure sensitive scanning control and feedback mechanism for controlling speed and direction of virtual surface scanning.

4. The refreshable scanning tactile graphic display apparatus of claim 1 wherein said high density array of stimulus points includes about 400 stimulus points per square centimeter.

5. The refreshable scanning tactile graphic display apparatus of claim 1 wherein said stimulus points are fluid activated and wherein said modulator is a microvalve array.

6. The refreshable scanning tactile graphic display apparatus of claim 5 wherein said microvalve array includes a number of valves equal to number of stimulus points in said array of stimulus points, each said valve operating a single said stimulus point.

7. The refreshable scanning tactile graphic display apparatus of claim 5 wherein pressure variation at said stimulus points is controlled by control unit signals at least one of causing varying pressure of working fluid to said modulator, causing selective temporal modulation of operation of valves in said microvalve array, and causing selective fluid throughput operation of valves in said microvalve array.

8. A refreshable scanning tactile graphic display apparatus for localized sensory stimulation to tactilely simulate a virtual display comprising:

a plurality of fluid actuated pressure variable stimulus points held at a matrix for stimulating a localized area of a user's body;