utilized to convey active responses to touch events such as signifying that an action was taken (e.g., button click). In some cases, a second secondary haptic device can be used to convey other active or passive responses. Some haptic devices (such as the secondary ones mentioned above) can be better at simulating mechanical clicks (e.g., dome switch) making the user experience similar to what they are used to in legacy devices that utilize mechanical inputs (switches) instead of electrical inputs (touch sensing).

[0053] By judiciously selecting appropriate materials, haptic response of device **100** can be adjusted based upon the acoustic properties of the materials that go into creating device **100**. Protective layer **120** can be formed from a material with localized damping properties such that vibro-tactile sensations in one quadrant are not substantially felt in another. For example, protective layer **120** can be glass or other transparent (or at least translucent) material having natural damping properties suitable for small form factor devices having small area displays. Generally speaking, substantially all of protective layer **120** can be provided with haptic sensations as a single unitary member, however, it is possible to provide for individually-moving portions of protective layer **120** by providing each portion with their own haptic actuator where the haptic responses can be limited to particular region of surface **126** with effective range R as shown in FIG. **2**A. In this way, haptic sensations can be provided for only a particular portion of protective layer **120** using the natural damping factor of glass to limit the effective range of the actuator. Moreover, the properties of protective layer **120** can be selected such that vibro-tactile transmissions from at least two haptic actuators can interfere with each other, either constructively or destructively, in order to provide a compound haptic sensation.

[0054] Although the resolution can be widely varied, in one embodiment, sensing regions **128** are placed coarsely about the surface. By way of example, sensing regions **128** can be placed at several quadrants (groups of touch sensors). As illustrated in FIG. **2**B, a surface **126** (as a rectangle) can include about n actuators with a concomitant number of sensing regions **128** in order to create vibro-tactile sensations within about n quadrants of the rectangular oriented touch surface. For example, if n=6, the quadrants can include upper right (I), upper left (II), center left (III), center left (IV), lower left (V) and lower left (VI). It should be noted that low resolution can be used to simulate a much higher resolution, especially when the touch surface is fairly small itself (hand sized). One of the advantages of the system **100** is that it can provide tactile feedback to more than one distinct point on surface **126** at about the same time. Surface **126** can be divided into an array of active areas each of which is influenced by a particular actuator. In this way, each haptic actuator can directly influence one area, however, effects from other actuators can combine to form a complex signal. For example, a finger placed at point X can receive a compound haptic response H(X) that can be a function of up to three haptic actuators associated with haptic regions n_1, n_2, and n_3 In other words, the compound haptic response at point X can be expressed as equation (1):

$$H(X)=H(n_1, n_2, n_3) \quad \text{eq (1)},$$

where the relative contributions of each haptic node n_1, n_2, and n_3 is related to the distance of X from each haptic node, respectively. For example, when at least two fingers are close together get one type signal can be generated. However when the at least two fingers move apart, then each of the at least two fingers can feel different haptic signals from different haptic actuators. Moreover, silent areas or quiescent areas (i.e., regions where a user would feel little or no appreciable sensation) can be created. These silent areas can be created when actuators generate signals that destructively interfere (signals are 180° out of phase with each other) within the region (also referred to as a null region).

[0055] In the case where the haptic actuators are piezoelectric in nature, the vibro-tactile response is generated by the mechanical flexion of a member composed of a piezoelectric material. FIG. **3** schematically illustrates the structure and the principle of the operation of a representative multiple layer piezoelectric actuator assembly (also referred to as haptic device) **300** in accordance with the invention. The piezoelectric assembly **300** comprises an upper piezoelectric layer piezoelectric **302** and a lower piezoelectric layer **304** (it should be noted that there can be any number of layers). The piezoelectric assembly **300** can either expand or contract in accordance with the direction of an applied voltage V. For example, by applying, to the upper layer **302**, a certain voltage of the direction opposite to the lower layer, the upper layer **302** contracts and the lower layer **304** expands at about the same time thereby causing the actuator **300** to bend upward (or downward) as a whole. Due to the inertial coupling of the actuator assembly **300** to the surface **126** when the inertial mass of the actuator is oscillated (by varying the applied voltage V), the inertial sensations are transmitted through member **306** to the surface **126**. A foam layer (or other compliant layer) can be coupled between actuator assembly **300** and the surface **126** to provide compliance and allow the surface **126** to move inertially. It should be noted that haptic actuator **300** has a fast tactile bandwidth so that it can be used into tactile feedback device. Haptic actuator **300** can activate with very small latency so that it can be used in interactive tactile feedback application and consumes relatively low power and requires very low voltage. Advantageously, by using the multi-layered piezoelectric haptic actuator, it is possible to form the haptic device into small and thin chip.

[0056] Haptic actuator **300** generates force F directly proportional to voltage V applied to the haptic actuator **300** by the controller. Depending upon the polarity of voltage V, layers **302/304** either expand/contract or contract/expand resulting in a displacement ΔY of beam member **306**. (It should be noted that displacement ΔY is much larger than the longitudinal contraction and expansion of each of layers **304/302**.) More specifically, the displacement ΔY can be calculated using equation (2):

$$\Delta Y = k_1 \times d_{31} \times \left(\frac{L}{t}\right)^2 \times V \quad \text{eq (2)}$$

[0057] where,

[0058] k_1: correction factor

[0059] d_{31}: piezoelectric constant value

[0060] L: length of the actuator

[0061] t: thickness of one layer of the actuator

[0062] V: voltage applied to the actuator