compared to the time needed to scan the entire display. If the source imagery is not in vector form, then the display driving algorithm must include the capability to efficiently transform other image formats to vector form. There are image processing programs currently commercially available that can be adapted to perform this function. Vector conversion may include the introduction of brief delay cycles in the drawing vectors to ensure that the drawing speed does not exceed the speed capability of the display components.

[0069] Tactile graphic vector drawing can be conducted using a tracker **93** either hand operated (in the simplest mode of operation) or mounted at a precision 2-dimensional guidance system **94** and having a freely rotating metal ball **95** maintained in the end of tube **97** (similar in structure to the tip of a ballpoint pen) to press against the pins on the back of the display when the actuator is engaged **(FIGS. 12 and 13)**. The diameter of the ball determines the number of pins that are expected to be set with any arbitrary motion of the tracker, and thus the solidity and thickness of the tactile line to be drawn. A thicker line can be drawn by multiple passes of tracker **93** with a slight offset of ball **95** for each pass.

[0070] Alternatives to the roller ball tracker **93** are a precision actuator tip that contacts selected pins individually (provides greater precision, but slower drawing), and a tip that vibrates with sufficient amplitude and sufficiently high frequency that it impacts and sets all the pins along the vectors being drawn.

[0071] The section above on pin locking describes the desired mechanical properties of the control for the pin locking mechanism—the need for precision motion control of the locking mechanisms for all the pins, moved all together for a very short distance, with the need for the locking mechanism to remain stable during the reading process. For a powered display, an actuator can provide the needed force to engage and disengage the lock, and can be controlled by the same control system that operates the other components of the display. Because reading may often be a lengthy process and the user may sometimes want a particular image to be displayed for a long period of time, it is desirable for retention of the lock to be performed by the mechanical linkage to the locking mechanism, so that the pins remain locked (and the image is retained) with no additional application of power once the lock is engaged.

[0072] When the time comes to reset the display, the pin locking mechanism is disengaged, and all the pins must be reset, possibly requiring force to overcome the effect of the temporary pin holding system. A device that engages all of the set pins of the display and moves them to the reset position is one approach, and could be made as part of the locking mechanism. This can be accomplished by including a plate in the array stack that can move vertically (perpendicular to the plane of the display) as well as horizontally, and has ovoid holes or other mechanism to catch the pins—for reset, the plate would be moved horizontally to catch all the pins that have been set, then vertically to move the pins to the reset position. A simpler approach is a roller or similar device that passes over reading surface **23** of the display apparatus and pushes all the pins to their lowest possible position. In a computer controlled display, the action of the resetting device can be controlled by the overall control algorithm of the display. If the resetting device contacts the parts of the display where the users put their fingers, it is desirable to include a guard to prevent the users' fingers from being caught in the resetting device. A safety interlock can also help in the prevention of injury or damage to the display.

[0073] Tactile graphic images embossed on paper or plastic represent a well-known and popular medium. Embossed images are somewhat different from tactile images formed by discrete pins, because in an embossed image the paper or plastic sheet forms a continuous connection between adjacent points (similar in concept to the tent material draped from pole to pole in a circus tent), which may tend to smooth out the sensations produced by the discrete nature of the embossed points, and (for example) make lines and curves feel continuous to a greater extent than would otherwise be the case.

[0074] While the use of discrete pins **21** with large rounded heads **31** as heretofore described produce a sensation of continuity comparable to that of embossed images on paper with the same pin spacing, there may be applications for which the additional smoothing effect of a continuous sheet is desirable. This can be implemented by placing a thin sheet of flexible material **101** between the image produced by the pins and the user's fingers (see **FIG. 13**). Holding the flexible sheet against the pins with a partial vacuum can produce an even closer approximation to the sensation of reading embossed images on paper. An additional benefit of this approach is a reduction in contamination of the internal components of the display by dirt and other substances introduced from the fingers and by environmental exposure.

[0075] A possible alternate use of a flexible sheet is the application of a tactile graphic array as a mold or form for production of a permanent record of a displayed image. As an example, the user interacts with the refreshable tactile graphic display system, and occasionally wants to save a copy of what is displayed for later reference or to transfer to another user who may not have a refreshable display. A thin sheet of thermoplastic material **103** is heated and placed against the display surface (see again **FIG. 13**). The material can be pressed or vacuum formed against the surface of the display until it cools and hardens, after which time it can be removed, and retains an image of what was displayed. This capability may also be helpful to a user who is performing design work or conducting research and needs simultaneous access to multiple tactile graphic images (more than can be shown on the refreshable display at one time). The use of the same surface for direct reading by the user and for production of hardcopies represents an additional convenience for the user.

[0076] A two-level display (each pin either extended or not extended) is sufficient for displaying lines, curves, and textured 2-dimensional surfaces, and thus provides the functionality of 2-dimensional graphics. For some users who have learned to interpret perspective, this may include the capability to display 2-D perspective drawings of 3-D objects. A higher level of tactile graphic representation would present a true three-dimensional tactile graphic object. An extended array tactile graphic display is not capable of presenting full 3-D tactile graphic images, but it can be used in an intermediate format that conveys some three-dimensional information. This format requires that the