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(54) **FORCE SENSITIVE INPUT DEVICES AND METHODS**

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H03M 11/00 (2006.01)

(52) **U.S. Cl.**
USPC **341/31**; 341/20; 341/34; 250/227.21; 250/227.11; 84/615; 84/462

(58) **Field of Classification Search**
USPC 341/20–22, 31, 34; 250/227.21, 227.11; 84/615, 462
See application file for complete search history.

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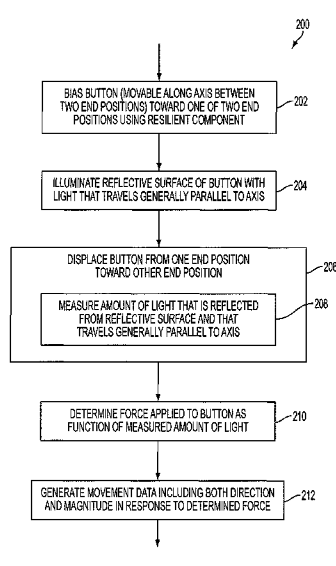
(57) **ABSTRACT**

Illustrative embodiments of force sensitive input devices and methods are disclosed. In at least one embodiment, a force sensitive input device may comprise a button movable along a first axis between a first end position and a second end position, the button including a reflective surface, a resilient component biasing the button toward the first end position, and a reflectance sensor configured to emit light that impinges upon the reflective surface and to measure an amount of the light that is reflected from the reflective surface, wherein the light travels generally parallel to the first axis.

29 Claims, 5 Drawing Sheets



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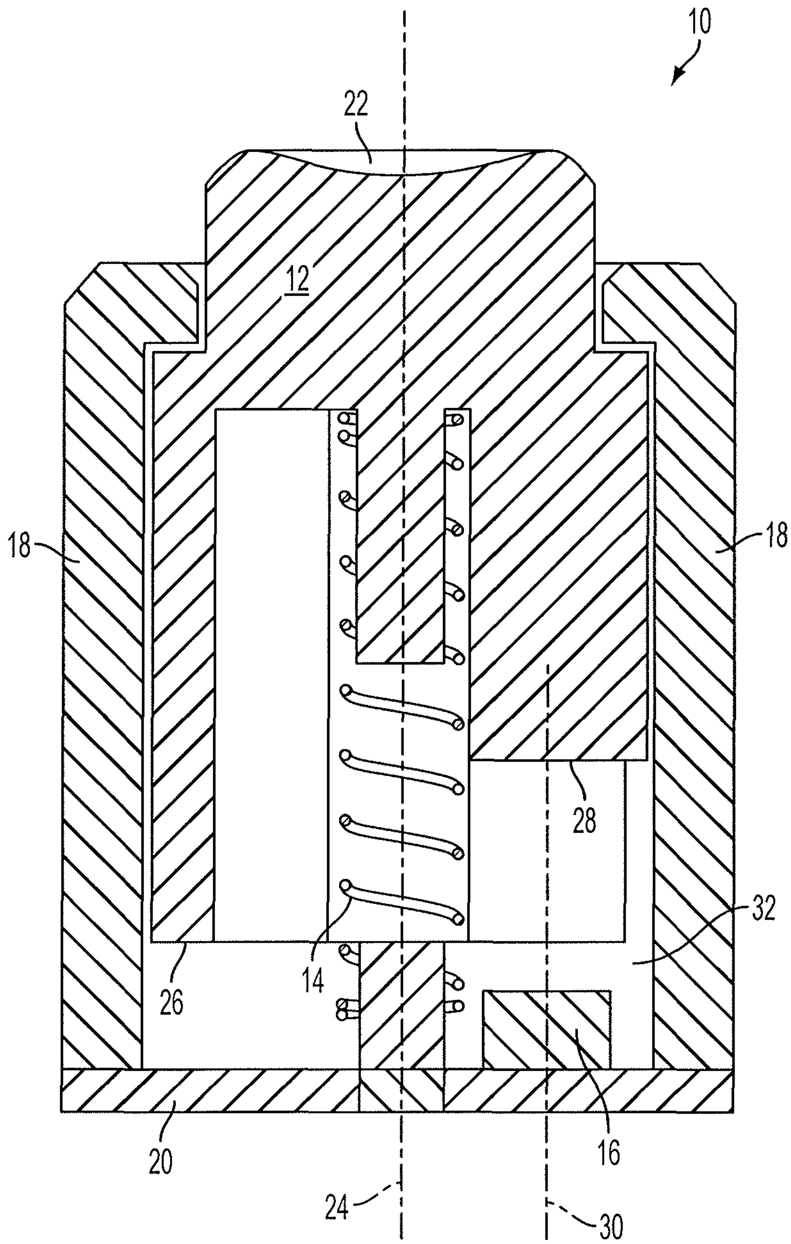


