device, an average position of the two positions is provided. However, these devices are currently limited in manipulating objects beyond 2.5 dimensions, i.e. X-position, Y-position, and positive Z-direction, and are not available in any intuitive controllers.

Force-sensitive transducers have been used in two-dimensional applications in place of spring-loaded joysticks. For example, U.S. Pat. No. 4,719,538 issued to John D. Cox teaches using force-responsive capacitive-transducers in a joystick-type device. However, these devices do not typically provide for 3D/6D inputs. An augmented 2D controller using force-sensitive devices is taught in U.S. Pat. No. 4,896,543 issued to Larry S. Gullman. Gullman describes a three-axis force measurement stylus used as a computer input device wherein the forces sensed by the stylus are used for recognizing ciphers, selecting colors, or establishing line widths and line densities. However, this device does not provide inputs for roll, yaw or pitch, and does not provide any input for a negative Z input (i.e. there is no input once the stylus is lifted). Thus, it is limited in its ability to provide 3D positioning information, as this would require an undesirable bias of some sort.

(c) Prior Art 3D/6D Field Controllers

3D/6D controllers are found in many field applications, such as controllers for heavy equipment. These devices must be rugged, accurate and immune from the affects of noise. Accordingly, many input control devices used for interactive computer graphics are not suitable for use in field applications. As a result, heavy equipment controllers typically consist of a baffling array of heavy-but-reliable levers which have little if any intuitive relationship to the function being performed. For example, a typical heavy crane includes separate lever controls for boom rotation (swing), boom telescope (extension), boom lift and hook hoist. This poor user interface requires the operator to select and select and pull one of a number of levers corresponding to the boom rotation control to cause the boom to rotate to the left. Such non-intuitive controls makes training difficult and time-consuming and increases the likelihood of accidents.

Accordingly, it is desirable to provide a 3D/6D controller that is easy to use, inexpensive, accurate, intuitive, not sensitive to electromagnetic or acoustic interference, and flexible in its ability to manipulate objects. Specifically, a substantial need exists for a graphical input device capable of providing for the precision manipulation of position and spatial orientation of an object. It is desirable that the device accept intuitive and simple input actions such as finger motion to manipulate position and orientation and does not require manipulation of a controller in free space or otherwise cause fatigue. It is desirable that the device provide the dual-functionality of both absolute and relative inputs, that is, inputs similar to a data tablet or touch panel that provide for absolute origins and positions, and inputs similar to mice and trackballs that report changes from former positions and orientations. It is desirable that the device recognize multiple points for versatile positioning and spatial orientation of one or more objects and allow the use of multiple finger touch to point or move a controlled object in a precise manner.

SUMMARY OF THE INVENTION

An input controller of the present invention incorporates multiple force/touch sensitive input elements and provides intuitive input in up to 36 degrees-of-freedom, including position and rotation, in either a Cartesian, cylindrical or spherical coordinate system. Input can be provided in the provided degrees of freedom without requiring movement of the controller, so that the controller is suitable for controlling both cursors or other computer objects in an interactive computer system and for controlling equipment such as heavy cranes and fork lift trucks.

More specifically, the preferred embodiment of the present invention provides a substantially cube-shaped input controller which includes a sensor on each of the six faces of the controller. The sensors are sensitive to the touch of a user's finger or other pointing object. In various embodiments, a controlled object may be translated by either a "pushing" or "dragging" metaphor on various faces of the controller. A controlled object may be rotated by either a "pushing," "twisting," or "gesture" metaphor on various faces of the controller. In certain embodiments, the same sensor is used for both position and rotational inputs, and the two are differentiated by the magnitude of the force applied to the sensor. Preferably, each sensor includes a main sensor located near the center portion of each face of the controller, and a number of edge sensors surrounding the main sensor and located proximate to the edges of each face of the controller.

According to one embodiment, each face of the controller can be used to provide input in six degrees of freedom to each control an object. If every face of the controller is used, a total of thirty-six degrees of freedom may be utilized. This allows the simultaneous control of multiple objects. In one embodiment, a computer generated object displayed on a computer screen includes a virtual hand. The entire hand and individual fingers of the hand may be simultaneously moved in several degrees of freedom by the user when providing input on multiple faces of the controller at the same time. In other embodiments, sets of faces can each control a separate object. For example, two opposing faces on the controller can command the translation and rotation of one object, while two different opposing faces can command the translation and rotation of a second object.

In a different embodiment, the controller of the present invention can be used to provide input to an application program implemented by a computer system, such as a computer aided design (CAD) program. A front face on the controller can be used to control a cursor in the program, and left and right faces can provide commands equivalent to left and right buttons on a mouse or other pointing device typically used with the program. An object displayed by the CAD program can be manipulated by using two touch points simultaneously. An object can be deformed, such as twisted, shrunk, or stretched, by providing input on the edge sensors of the controller. Two points of an object can be simultaneously deformed using separate faces of the controller.

In another embodiment, "pseudo force feedback" is provided to the user when the user controls a computer-generated object in a virtual environment. When a user-controlled computer object, such as a virtual hand, engages another object in the virtual environment, such as an obstacle, the user-controlled object is not allowed to move further in the direction of the obstacle object. The user thus feels the surface of the controller as if it were the surface of the obstacle, and receives visual feedback confirming this pseudo-sensation. In another embodiment, active tactile feedback can be provided to the user with the use of tactile sensation generators, such as vibratory diaphragms, placed on the controller or on peripheral surfaces to the controller.

The present invention provides an intuitive, inexpensive, and accurate controller for providing input in 3 or more degrees of freedom. The controller is flexible in its ability to manipulate objects and provide a relatively large number of