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Attorney Docket No.: IMM1P093+

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## TITLE OF INVENTION (280 characters max)

**HYBRID CONTROL OF FORCE FEEDBACK FOR A HOST COMPUTER AND INTERFACE DEVICE**

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## ENCLOSED APPLICATION PARTS (check all that apply)

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_X_ Other (specify) _Cover Sheet_

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At least some of the inventions were made under a contract with an agency of the United States Government.

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Department of Defense, Contract No. M67004-97-C-0026

**Respectfully Submitted,**

**SIGNATURE**

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**REGISTRATION NO.** 36,651

# HYBRID CONTROL OF FORCE FEEDBACK FOR A HOST COMPUTER AND INTERFACE DEVICE

BY INVENTORS
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## BACKGROUND OF THE INVENTION

Force feedback interface devices are currently available to interface a person with a host computer device such as a personal computer, game console, portable computer, or other type of computer. Several different types of consumer level force feedback devices are available, including joysticks, mice, steering wheels, gamepads, etc. The computer displays a graphical environment such as a game, graphical user interface, or other program and the user controls a graphical object or other aspect of the environment by inputting data using the interface device, typically by moving a manipulandum or "user manipulatable object" such as a joystick handle or steering wheel. The computer also may output force feedback information to the interface device which controls the device to output force feedback to the user using motors or other actuators on the device. The force feedback is in the form of vibrations, spring forces, textures, or other sensations conveyed to the user who is physically grasping or otherwise contacting the device. The force feedback is correlated to events and interactions in the graphical environment to convey a more immersive, entertaining, and functional environment to the user.

In most commercially available force feedback interface devices, the goal has been to reduce the processing loading on the host computer by offloading as much of the processing as possible to the device itself. Thus, while force feedback devices may have significant differences, most of the more sophisticated devices share a common feature: a local microcontroller on the device that is able to compute and output forces as directed by high-level commands from the host computer. This results in devices that produce very high quality force feedback output while presenting a minimal processing load on the host system.

However, in order to achieve these capabilities on the device, there is a price to pay. The force computations that are required to generate the output can be computationally expensive operations. As a result, the microcontroller that is embedded into the interface device needs to be sufficiently powerful in order to handle this processing. The end result is that the device microcontroller is expensive and the completed interface products have a significant cost to consumers. While this extra cost is bearable when the market for these devices is new, the cost of these consumer devices is constantly being driven to lower levels as the market continues to mature.

In order to reduce the processing power (and thereby the cost) of the device microcontroller and maintain the product quality level, other alternate solutions should be explored.

## SUMMARY OF INVENTIONS

A method of the present invention for reducing the processing power of the device microcontroller and maintaining the quality of force feedback includes sharing the force processing loading between the device microcontroller and the processor of the host computer. This sharing of processing results in a "hybrid" device that functions much like existing devices but allows a more limited, inexpensive processor to be used in the device and allows the host computer to handle enough of the computations to maintain the overall quality of the force feedback system. Several inventive embodiments and aspects of a hybrid system are described herein.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIGURE 1 is a block diagram illustrating a force feedback interface system 10 suitable for use with the present invention controlled by a host computer system. Interface system 10 includes a host computer system 12 and an interface device ("device") 14.

Host computer system 12 is preferably a personal computer, such as a PC or Macintosh personal computer, or a workstation, such as a SUN or Silicon Graphics workstation. Alternatively, host computer system 12 can be one of a variety of home video game systems, such as systems available from Nintendo, Sega, or Sony, a television "set top box" or a "network computer", a portable computer, game device, or personal digital assistant, etc. Host computer system 12 preferably implements a host application program with which a user 22 is interacting via peripherals and interface device 14. For example, the host application program can be a video game, medical simulation, scientific analysis program, operating system, graphical user interface, or other application program that utilizes force feedback. Typically, the host application provides images to be displayed on a display output device, as described below, and/or other feedback, such as auditory signals.

Host computer system 12 preferably includes a host microprocessor 16, random access memory (RAM) 17, read-only memory (ROM) 19, input/output (I/O) electronics 21, a clock 18, a display screen 20, and an audio output device 21. Display screen 20 can be used to display images generated by host computer system 12 or other computer systems, and can be a standard display screen, CRT, flat-panel display, 3-D goggles, or any other visual interface. Audio output device 21, such as speakers, is preferably coupled to host microprocessor 16 via amplifiers, filters, and other circuitry well known to those skilled in the art (e.g. in a sound card) and provides sound output to user 22 from the host computer 18. Other types of peripherals can also be coupled to host processor 16, such as storage devices (hard disk drive, CD ROM/DVD-ROM drive, floppy disk drive, etc.), printers, and other input and output devices. Data for implementing the interfaces of the present invention can be stored on computer readable media such as memory (RAM or ROM), a hard disk, a CD-ROM or DVD-ROM, etc.

An interface device 14 is coupled to host computer system 12 by a bi-directional bus 24. The bi-directional bus sends signals in either direction between host computer system 12 and the interface device, and can be a serial bus, parallel bus, Universal Serial Bus (USB), Firewire (IEEE 1394) bus, wireless communication interface, etc. An interface port of host computer system 12, such as an RS232 or Universal Serial Bus (USB) serial interface port, parallel port, game port, etc., connects bus 24 to host computer system 12.