FIG. 1

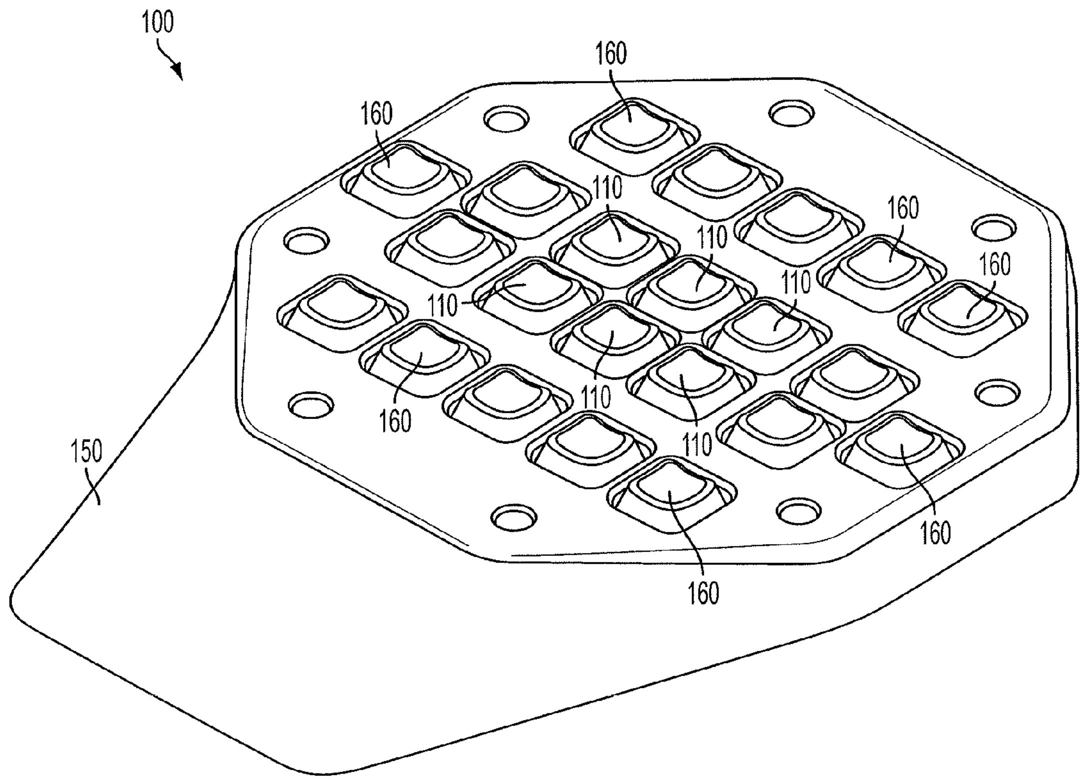
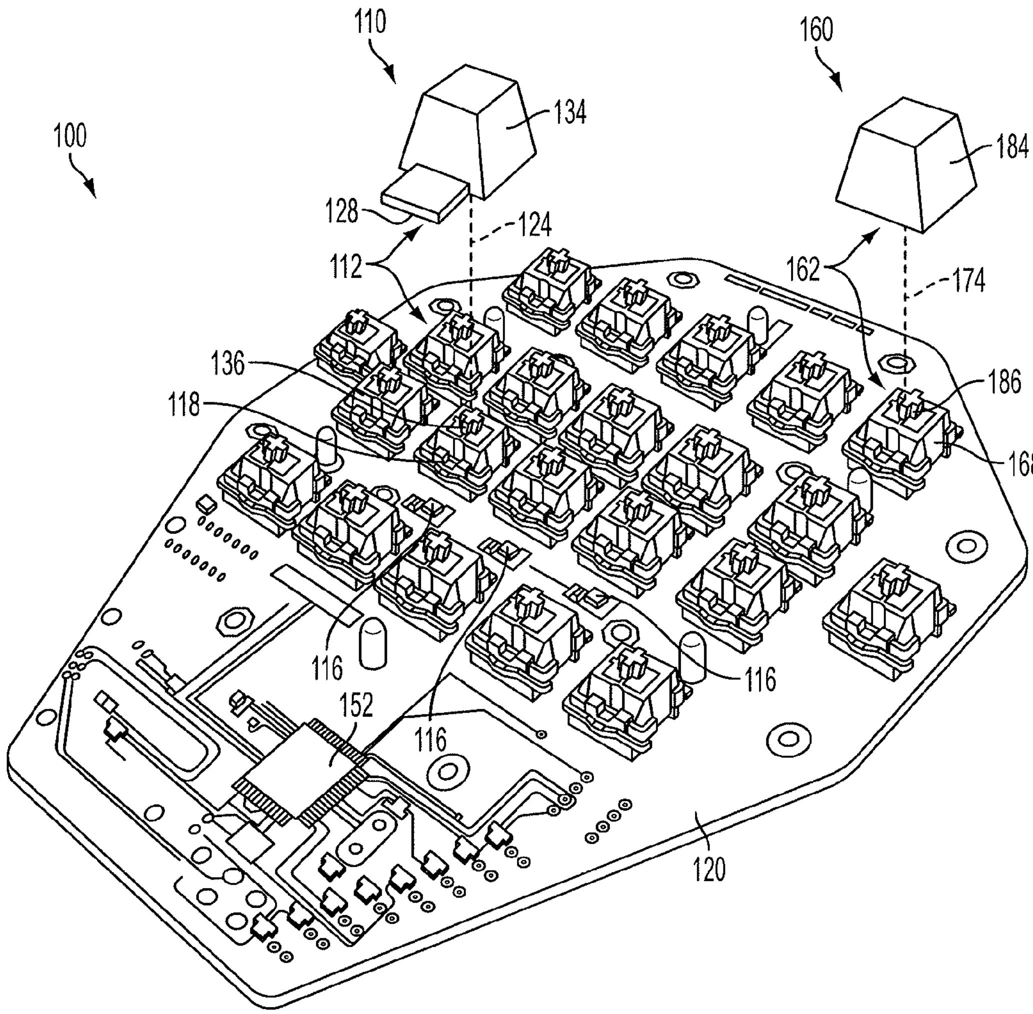


