co-pending patent application Ser. No. 09/049,155, filed Mar. 26, 1998, and U.S. Pat. No. 5,734,373, which are both assigned to the assignee of the present invention and incorporated by reference herein in their entirety.

In one embodiment, device **10** includes an electronic portion having a local microprocessor **202**, local clock **204**, local memory **206**, sensor interface **208**, and actuator interface **210**.

Local microprocessor **202** is considered "local" to device **10**, where "local" herein refers to processor **202** being a separate microprocessor from any other microprocessors, such as in a controlling host computer or other apparatus **218**, and refers to processor **202** being dedicated to force feedback and/or sensor I/O for the device **10**. In force feedback embodiments, the microprocessor **202** reads sensor signals and can calculate appropriate forces from those sensor signals, time signals, and force processes selected in accordance with a host command, and output appropriate control signals to the actuator. Suitable microprocessors for use as local microprocessor **202** include the 8X930AX by Intel, the MC68HC711E9 by Motorola and the PIC16C74 by Microchip, for example. Microprocessor **202** can include one microprocessor chip, or multiple processors and/or co-processor chips, and can include digital signal processor (DSP) functionality. Also, "haptic accelerator" chips can be provided which are dedicated to calculating velocity, acceleration, and/or other force-related data. Alternatively, fixed digital logic and/or state machines can be used to provide similar functionality to microprocessor **202**.

A local clock **204** can be coupled to the microprocessor **202** to provide timing data, for example, to compute forces to be output by actuator **70**. Local memory **206**, such as RAM and/or ROM, is preferably coupled to microprocessor **202** in interface device **10** to store instructions for microprocessor **202**, temporary data, and other data. Display **132** can be coupled to local microprocessor **202** in some embodiments. Alternatively, a different microprocessor or other controller can control output to the display **132**.

Sensor interface **208** may optionally be included in device **10** to convert sensor signals to signals that can be interpreted by the microprocessor **202**. For example, sensor interface **208** can receive signals from a digital sensor such as an encoder and convert the signals into a digital binary number. An analog to digital converter (ADC) can also be used. Such circuits, or equivalent circuits, are well known to those skilled in the art. Alternately, microprocessor **202** can perform these interface functions. Actuator interface **210** can be optionally connected between the actuators **38** and **42** and microprocessor **202** to convert signals from microprocessor **202** into signals appropriate to drive the actuators. Actuator interface **210** can include power amplifiers, switches, digital to analog controllers (DACs), and other components, as well known to those skilled in the art. Actuator interface **210** circuitry can also be provided within microprocessor **202** or in the actuators.

A power supply **212** call be coupled to actuators **38** and **42** and/or actuator interface **210** to provide electrical power. In a different embodiment, power can be supplied to the actuators and any other components (as required) by an interface bus. Power can also be stored and regulated by device **10** and thus used when needed to drive the actuators.

Sensors **32** and **34** sense the position, motion, and/or other characteristics of arm assembly **14** and roller **22** along one or more degrees of freedom and provide signals to microprocessor **202** including information representative of those characteristics. A single compound sensor can be used for multiple degrees of freedom. Examples of sensors suitable for sensors **32** and **34** include optical encoders, analog sensors such as potentiometers, Hall effect magnetic sensors, optical sensors such as a lateral effect photo diodes, tachometers, and accelerometers. Furthermore, both absolute and relative sensors may be used.

In those embodiments including force feedback, actuators **38** and **42** are provided to transmits forces to arm assembly **14** and roller **22** in response to signals output by microprocessor **202** or other electronic logic or device, i.e., the actuators are "electronically-controlled." The actuators **38** and **42** produce electronically modulated forces which means that microprocessor **202** or other electronic device controls the application of the forces. In some embodiments, additional actuators can also be provided for other controls on device **10** (such as buttons, gamepad, etc.) or degrees of freedom of arm assembly **14**. Actuators **38** and **42** can be active actuators, such as linear current control motors, stepper motors, pneumatic/hydraulic active actuators, a torquer (motor with limited angular range), voice coil actuators, etc.; or passive actuators, such as magnetic particle brakes, friction brakes, or pneumatic/hydraulic passive actuators. In some embodiments, sensor/actuator pair transducers can be used.

In some embodiments, a drive transmission such as a capstan drive mechanism can be used to provide mechanical advantage to the forces output by actuators **14** and/or **22**. Some examples of capstan drive mechanisms are described in U.S. Pat. No. 5,731,804, incorporated herein by reference. Alternatively, a belt drive system, gear system, or other mechanical amplification/transmission system can be used.

Other input devices **214** can be included in control device **10** and send input signals to microprocessor **202**. Such input devices can include buttons provided on various locations of housing **12** and/or carrier portion **24**, used to supplement the input from the arm assembly and roller **22**. Also, dials, switches, voice recognition hardware (e.g. a microphone, with software implemented by microprocessor **202**), or other input mechanisms can be used. Furthermore, a safety or "deadman" switch **216** can optionally be included in those implementations providing force feedback. The safety switch prevents forces from being output when the user is not contacting the roller **22** or carrier portion **24**, and to prevent these components from moving on their own when the user is not touching them. The safety switch can detect contact of a user's digit (finger, thumb, etc.) with the components using a sensor such as a capacitive sensor or resistive sensor, pressure sensor, optical sensor, etc.

Controlled apparatus **218** is preferably included to communicate with local microprocessor **202** or other electronic components of control device **10**. Microprocessors **202** and **218** are preferably coupled together by a bi-directional bus **220**. Additional electronic components may also be included for communicating via standard protocols on bus **220**. These components can be included in device **10** or another connected device. Bus **220** can be any of a variety of different communication busses. For example, a bi-directional serial or parallel bus, a wireless link, or a uni-directional bus can be provided.

Controlled apparatus **218** can be any of a variety of devices, including a host computer, appliance, or other device as described with reference to FIG. **1***a*. Microprocessors **202** and apparatus **218** can exchange information as needed to facilitate control of various systems, output event notifications to the user, etc. For example, apparatus **218** can be a host computer including a microprocessor that commands the local microprocessor **202** to output force sensations by sending host commands to the local microprocessor.