may employ a "hybrid" organization where some types of forces (e.g. closed loop effects) are controlled purely by the local microprocessor, while other types of effects (e.g., open loop effects) may be controlled by the host.

[0064] Local memory **122**, such as RAM and/or ROM, is preferably coupled to microprocessor **110** in device **12** to store instructions for microprocessor **110** and store temporary and other data. In addition, a local clock **124** can be coupled to the microprocessor **110** to provide timing data, similar to system clock **102** of host computer **14**.

[0065] Sensors **112** sense the position or motion of the device (e.g. the housing or a manipulandum) in degrees of freedom and provides signals to microprocessor **110** (or host **14**) including information representative of the position or motion. Sensors suitable for detecting motion include digital optical encoders, other optical sensor systems, linear optical encoders, potentiometers, optical sensors, velocity sensors, acceleration sensors, strain gauge, or other types of sensors can also be used, and either relative or absolute sensors can be used. Optional sensor interface **114** can be used to convert sensor signals to signals that can be interpreted by the microprocessor **110** and/or host computer system **14**, as is well known to those skilled in the art.

[0066] Actuator(s) **18** transmits forces to the housing, manipulandum, buttons, or other portion of the device in response to signals received from microprocessor **110** and/or host computer **14**. Device **12** preferably includes one or more actuators which are operative to produce forces on the device **12** (or a component thereof) and haptic sensations to the user. The actuator(s) are electroactive polymer (EAP) actuators, which are described in greater detail below, and are "computer-controlled", e.g., the force output from the actuators is ultimately controlled by signals originating from a controller such as a microprocessor, ASIC, etc. Many types of additional actuators can be used in conjunction with the electroactive polymer actuators described herein, including a rotary DC motors, voice coil actuators, moving magnet actuators, pneumatic/hydraulic actuators, solenoids, speaker voice coils, piezoelectric actuators, passive actuators (brakes), etc. Actuator interface **116** can be optionally connected between actuator **18** and microprocessor **110** to convert signals from microprocessor **110** into signals appropriate to drive actuator **18**. Interface **116** can include power amplifiers, switches, digital to analog controllers (DACs), analog to digital controllers (ADCs), and other components, as is well known to those skilled in the art.

[0067] In some of the implementations herein, the actuator has the ability to apply short duration force sensation on the housing or manipulandum of the device, or via moving an inertial mass. This short duration force sensation can be described as a "pulse." The "pulse" can be directed substantially along a particular direction in some embodiments. In some embodiments, the magnitude of the "pulse" can be controlled; the sense of the "pulse" can be controlled, either positive or negative biased; a "periodic force sensation" can be applied, where the periodic sensation can have a magnitude and a frequency, e.g. a sine wave; the periodic sensation can be selectable among a sine wave, square wave, saw-toothed-up wave, saw-toothed-down, and triangle wave; an envelope can be applied to the period signal, allowing for variation in magnitude over time. The wave forms can be "streamed" from the host to the device, as described in applicant's U.S. Pat. No. 6,411,276, or can be conveyed through high level commands that include parameters such as magnitude, frequency, and duration.

[0068] Other input devices **118** can be included in device **12** and send input signals to microprocessor **110** or to host **14** when manipulated by the user. Such input devices include buttons, dials, switches, scroll wheels, knobs, or other controls or mechanisms. Power supply **120** can optionally be included in device **12** coupled to actuator interface **116** and/or actuator **18** to provide electrical power to the actuator. or be provided as a separate component. Alternatively, power can be drawn from a power supply separate from device **12**, or power can be received across bus **20**. Also, received power can be stored and regulated by device **12** and thus used when needed to drive actuator **18** or used in a supplementary fashion.

[0069] The interface device **12** can be any of a variety of types; some embodiments are described further below. For example, the device **12** can be a mouse device having planar degrees of freedom, in which the entire housing is moved. Alternatively, a manipulandum on the device, such as a joystick handle, a knob, a steering wheel, a trackball, etc., is moved by the user and tracked by sensors. Device **12** can also be a gamepad, joystick, steering wheel, stylus, touchpad, spherical controller, finger pad, knob, track ball, or other device, some embodiments of which are described below. Alternatively, a hand-held remote control device used to select functions of a television, video cassette recorder, sound stereo, internet or network computer (e.g., Web-TV™) can be used with the haptic feedback components described herein, or a cell phone, personal digital assistant, etc. The forces from the actuator(s) **18** can be applied to the housing of the device **12**, and/or a movable manipulandum such as a joystick handle, steering wheel, knob, button, etc.

Electroactive Polymers in Haptic Feedback Devices

[0070] Electroactive polymers (EAP) are a class of polymers which can be formulated and/or processed to exhibit a wide range of physical, electrical, and electro-optical behaviors and properties.

[0071] When activated, such as by an applied voltage, EAP materials can undergo significant physical movement or deformations, typically referred to as electrostriction. These deformations can be along the length, width, thickness, radius, etc. of the material and in some cases can exceed 10% strain. Elastic strains of this magnitude are very unusual in common materials and even more unusual in that they can be fully controlled with the proper electronic systems. Materials in this class can be used to do useful work in a compact, easy to control, low power, fast, and potentially inexpensive package. They are often referred to as "electric muscles" because of these properties. These deformation properties can be used to provide forces to a user in a haptic feedback device.

[0072] Many of the materials can also act as high quality sensors, particularly for time-varying (i.e. AC) signals. When mechanically deformed (e.g. by bending, pulling, etc.), most EAP materials develop differential voltages which can be electrically measured. This ability to essentially generate electric potential makes them promising as force, position, velocity, acceleration, pressure, etc. sensors in haptic feedback devices. Many of these materials exhibit bi-directional behavior, and can act as either sensors or actuators, or act simultaneously as both sensors and actuators, depending on system design.