FIG. 2


110
160
100
134
184
128
124
112
162
174
136
186
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152
116
120

FIG. 3

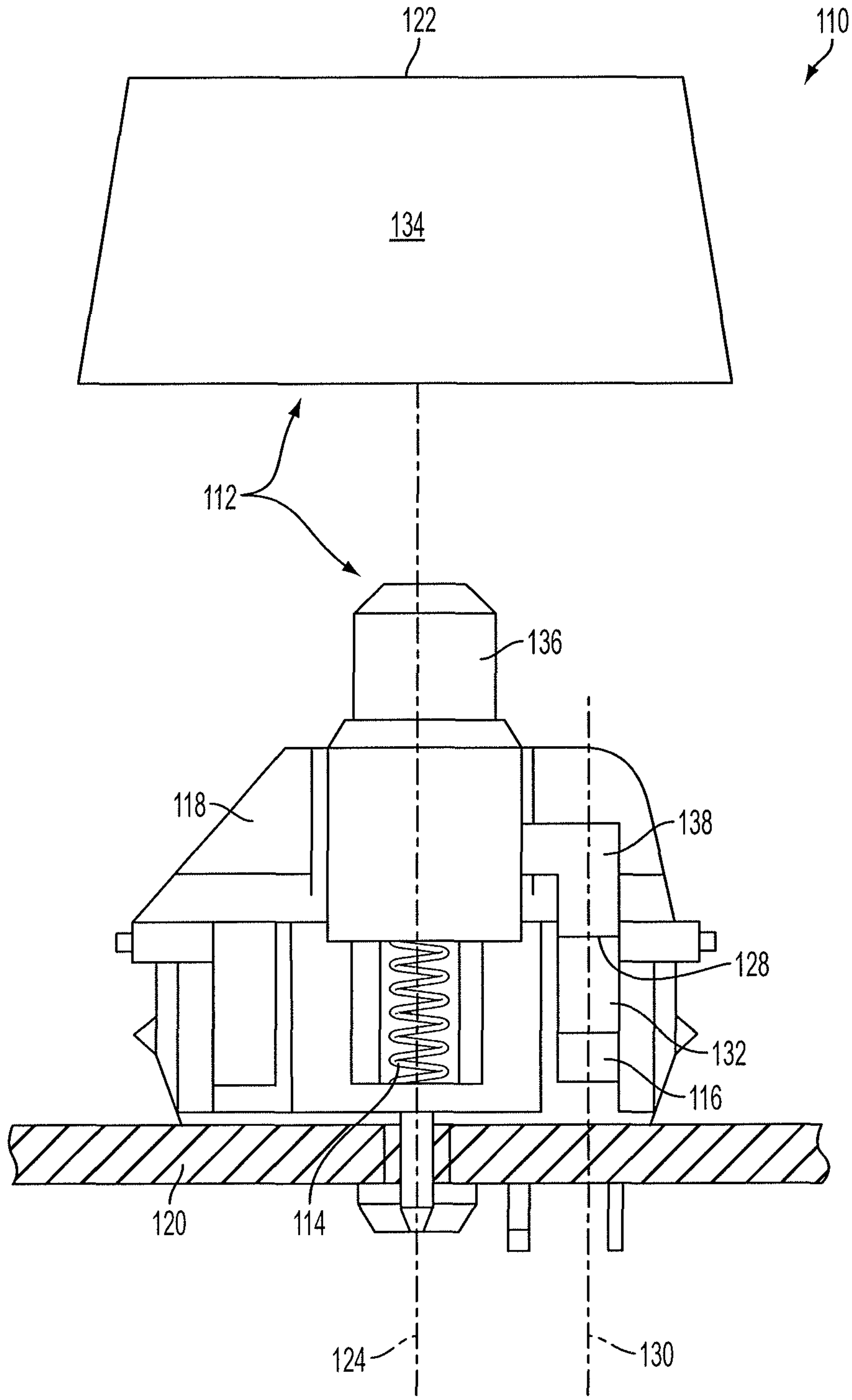

FIG. 4

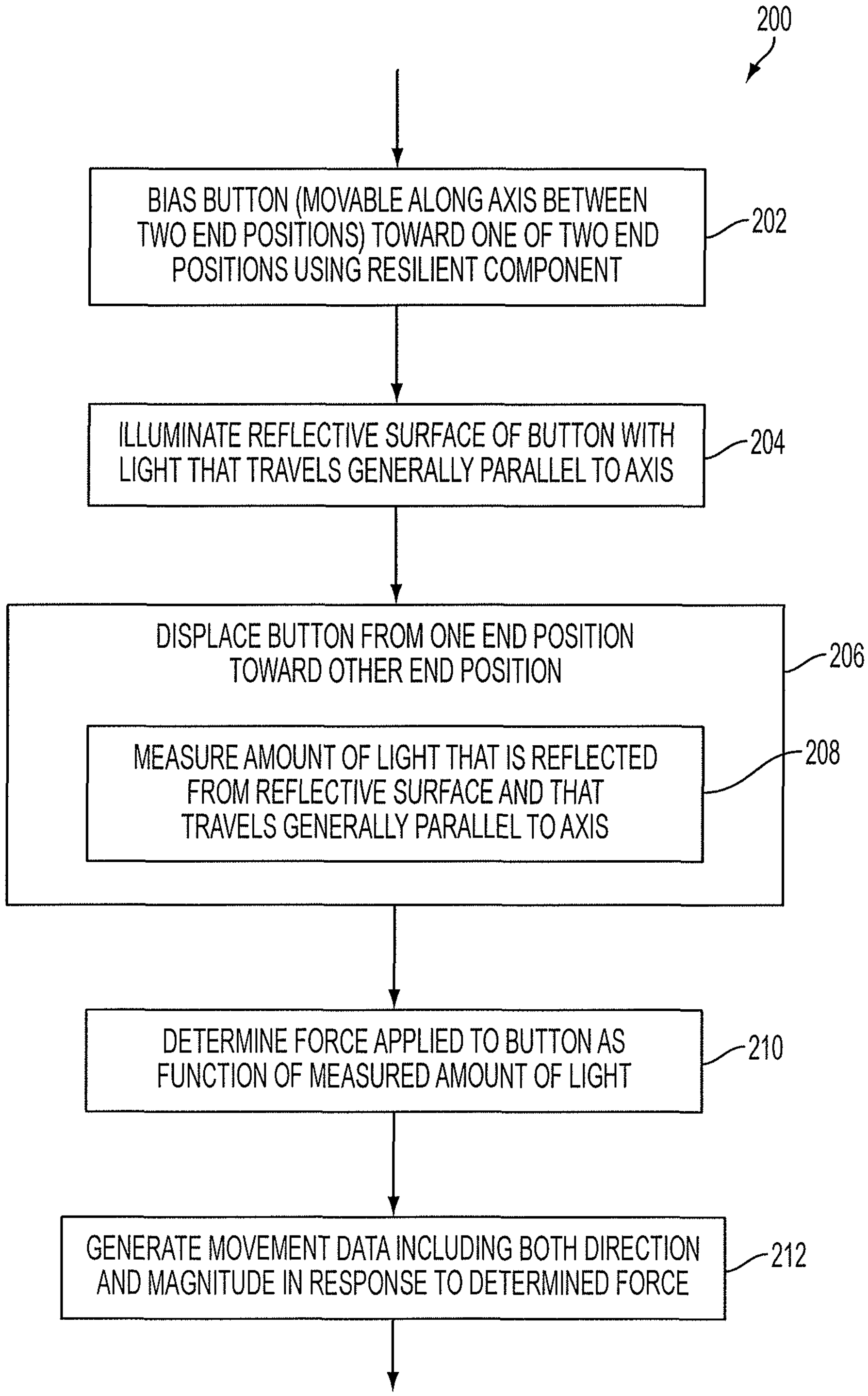
200
BIAS BUTTON (MOVABLE ALONG AXIS BETWEEN TWO END POSITIONS) TOWARD ONE OF TWO END POSITIONS USING RESILIENT COMPONENT
202
ILLUMINATE REFLECTIVE SURFACE OF BUTTON WITH LIGHT THAT TRAVELS GENERALLY PARALLEL TO AXIS
204
DISPLACE BUTTON FROM ONE END POSITION TOWARD OTHER END POSITION
206
MEASURE AMOUNT OF LIGHT THAT IS REFLECTED FROM REFLECTIVE SURFACE AND THAT TRAVELS GENERALLY PARALLEL TO AXIS
208
DETERMINE FORCE APPLIED TO BUTTON AS FUNCTION OF MEASURED AMOUNT OF LIGHT
210
GENERATE MOVEMENT DATA INCLUDING BOTH DIRECTION AND MAGNITUDE IN RESPONSE TO DETERMINED FORCE
212

