[0033] FIG. **4**A shows an illustrative button icon **402** that is arranged to appear to have a dimension of depth. Visual effects such as drop shadows, perspective, and color may be applied to a **2**-D element displayed on a touch screen (e.g., touch screen **110** or **310** in FIGS. **1** and **3**, respectively) to give it an appearance of having 3-D form. In this example, the visual effect is applied to the button icon **402** when it is in an un-actuated state (i.e., not having been operated or "pushed" by a user) so that its top surface appears to be located above the plane of the touch screen just as a real button might extend from a surface of a portable computing device.

[0034] FIG. **4**B shows a button icon **411** as it would appear when actuated by a user by touching the button icon with a finger or stylus. As shown, the visual effect is removed (or alternatively, reduced in effect or applied differently) so that the button icon **402** appears to be lower in height when pushed. In those applications where pressure-sensitivity is employed with the touch screen, the visual effect may be reduced in proportion, for example, to the amount of pressure applied. In this way, the button icon **411** can appear to go down further as the user presses harder on the touch screen **110**.

[0035] FIGS. **5**A and **5**B show the application of similar visual effects as described above in the text accompanying FIGS. **4**A and **4**B when applied to an illustrative keycap. FIG. **5**A shows a keycap **502** in its un-actuated state, while FIG. **5**B shows a keycap **511** as it would appear when actuated by a user by touching the keycap with a finger or stylus.

[0036] FIG. **6** shows the illustrative portable computing device **105** as configured to provide a combination of tactile, audio, and visual feedback to a user to provide the user **102** with the sensory illusion of interacting with a real 3-D key when a keycap in the virtual keyboard **206** is actuated using the device's touch screen **110**. In some applications of the present 3-D object simulation, it is anticipated that utilization of the combination of all three feedback mechanisms (tactile, audio, and visual) will provide a highly satisfactory user experience while fully enabling blind input and/or touch typing on a device. However, in other scenarios, use of feedback singly or in various combinations of two may also provide satisfactory results depending on the requirements of a particular application. While FIG. **6** shows an illustrative example of a virtual keyboard, it is emphasized that the use of the feedback techniques described here are also applicable to icons used for control or navigation, and icons which may represent content that is stored or available on the device **105**.

[0037] The visual feedback in this example includes the application of the visual effects shown in FIGS. **4**A, **4**B, **5**A and **5**B and described in the accompanying text to the keycaps in the virtual keyboard **206** to visually indicate to the user when a particular keycap is being pressed. As shown, the keys in the virtual keyboard **206** are arranged with drop shadows to make them appear to stand off from the surface of the touch screen **110**. This drop-shadow effect is removed (or can be lessened) when a keycap is touched. In this example as shown, the user is pushing the "G" keycap.

[0038] The audio feedback will typically comprise the playing of an audio sample, such as a "click" (indicated by reference numeral **602** in FIG. **6**), through a speaker **606** or external headset that may be coupled to the device **105** (not shown). The audio sample is arranged to simulate the sound of a real key being actuated in a physically-embodied keyboard. In alternative arrangements, the audio sample utilized may be configured as some arbitrary sound (such as a beep, jingle, tone, musical note, etc.) which does not simulate a particular physical action, or may be user selectable from a variety of such sounds. In all cases, the utilization of the audio sample provides auditory feedback to the user when a keycap is actuated.

[0039] The tactile feedback is arranged to simulate interaction with a real keycap through the application of motion to the device **105**. Because the touch screen **110** is essentially rigid, motion of the device **105** is imparted to the user at the point of contact with the touch screen **110**. In this example, the motion is vibratory, which is illustrated in FIG. **6** using the wavy lines **617**.

[0040] FIGS. **7**A and **7**B show respective front and orthogonal views of an illustrative vibration motor **704** and rotating eccentric weight **710** which comprise a vibration unit **712**. Vibration unit **712** is used, in this illustrative example, to provide the vibratory motion used to implement the tactile feedback discussed above. In alternative embodiments, other types of motion actuators such as piezoelectric vibrators or motor-driven linear or rotary actuators may be used.

[0041] The vibration motor **704** in this example is a DC motor having a substantially cylindrical shape which is arranged to spin a shaft **717** to which the weight **710** is fixedly attached. Vibration motor **704** is further configured to operate to rotate the weight **710** in both forward and reverse directions. In some applications, the vibration motor **704** may also be arranged to operate at variable speeds. Operation of vibration motor **704** is typically controlled by the motion controller, application, and sensory feedback logic components described in the text accompanying FIG. **10** below.

[0042] Eccentric weight **710** is shaped asymmetrically with respect to the shaft **717** so that center of gravity (designated as "G" in FIG. **7**A) is offset from the shaft. Accordingly, a centrifugal force is imparted to the shaft **717** that varies in direction as the weight rotates and increases in magnitude as the angular velocity of the shaft increases. In addition, a moment is applied to the vibration motor **704** that is opposite to the direction of rotation of the weight **710**.

[0043] In portable device implementations, the vibration unit **712** is typically fixedly attached to an interior portion of the device, such as device **105** as shown in the top cutaway view of FIG. **7**C. Such attachment facilitates the coupling of the forces from operation of the vibration unit **712** (i.e., the centrifugal force and moment) to the device **105** so that the device vibrates responsively to the application of a drive signal to the vibration unit **712**.

[0044] Through application of an appropriate drive signal, variations in the operation of the vibration unit **712** can be implemented, including for example, direction of rotation, duty cycle, and rotation speed. Different operating modes can be expected to affect the motion of the device **105**, including the direction, duration, and magnitude of the coupled vibration. In addition, while a single vibration unit is shown in FIG. **7**C, in some applications of the present arrangement for 3-D object simulation, multiple vibration units may be fixedly mounted in different locations and orientations in the device **105**. In this case, finer control over the direction and magnitude of the motion that is imparted to the device **105** may typically be implemented. It will be appreciated that multiple degrees of freedom of motion with varying levels of intensity can thus be achieved by operating the vibration motors singly and in combination using different drive signals. Accordingly, a variety of tactile effects may be implemented so that different sensory illusions may be achieved. Particularly