The invention in summary provides a tactile stimulator array system which includes a plurality of tactile elements having touch-stimulating portions which are moved between first and second positions by shape-memory alloy actuators. The actuators move between a contracted or "memory" shape when heated through a phase change transition temperature, and an elongated shape when cooled below that temperature. Movement of the touch-stimulating portions by means of time-varying signals, such as from a programmed computer system, provides tactile feedback to a person using the stimulator array.

The device is useful for virtual reality studies such as training cockpits for pilots and operators, for tactile feedback in tele-operator systems for remote operation of robots, for communication by the visually or hearing impaired, for laboratory and clinical evaluation of medical conditions including peripheral neuropathy, or as part of a control system for computer games of the type employing gloves which are worn to interact with the computer, or as an enhancement to a mouse for the control of input-output functions in personal computer use.

One embodiment of the device comprises a set of levers cut from a sheet of elastic metal, each lever attached to a wire of nickel-titanium shape-memory alloy in such a way that contraction of the shape-memory alloy wire causes the lever to bend upward, raising a portion of the lever above a surface where its motion is detected by the sense of touch.

The foregoing and additional objections and features of the invention will appear from the following specification in which the several embodiments have been set forth in detail in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective, partially cut-away, view illustrating components of a tactile stimulator array system according to one embodiment of the invention;

FIG. **2** is a plan view of the tactile elements for the system of FIG. **1**;

FIG. **3** is a fragmentary vertical section view of the array system of FIG. **1** showing one tactile element and its associated shape-memory alloy actuator in a first operating position;

FIG. **4** is a view similar to FIG. **3** showing a changed position of the tactile element and its actuator;

FIG. **5** is a schematic diagram showing the control circuit for use with the array system of FIG. **1**;

FIG. **6** is a schematic diagram showing an implementation of another embodiment of the invention under programmed control of a computer system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the drawings FIG. **1** illustrates generally at **10** a stimulator array system according to one embodiment which provides tactile feedback to a human user. As used herein, tactile feedback means time-varying tactile signals which are presented to human sense organs, such as a person's fingers, for the purpose of conveying information. For example, the information can be the shape and texture of a remote object, which may be either real or virtual. In the case of a real object, the shape and texture information may be generated by tactile sensors in contact with the surface of a solid object, converted to electrical signals, and then transmitted via computer to tactile stimulator array system **10**. In the case of virtual objects, information may be created by computer software to simulate the shape and texture of entities which are represented by numerical description, such as CAD drawings, icons or video game sprites. To convey shape and texture information, tactile feedback would in general utilize through the invention arrays containing multiple stimulators which move independently of each other.

Stimulator array system **10** includes a touch plate **12** which is mounted on a base plate **14** which in turn is mounted on a suitable support or housing, not shown. Touch plate **12** is comprised of a plurality, through the touch plate in a series of rows. The openings are suitably spaced-apart so that one or more of the person's fingers can be comfortably placed over the array of openings.

The array system further includes a plurality of tactile elements **18**, **18'**, each of which is associated with a respective opening **16**, **16'** in the touch plate. As best shown in FIGS. **3** and **4**, tactile elements **18** are comprised of elongate, thin and flexible cantilever beams **20**, each of which has a proximal end **22** integral with base plate **14** and a distal end **24**. The distal end is bent upwardly at substantially a right angle so as to project at least partially through the associated opening **16**. A suitable cap **26**, which can be of a plastic material, is secured to the distal end of each cantilever beam for comfortable contact with the person's fingers.

FIG. **2** illustrates in plan the cantilever beam elements **18** formed integral with the common base plate **14**. Preferably the base plate and elements are made from a suitable spring metal material, such as BeCu. The pattern of cantilever elements can advantageously be formed on a flat blank plate of BeCu or other such material by means of conventional chemical etching techniques, followed by bending of the beam ends and heat treatment. FIG. **2** shows thirty elements closely spaced together into a high density array for compactness. It is understood that the pattern and number of elements can be varied as required for a particular application. The longitudinal positions of adjacent cantilever elements are staggered so that, with the base plate mounted under the touch plate, the distal ends **24** are aligned with and project upwardly through the proper openings.

Actuator means for the tactile elements is provided and includes a plurality of wire actuators **28** formed of a shape-memory alloy material, also called "SMA" material. The shape-memory alloy material can be TiNi, which is a nickel-titanium alloy, or other suitable Joule-effect alloy. These alloys undergo a temperature-dependent phase change at near ambient room temperature. At room temperature, the metal is easily deformed plastically by as much as a few percent, and remains deformed until the temperature is raised above the transition temperature, when it forcefully reverts to its original or memory shape. As used herein, "memory" shape means the contracted shape of the wire in its high temperature phase, and "deformed" shape means the elongated shape of the wire in its low temperature phase. As much as a Joule per gram of work may be accomplished in the shape recovery. Actuation may be by the application of heated fluid, or by Joule heating of the SMA material itself by passing an electric current through the wire.

Separate SMA wire actuators **28** are provided for each cantilever tactile element **18**. As best illustrated in