FIG. 5

FORCE SENSITIVE INPUT DEVICES AND METHODS

TECHNICAL FIELD

The present disclosure relates, generally, to input devices and methods and, more particularly, to force sensitive input devices and methods.

BACKGROUND

One common input device used in interfacing with a computing device is the digital switch or button. Digital switches typically include a physical electrical contact designed to present a low electrical resistance when the switch is activated and an open circuit when the switch is not activated. Such switches generally have a binary output (i.e., on or off, high or low). Many types of physical mechanisms, with different behaviors, may be used for digital switches. For example, rocker switches, toggle switches, tactile switches, and sliding switches are all examples of switches that take discrete on or off values. Some digital switches can represent more than two values (e.g., via multiple positions) by connecting some combination of three or more contacts. However, all of these switches have the significant limitation of only being able to take a discrete number of positions and, thus, only being able to represent a limited set of possible user intents.

Analog sensors may also be used in interfacing with a computing device to achieve more granularity along a continuum of user intent. As analog sensors typically measure a physical behavior or phenomenon that can vary continuously under the control of the user, they generally have a continuous range of output values. One example of an analog sensor is a potentiometer (i.e., variable resistor) coupled to a slider or knob that is manipulated by a user. The user may adjust the slider or knob to set the resistance of the potentiometer along a continuum of values, and this resistance may be measured by an appropriate circuit. Prior analog sensors, such as those based on variable resistors, have suffered from poor response time due to the measurement methods used and/or the relaxation time required by the materials utilized. Prior analog sensors have also provided poor tactile, or haptic, response that does not feed back the performance of the sensor to the user or provide reassurance that the input would be what the user expected.

When used in an input device, a sensor must fit into the form factor needed for the particular application. One common form factor used for interfacing with a computing device is the keyswitch (or "key"), which has been used in personal computer keyboards, gaming controllers, control panels of computer-numerically controlled (CNC) industrial equipment (e.g., lathes, saws, milling machines, and the like), and other computing devices. The key typically includes a resilient component (e.g., a metal coil spring, a rubber dome, etc.) that returns a keycap to a home state when a user is not interacting with the key. For many analog sensors, the incorporation of the additional circuitry used to measure the subject physical behavior or phenomenon into the form factor of a standard key is impractical. For instance, in an analog sensor utilizing a potentiometer (as described above), the potentiometer may not fit within the form factor of a standard key.

Gaming controllers used as input devices are often used to control the movement and/or actions of a character in an electronic game (e.g., a computer game). Gaming controllers typically include a number of digital switches or buttons. As described above, the digital buttons of such gaming controllers typically have a binary output that results in a character

either moving at a constant speed or not moving at all. While controlling a character using four digital buttons (e.g., up, down, left, and right buttons) may result in a precise direction of movement, the magnitude or speed of movement is fixed. Some gaming controllers also include an analog joystick to allow more granular control of character movement and/or actions. Typically, analog sensors in the gaming controller determine how far the joystick is displaced from a center position along both an x-axis and a y-axis (simultaneously). Thus, in contrast to digital buttons, an analog joystick is able to control character movement in any direction (i.e., 360 degrees) and at different magnitudes (based on how far the joystick is moved from the center position). Unlike digital buttons, however, a user is not able to precisely control the direction of character movement (e.g., at exactly 90 degrees) with an analog joystick.

