DETAILED DESCRIPTION OF THE INVENTION

[0040] According to the present invention a semi-active haptic interface system **20** is illustrated schematically in **FIG. 1A**. The semi-active haptic interface system **20** provides resistance forces to an operator **22** and comprises a magnetically-controllable device **24** that imparts force feedback resistance sensations to the operator through a haptic interface device **26** by opposing the movement of the haptic interface device. Operator **22** moves haptic interface device **26** to control and respond to a control program or algorithm executed by the controller **28**. Signals relating to the application where the system is located such as a vehicle, machine or computer simulation are sent by the output device **30** to controller **28** where they are processed in order to determine the required effect on magnetically-controllable device **24**. The output device may comprise a monitor, with corresponding images displayed on the monitor **30**. A sensor **32** detects the movements of haptic interface device **26** and reports the movements to controller **28**. The controller **28** for purposes of the description of the preferred embodiment of the invention is a computer system **28** that interactively responds by generating new images on monitor **30** and by controlling magnetically-controllable device **24** to provide a variable resistance force corresponding to the movement of haptic interface device **26** and corresponding to the images on the monitor **30**. Thus, haptic interface system **20**, and particularly magnetically-controllable device **26**, advantageously provide a simple, cost-effective, high-performance solution for supplying a semi-active resistance force enabling operator **22** to feel realistic force feedback sensations.

[0041] When the system is installed in a vehicle or machine the system may not include a monitor. The monitor would be included in a computer simulation application of the invention as shown in **FIG. 1B**.

[0042] The semi-active feature of haptic interface system **20** of the present invention is particularly beneficial in providing a very cost-efficient, compact and robust system. As used herein, the term "semi-active" refers to the ability to provide a dissipative opposing resistance force in response to an applied motion. In contrast to prior art haptic interface systems that provide "active" force feedback utilizing expensive motors, haptic interface system **20** of the present invention advantageously utilizes magnetically-controllable device **24** including a magnetically controllable medium **34** **(FIG. 2A)** to provide semi-active, variable resistance forces. The term "active" refers to the ability to independently impart a force to the haptic interface device without requiring the operator to move the device. Through continual feedback between haptic interface device **26** and controller **28**, the controller directs magnetically-controllable device **24** to provide variable resistance forces that oppose the movement of the haptic interface device **26**. Further, based on running the interactive program, controller **28** directs the resistance provided by magnetically-controllable device **24** to vary in conjunction with images on display **30** and/or with the movement of the haptic interface device **26**.

[0043] For example, if the operator is controlling a computer simulation of **FIG. 1B** such as a race car driving interactive program, and operator **22** attempts to move haptic interface device **26** in a direction that steers the car into a non-destructible wall, then the computer system will provide a control signal. The signal controls magnetically-controllable device **24** to provide resistance forces equal to or greater than the force applied to the haptic interface device by the operator. This opposes any movement of the haptic interface device and simulating the feel of driving into an immovable wall.

[0044] Similarly, given the same interactive race car driving program and operator **22** driving the car around a curve, controller **28** provides a variable amount of resistance force less than the force applied by operator **22** to haptic interface device **26** to simulate the actual centrifugal and friction forces. The amount of the variable resistance force depends upon the speed and traction of the car and the sharpness of the curve, for example. As a result, magnetically-controllable device **24** creates resistance force feedback sensations felt by operator **22** through haptic interface device **26**, giving the interactive program a realistic feel. Thus, as operator **22** maneuvers haptic interface device **26**, the system of the present invention supplies resistance to oppose the motion of the haptic interface device to simulate real-life forces. As indicated hereinabove, the haptic interface system of the present invention may be used to control vehicle steering, throttling and braking; computer simulations; machinery motion and functionality. However as the description of the haptic interface system of the present invention proceeds, for purposes of describing the operation of the invention the system will be used to control computer simulations. Schematic representations of the system **20** integrated in the vehicle/machine steering wheel or joystick are shown in **FIGS. 1C and 1D**.

[0045] Magnetically-controllable device **24** beneficially contributes to the cost-efficient, compact and robust design of haptic interface system **20**. Referring to **FIGS. 2A and 2B**, a typical magnetically-controllable device **24** generally comprises a magnetically-controllable medium **34** contained in a working space **36** between first member **38** and second member **40**. Members **38**, **40** are disposed for relative movement along the mating surfaces, such as linear or rotational motion as indicated by the arrows. Magnetically-controllable medium **34** is under the influence of an annular-shaped magnetic-field generating device **42** **(FIG. 2B)** energizable to produce a variable strength magnetic field across the medium. Magnetically-controllable medium **34** is a medium that has a shear strength that changes in proportion to the strength of an applied magnetic field. In other words, the "apparent viscosity" of the medium changes proportionally with the strength of an applied magnetic field, providing controllable shear force to resist relative movement between members **38**, **40**.

[0046] A suitable magnetically-controllable medium **34** may comprise magnetorheological fluids such as described in commonly assigned U.S. Pat. Nos. 5,683,615 and 5,705,085 hereby incorporated by reference. Other fluids, such as carbonyl iron dispersed in hydrocarbon oil, or and any medium exhibiting a change in properties in response to an applied magnetic field. Other magnetorheological fluids which may be used in the present invention are disclosed in, for example, U.S. Pat. No. 5,382,373 to Carlson et al. and U.S. Pat. No. 5,578,238 to Weiss, et al., hereby incorporated by reference.