Interface device 14 includes a local microprocessor 26, sensors 28, actuators 30, a user object 34, optional sensor interface 36, an optional actuator interface 38, and other optional input devices 39. Local microprocessor 26 is coupled to bus 24 and is considered local to interface device 14 and is dedicated to force feedback and sensor I/O of interface device 14. Microprocessor 26 can be provided with software instructions to wait for commands or requests from computer host 16, decode the commands or requests, and handle/control input and output signals according to the commands or requests. In addition, processor 26 preferably operates independently of host computer 16 by reading sensor signals and calculating appropriate forces from those sensor signals, time signals, and stored or relayed instructions selected in accordance with a host command. Suitable microprocessors for use as local microprocessor 26 include the I-Force Processor from Immersion Corp., the MC68HC711E9 by Motorola, the PIC16C74 by Microchip, and the 82930AX by Intel Corp., for example, or more lower-end microprocessors in some embodiments (e.g. if the host is sharing significant force processing according the present invention). Microprocessor 26 can include one microprocessor chip, or multiple processors and/or co-processor chips, and/or digital signal processor (DSP) capability. In some embodiments, the microprocessor 26 can be more simple logic circuitry, state machines, or the like.

Microprocessor 26 can receive signals from sensors 28 and provide signals to actuators 30 of the interface device 14 in accordance with instructions provided by host computer 12 over bus 24. For example, in a preferred local control embodiment, host computer system 12 provides high level supervisory commands to microprocessor 26 over bus 24, and microprocessor 26 manages low level force control loops to sensors and actuators in accordance with the high level commands and independently of the host computer 18. The force feedback system thus provides a host control loop of information and a local control loop of information in a distributed control system. This operation is described in greater detail in U.S. Patent No. 5,739,811 and patent application serial nos. 08/877,114 and 08/050,665 (which is a continuation of U.S. Patent No. 5,734,373), all incorporated by reference herein. The microprocessor 26 is preferably operative to implement local closed loop effects dependent on position (and/or velocity, acceleration) of the user manipulatable object, as well as operative to receive commands for open loop effects which are calculated and directly output when conditions are appropriate, although the host can share in this processing according to the present invention, as described in detail below. Microprocessor 26 can also receive commands from any other input devices 39 included on interface apparatus 14, such as buttons, and provides appropriate signals to host computer 12 to indicate that the input information has been received and any information included in the input information. Local memory 27, such as RAM and/or ROM, is preferably coupled to microprocessor 26 in interface device 14 to store instructions for microprocessor 26 and store temporary and other data. In addition, a local clock 29 can be coupled to the microprocessor 26 to provide timing data.

Sensors 28 sense the position, motion, and/or other characteristics of a user object 34 of the interface device 14 along one or more degrees of freedom and provide signals to microprocessor 26 including information representative of those characteristics. Rotary or linear optical encoders, potentiometers, optical sensors, velocity sensors, acceleration sensors, strain gauge, or other types of sensors can be used. Sensors 28 provide an electrical signal to an optional sensor interface 36, which can be used to convert sensor signals to signals that can be interpreted by the microprocessor 26 and/or host computer system 12.

Actuators 30 transmit forces to user object 34 of the interface device 14 in one or more directions along one or more degrees of freedom in response to signals received from microprocessor 26. In some embodiments, the actuators 30 transmit forces to the housing of the device 14 (instead of or addition to object 34) which are felt by the user. Actuators 30 can include two types: active actuators and passive actuators. Active actuators include linear current control motors, stepper motors, pneumatic/hydraulic active actuators, a torquer (motor with limited angular range), voice coil actuators, and other types of actuators that transmit a force to move an object. Passive actuators can also be used for actuators 30, such as magnetic particle brakes, friction brakes, or pneumatic/hydraulic passive actuators. Actuator interface 38 can be optionally connected between actuators 30 and microprocessor 26 to convert signals from microprocessor 26 into signals appropriate to drive actuators 30. Optionally, some or all of the functionality of the sensor interface 36 and/or actuator interface 38 can be incorporated into the microprocessor 26, such as pulse width modulation (PWM) controllers for actuators, encoder processing circuitry, etc.

Other input devices 39 can optionally be included in interface device 14 and send input signals to microprocessor 26 or to host processor 16. Such input devices can include buttons, dials, switches, levers, or other mechanisms. For example, in embodiments where user object 34 is a joystick, other input devices can include one or more buttons provided, for example, on the joystick handle or base. Power supply 40 can optionally be coupled to actuator interface 38 and/or actuators 30 to provide electrical power. A safety switch 41 is optionally included in interface device 14 to provide a mechanism to deactivate actuators 30 for safety reasons.

User manipulable object 34 ("user object" or "manipulandum") is a physical object, device or article that may be grasped or otherwise contacted or controlled by a user and which is coupled to interface device 14. By "grasp", it is meant that users may releasably engage a grip portion of the object in some fashion, such as by hand, with their fingertips, or even orally in the case of handicapped persons. The user 22 can manipulate and move the object along provided degrees of freedom to interface with the host application program the user is viewing on display screen 20. Object 34 can be a joystick, mouse, trackball, stylus (e.g. at the end of a linkage), steering wheel, sphere, medical instrument (laparoscope, catheter, etc.), pool cue (e.g. moving the cue through actuated rollers), hand grip, knob, button, gamepad, gamepad control, or other article. Many types of mechanisms and linkages can also be employed to provide the degrees of freedom to the user manipulatable object, as well as amplification transmissions such as gears, capstan drives, and belt drives, to amplify movement for increased sensor resolution and amplify forces for output.

## Hybrid Architecture

The "hybrid" architecture of the present invention allows sharing of the force processing between the force feedback interface device and the host computer. In a hybrid architecture, the host computer computes at least some of the force values that are sent to the actuators of the device, thus reducing the processing requirements of the local microprocessor 26 on the device. A "force value" is a value that indicates a magnitude and direction of a force and which can be directly translated into that force by the actuator and/or by an actuator interface, such as a PWM circuit. For example, a force value can be provided for each axis or degree of freedom for a device (including direction on that axis), or a force value can include a magnitude portion and a direction portion for a force in a multi-dimensional space. In

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