SUMMARY

The present invention comprises one or more of the features recited in the appended claims and/or the following features which, alone or in any combination, may comprise patentable subject matter:

According to one aspect, a force sensitive input device may comprise a button movable along a first axis between a first end position and a second end position, the button including a reflective surface, a resilient component biasing the button toward the first end position, and a reflectance sensor configured to emit light that impinges upon the reflective surface and to measure an amount of the light that is reflected from the reflective surface, wherein the light travels generally parallel to the first axis.

In some embodiments, the button may be positionable at an infinite number of positions between the first and second end positions. The button may comprise a keycap configured to be pressed by a user to move the button along the first axis toward the second end position, and a plunger supporting the keycap, the plunger engaging the resilient component. The resilient component may be a spring coupled to the plunger. The reflective surface may be a surface of the keycap, may be coupled to the keycap, may be a surface of the plunger, or may be coupled to the plunger.

In some embodiments, the reflective surface may be configured to move along a second axis that is parallel to the first axis. The reflective surface may be generally perpendicular to the second axis. The force sensitive input device may further comprise an opaque housing defining a chamber, and the reflective surface and the reflectance sensor may be disposed in the chamber. The reflectance sensor may comprise a light-emitting diode (LED) configured to emit the light and a phototransistor configured to receive the amount of the light that is reflected from the reflective surface. The LED may be configured to emit infrared light.

In some embodiments, the resilient component may be configured to allow a displacement of the button from the first end position that is proportional to a force applied to the button by a user. The amount of the light that is reflected from the reflective surface may be monotonically related to the displacement of the button from the first end position. The amount of the light that is reflected from the reflective surface may be monotonically related to a force applied to the button by a user.

In some embodiments, the reflectance sensor may be configured to output an analog signal that is a function of the amount of the light that is reflected from the reflective surface. The force sensitive input device may further comprise an analog-to-digital converter (ADC) configured to output a digital signal based upon the analog signal. The force sensitive input device may further comprise a low-pass filter configured to reduce noise in the analog signal before the analog signal is received by the ADC.

According to another aspect, an input device may comprise a first input key configured to output a first analog signal as a function of force applied to the first input key, a second input key configured to output a second analog signal as a function of force applied to the second input key, a third input key configured to output a third analog signal as a function of force applied to the third input key, a fourth input key configured to output a fourth analog signal as a function of force applied to the fourth input key, and a controller configured to output movement data including both direction and magnitude in response to the first, second, third, and fourth analog signals. Each of the first, second, third, and fourth input keys may comprise any one of force sensitive input devices described above.

In some embodiments, the controller may comprise an analog-to-digital converter (ADC) configured to convert the first, second, third, and fourth analog signals into digital signals. The input device may further comprise a low-pass filter configured to reduce noise in at least one of the first, second, third, and fourth analog signals before the analog signal is received by the ADC of the controller.

In some embodiments, the controller may be configured to format the movement data for presentation to a driver of a computing device. The movement data may include an x-axis component and a y-axis component, the x-axis component being a function of the first and second analog signals, and the y-axis component being a function of the third and fourth analog signals. The input device may further comprise a number of binary input keys, each of the binary input keys being configured to output a digital signal indicating whether or not the binary input key has been pressed.

According to yet another aspect, a method may comprise biasing a button that is movable along a first axis between a first end position and a second end position toward the first end position using a resilient component, illuminating a reflective surface of the button with light that travels generally parallel to the first axis, measuring, while the button is displaced from the first end position toward the second end position, an amount of the light that is reflected from the reflective surface and that travels generally parallel to the first axis, and determining a force applied to the button as a function of the measured amount of the light.

In some embodiments, biasing the button toward the first end position may comprise biasing the button using a spring. Illuminating the reflective surface of the button may comprise emitting light from a light-emitting diode (LED) facing the reflective surface. Emitting light from the LED may comprise emitting infrared light. The amount of the light that is reflected from the reflective surface may be monotonically related to the force applied to the button. The method may further comprise generating movement data including both direction and magnitude in response to the determined force.

In some embodiments, measuring the amount of the light that is reflected from the reflective surface may comprise receiving light using a phototransistor. The phototransistor may output an analog signal that is a function of the amount of the light that is reflected from the reflective surface. Determining the force applied to the button may comprise converting the analog signal output by the phototransistor into a digital signal using an analog-to-digital converter (ADC). Determining the force applied to the button further may comprise reducing noise in the analog signal using a low-pass filter, prior to the analog signal being converted by the ADC.

