the edges of the tiling might be unused, and perhaps covered with the hand rest to prevent use or indicate the touchable portion.

[0069] Preferably, high flexibility wire is used for coil cable **114** and XY cable **118** because of the relatively large motion of the moving assembly relative to the short length of the wires. The wire is preferably very finely stranded wire with silicone insulation. The wires should not significantly impede the motion of the moving assembly. Suitable parts are exemplified by devices with trade designation AS999-30-2SJ for the two conductor coil cable and AS-155-28-5SJ for the five conductor XY cable, available from Cooner Wire of Chatsworth, Calif..

Proximity sensor operation

[0070] Proximity sensor **308** is preferably designed to provide high resolution and bandwidth at a reasonable cost. High resolution increases the fidelity of the haptic display in general and in particular improves the quality of velocity and acceleration measurements derived from the output of proximity sensor **308**. Proximity sensor **308** preferably provides a resolution of 0.05 mm, and most preferably a resolution of about 0.01 mm.

[0071] The position of moving assembly **100** within its range of travel is measured by proximity sensor **308**. In one embodiment, proximity sensor **308** contains an infrared LED and an infrared phototransistor in the same enclosure. In such a device, the LED and phototransistor point upward and are optically isolated from each other within proximity sensor **308**. An example of such a device is available from Optek of Carrollton, Tex. under the trade designation OPB-710.

[0072] Position circuit **700**, shown in **FIG. 7**, interfaces proximity sensor **308** to analog input card **906**. Resistor RI limits the current through the LED to an allowed value, causing the LED to emit a constant amount of light. A typical value would be 76.8 Ohm. The light emitted by the LED is reflected by the interior top of coil holder **104**. Some of the reflected light is received by the phototransistor. The current through the phototransistor is proportional to the quantity of light falling thereon. Resistor R2 converts this phototransistor current to a voltage which forms the input of low pass filter **702**. A typical value for R2 is 2.21 kOhrn. Low pass filter **702** is a voltage-controlled voltage-source 2-pole Butterworth filter with a 3 dB roll-off point at 1.3 kHz and gain of 1.59. Typical component values are 12.1 kOhm for resistor R**3**, 0.01 microFarad for capacitors C**1**, 33.2 kOhm for resistor R**4**, 56.2 kOhm for resistor R**5**, and 0.1 microFarad for bypass capacitors C**2**. Op amp **704** is a CMOS operational amplifier with rail-to-rail operation. Suitable parts are available from National Semiconductor of Santa Clara, Calif. under trade designation LMC6482. The frequency roll-off of the low-pass filter is preferably lower than half of the per-channel sampling rate of the analog input card. Additionally, it will be noted that, preferably, the phototransistor provides bandwidth commensurate with its sampling rate. Using a 12-bit resolution analog input card as analog input card **906**, control system **902** can discern between moving assembly positions separated by about 0.01 mm.

[0073] The interior top of coil holder **104** is preferably painted to diffusely reflect infrared light. Diffuse reflectivity ensures that the phototransistor current varies smoothly and monotonically with distance, and provides a consistent reading independent of any tilt of the moving assembly. The interior sides of coil holder **104**, and the exterior top and sides of flux disk **306**, are preferably painted to absorb infrared light so that light does not reach the phototransistor through secondary reflections. Such an embodiment provides better contrast between readings at the limits of travel.

[0074] The output of position circuit **700** is usually not linear with respect to the position of moving assembly **100**. The output may be characterized as being approximately the inverse square of the distance between proximity sensor **308** and the inside surface of coil holder **104**. This effect can be corrected, for example, by calibrating proximity sensor **308** prior to use. The moving assembly **100** is moved across its range of possible positions very precisely, for example, with a micrometer in steps of 0.001 inch. The output of the position circuit is then measured and recorded. Later, when a making a position measurement, the output corresponds to one of position circuits **700(1)**-(N) and is compared to the stored values, and the distance is computed with an interpolation of the two closest readings. This calibration procedure also corrects for any non-linearity in the response curve of the phototransistor. Alternatively, an equation could be fit to the calibration data to allow a direct computation of the position from a reading.

XY sensor operation

[0075] XY sensor **116** may be of many conventional designs, such as a resistive film position sensor. The effective resolution of a resistive film position sensor is typically greater than 100 dots per inch (dpi). In the scenario in which haptel grid **604** is mapped to a display (not shown), the cumulative resolution of XY sensors **116(1)**-(N) on haptel grid **604** is preferably equal to or greater than the resolution of the display area mapped to I/O device **900** (e.g., as a result of the direct mapping between haptel grid **604** and the display). However, there may be pixels on the display which cannot be touched by the user. For example, the resolution of computer displays is typically 75 to 100 dpi, thus haptel grid **604** can be mapped to an equal or somewhat larger display area when resistive film technology is used in XY sensors **116(1)**-(N).

[0076] The actuation force of this type of sensor can be controlled during its manufacture. Unlike other uses for these touch sensors, the sensor is not used to initiate actions but only to sense position. Because each haptel potentially maps to multiple user interface elements, the device cannot determine which haptic effect to generate until the XY coordinates of a touch are known. Preferably, the lowest possible actuation force is thus used. For example, a value of 5 grams could be employed.

[0077] Actuation force also comes into play when touches overlap multiple haptels. Because applied force is spread across the haptels involved in the touch, it is possible that the force on one or more of the haptels is below the threshold of its XY sensor. In the worst case, a force of 20 grams would have to be applied at the vertex of 4 haptels before getting an XY reading (using a 5 gram actuation force). While users can adapt to differences in actuation force for different parts of the display, the user experience is enhanced by a more uniform and lower actuation force. An alternative is the use of sensors that exhibit a reduced actuation force, such as capacitive proximity sensors.