MAGNETICALLY-CONTROLLABLE, SEMI-ACTIVE HAPTIC INTERFACE SYSTEM AND APPARATUS

CROSS REFERENCE COPENDING APPLICATION

[0001] The present application is a continuation-in-part application of copending U.S. patent application Ser. No. 09/189,487, filed Nov. 10, 1998.

FIELD OF THE INVENTION

[0002] The present invention relates generally to a haptic interface system for providing force feedback sensations, and more particularly, to a haptic interface system employing a magnetically-controllable medium to provide resistance forces.

BACKGROUND

[0003] Haptic interface systems, also known as force feedback systems, provide an operator holding an interface device, such as a joystick or steering device, with "feel" or tactile sensations in response to whatever is being controlled by the interface device. The haptic interface system is often used for controlling the steering and operation of vehicles and machinery. Frequently such devices are used in combination with a computer game. In such a game, the action on a video display and the movement of a joystick or steering device are coordinated with physical force imparted to the operator's hand through the joystick or steering device, to provide a simulated "feel" for events happening on the display. For example, in an auto racing game, when an operator steers a car around a sharp turn at high speed, the haptic interface system imparts force on the steering wheel to make it more difficult to turn the wheel into the curve. This force feedback simulates the centrifugal force of the car making the turn and the friction forces applied to the tires as they are turned. Thus, haptic interface systems provide remote simulation of the actual physical feeling associated with an action or event through force feedback.

[0004] Typical haptic interface systems include one or more motors connected to the interface device in order to impart the force feedback sensation. Typical motors include direct current (DC) stepper motors and servo-motors. If the interface device is a joystick, motors are used to impart force in an x-direction, in a y-direction, or in combination to provide force in any direction that the joystick may be moved. Similarly, if the interface device is a steering wheel, motors are used to impart rotational force in a clockwise or counterclockwise direction. Thus, motors are used to impart forces in any direction that the interface device may be moved.

[0005] In a system using a single motor, the motor may be connected to the interface device through a gear train, or other similar energy transfer device, in order to provide force in more than one direction. In order to enable one motor to be used in a system, a reversible motor is typically utilized to provide force in two different directions. Additionally, mechanisms are required to engage and disengage the various gears or energy transfer devices to provide force in the proper direction at the proper time. In contrast, other typical systems use more than one motor to provide force in the required directions. Thus, current systems utilize a number of differing approaches to handle the delivery of force feedback sensations.

[0006] Current haptic interface systems may be disadvantageous, however, for a number of reasons. One primary area of concern is the cost of such systems. One item greatly contributing to the cost of a typical system is the use of DC stepper and servo-motors, and reversible motors. These types of motors are very sophisticated, requiring the ability to change speeds or rotations per minute (rpm), maintain different speeds, and reverse rotational direction. These features require greater mechanical and electrical complexity, which equates to a comparatively very high cost. Further, these motors need to be small in size in order to keep the haptic interface system from becoming unwieldy. This additionally complicates their design and increases cost. Also, because of their relatively small size, the sophisticated motors typically required in a haptic interface system are only able to generate a limited amount of torque. As such, the operator of an interface device may easily be able to overcome the torque or force feedback supplied by the motor. Thus, providing a small, sophisticated motor for a haptic interface system is relatively very costly, and may result in insufficient force feedback.

[0007] Also disadvantageously, typical DC motors used in haptic interface systems are not designed to perform in the manner required by the system. In order to provide force feedback, typical systems use direct drive motors configured to mechanically engage the output shaft of the motor with the interface device. For example, the output shaft of a DC motor may be geared to a steering wheel shaft or linked to a slide or other mechanism controlling the movement of a joystick. When the motor engages the gear or slide, the motor drives the interface device to provide force feedback. The operator holding the interface device, however, typically opposes the force feedback. The opposing force supplied by the operator then works against the direction of the motor output, which tends to stall the motor. Not only does this opposing force tend to wear out and/or strip components within the motor, but the stall condition leads to the generation of higher electric currents within the motor, straining the electrical components in the motor. Due to the repetitious nature of a haptic interface system, the reliability and longevity of motors in such haptic interface systems are severely reduced. Thus, motors used in typical haptic interface systems are typically not very well suited for the demanding environment in which they are operated.

[0008] Yet another disadvantage of current commercial haptic interface systems is that high impact forces from a motor connected to an interface device may be dangerous for the operator of the interface device. When the haptic interface system requires a quick, high impact force, a motor connected to an interface device may respond with a large force that may injure the operator if the operator is not ready for the abrupt force. This may be accounted for by ramping up the speed of the motor to achieve the force, but then the sensation becomes less realistic. Further, varying the engagement speeds of the motor complicates the software program that is used to run the haptic interface system, thereby further increasing cost. Thus, producing a realistic-feeling high impact force with current haptic interface systems may be dangerous to the operator or may require costly and complex system programming.

[0009] Some prior art devices have attempted to overcome some of the drawbacks of current haptic interface systems, with limited results. An electrorheological (ER) actuator, utilized in a force display system, is proposed by J. Furusho and M. Sakaguchi entitled "New Actuators Using ER Fluid And Their Applications To Force Display Devices In Virtual