BRIEF DESCRIPTION OF THE DRAWINGS

The concepts described in the present disclosure are illustrated by way of example and not by way of limitation in the accompanying figures. For simplicity and clarity of illustration, elements illustrated in the figures are not necessarily drawn to scale. For example, the dimensions of some elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, the same reference labels or similar reference labels (e.g., reference labels ending in the same two digits) have been repeated among the figures to indicate corresponding or analogous elements. The detailed description particularly refers to the accompanying figures in which:

FIG. **1** is a cross-sectional view of one illustrative embodiment of a force sensitive input device;

FIG. **2** is a perspective view of one illustrative embodiment of an input device including a number of force sensitive input keys and a number of binary input keys;

FIG. **3** is a partially-exploded perspective view of several components of the input device of FIG. **2**;

FIG. **4** is a cross-sectional view of another illustrative embodiment of a force sensitive input key that may be used in the input device of FIG. **2**; and

FIG. **5** is a simplified flow diagram showing one illustrative embodiment of a force sensitive input method.

DETAILED DESCRIPTION OF THE DRAWINGS

While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific exemplary embodiments thereof have been shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the concepts of the present disclosure to the particular forms disclosed, but, on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

In the following description, numerous specific details, such as types and interrelationships of circuit components, are set forth in order to provide a more thorough understanding of the present disclosure. It will be appreciated, however, by one skilled in the art that embodiments of the disclosure may be practiced without such specific details. In other instances, various circuit components have not been shown in detail (or not labeled in every instance) in order to not obscure the invention. Those of ordinary skill in the art, with the included descriptions, will be able to implement appropriate functionality without undue experimentation.

References in the specification to "one embodiment," "an embodiment," "an illustrative embodiment," etcetera, indicate that at least one embodiment described may include a particular feature, structure, or characteristic, but not every embodiment necessarily includes the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

Referring now to FIG. **1**, one illustrative embodiment of a force sensitive input device **10** is shown in cross-section. In this illustrative embodiment, the input device **10** generally includes a button **12**, a resilient component **14**, a reflectance sensor **16**, and a housing **18**. In some embodiments, such as that shown in FIG. **1**, a bottom side of the housing **18** may be open, allowing the input device **10** to be secured to a support surface, such as a printed circuit board (PCB) **20**. It is contemplated that, in other embodiments, the input device **10** may contain additional or different components to those illustrated in FIG. **1**.

The button **12** of the input device **10** includes a surface **22** that is exposed through the housing **18** and is designed to be pressed by a user. The button **12** is movable relative to the housing **18** along an axis **24** between two end positions. The button **12** is illustrated in FIG. **1** in a top end position. When the surface **22** of the button is pressed by a user, the button **12** may move along the axis **24** (downward in FIG. **1**) until the button **12** reaches a bottom end position. In the illustrative embodiment, a bottom surface **26** of the button **12** will be proximate to the PCB **20** when the button **12** is in the bottom end position. As the button **12** is an analog mechanism, the button **12** is positionable at an infinite number of positions between the top and bottom end positions.

The button **12** includes a reflective surface **28** that partially or fully reflects some or all types of light. By way of example, the reflective surface **28** may reflect light of a particular wavelength or spectrum of wavelengths. In the illustrative embodiment, the reflective surface **28** is a surface of the button **12** (i.e., the reflective surface **28** is integrally formed with the button **12**). In other embodiments, the reflective surface **28** may be coupled to the button **12** after the button **12** has been formed. By way of example, the reflective surface **28** may be applied to a surface of the button **12** as a reflective coating.

The resilient component **14** of the input device **10** biases the button **12** toward the top end position. As shown in FIG. **1**, the resilient component **14** is illustratively embodied as a metal coil spring **14**. One end of the spring **14** is engaged with the button **12**, while the other end of the spring **14** is engaged with the PCB **20**. In the illustrative embodiment of FIG. **1**, the spring **14** has a generally cylindrical shape, and the button **12** and the PCB **20** each include a cylindrical feature that is received within one end of the spring **14** to maintain engagement with the spring **14**. The resilient nature of the spring **14** allows the button **12** to move along the axis **24** when a force is applied to the button **12** by a user, but causes the button **12** to return to the top end position, shown in FIG. **1**, when the force is no longer applied by the user. This configuration of the button **12** and the spring **14** provides haptic feedback that allows a user to feel the amount of input (i.e., force) that the user is applying to the button **12**. Furthermore, the spring **14** may be designed with a fast, robust response that requires very little relaxation time. It will be appreciated that, in other embodiments, the resilient component **14** may be any type of component that allows movement of the button **12** along the axis **24**, but biases the button **12** toward the top end position (e.g., a rubber dome).

The reflectance sensor **16** of the input device **10** is configured to emit light that impinges upon the reflective surface **28**. An amount of the light that impinges upon the reflective surface **28** will be reflected back toward the reflectance sensor **16** and will be measured by the reflectance sensor **16**. As shown in FIG. **1**, the light emitted from the reflectance sensor **16** that is reflected by the reflective surface **28** and then returns to the reflectance sensor **16** generally travels along an axis **30** that is parallel to the axis **24**. In the illustrative embodiment, the reflective surface **28** is generally perpendicular to the axis **30**. As the button **12** moves along the axis **24** (e.g., when a force is applied to the button **12** by a user), the reflective surface **28** of the button **12** will move along the axis **30**.

As the distance between the reflectance sensor **16** and the reflective surface **28** of the button **12** changes, the amount of light that is reflected from the reflective surface **28** back to the reflectance sensor **16** will also change (for instance, when the reflective surface **28** and the reflectance sensor **16** are farther apart, more scattering will occur and less light will return to the reflectance sensor **16**). In particular, the amount of light that is reflected from the reflective surface **28** is monotonically related to the displacement of the button **12** from the top end position (i.e., the distance the button **12** travels along the axis **24**, which is also the distance the reflective surface **28** travels along the axis **30**). As such, by measuring the amount of light that is reflected from the reflective surface **28**, the reflectance sensor **16** is able to indirectly measure the distance between the reflectance sensor **16** and the reflective surface **28** of the button **12**.

The measurement by the reflectance sensor **16** of the amount of light that is reflected from the reflective surface **28** is related not only to the distance between the reflectance sensor **16** and the reflective surface **28** but also, as a result of the spring **14**, to the force applied to the button **12** by a user. The particular properties of the spring **14** (or other resilient component **14**) used in the input device **10** will result in a particular relationship between the amount of force applied to the button **12** and the displacement of the button **12** allowed by the spring **14**. In the illustrative embodiment, the spring **14** is configured to allow a displacement of the button **12** from the top end position that is proportional to the force applied to the button **12**. As the displacement of the button **12** is proportional to the force applied, and the amount of light reflected from the reflective surface **28** is monotonically related to the displacement of the button **12**, the amount of the light that is reflected from the reflective surface **28** is also monotonically related to the force applied to the button **12**. As such, by measuring the amount of light that is reflected from the reflective surface **28**, the reflectance sensor **16** is also able to indirectly measure a force applied to the button **12** by a user.

In the illustrative embodiment, the reflectance sensor **16** includes a light-emitting diode (LED) configured to emit the light and a phototransistor configured to receive and measure the amount of the light that is reflected from the reflective surface **28**. In particular, the reflectance sensor **16** is illustratively embodied as a QRE1113 Minature Reflective Object Sensor, commercially available from Fairchild Semiconductor Corporation of San Jose, Calif. As shown in FIG. **1**, the reflectance sensor **16** may be soldered to the PCB **20** with the LED and the phototransistor facing the reflective surface **28**. When energized, the LED of the reflectance sensor **16** emits infrared light toward the reflective surface **28**. Infrared light returning from the reflective surface **28** to the reflectance sensor **16** impinges upon the phototransistor. In the illustrative embodiment, the phototransistor of the reflectance sensor **16** is a bipolar junction transistor (BJT) with a light sensitive base. As such, the phototransistor will output an analog signal (e.g., of varying voltage) that is a function of the amount of the light that is reflected from the reflective surface **28** back to the reflectance sensor **16**. This analog signal may be processed to determine a force applied to the button **12**, as further described below. It is contemplated that, in other embodiments, the reflectance sensor **16** may have other configurations that include different light sources and/or light sensors.

The housing **18** may have any suitable shape for supporting the components of the input device **10**. In the illustrative embodiment, the housing **18** defines a chamber **32** in an interior portion of the housing **18**. As shown in FIG. **1**, the reflectance sensor **16** is disposed in the chamber **32**. A portion of the button **12** is also disposed in the chamber **32**. In particular, the reflective surface **28** of the button **12** is disposed in the chamber **32**. In the illustrative embodiment, the housing

18 is formed of an opaque material, such that the light emitted by the reflectance sensor **16** does not pass through the housing **18**. The opaque housing **18** also prevents outside light from impinging upon and being measured by the reflectance sensor **16**.

Referring now to FIGS. **2** and **3**, one illustrative embodiment of an input device **100** is shown as a gaming controller, or game pad, **100**. While the present disclosure generally describes applications involving electronic games (e.g., computer games), it will be appreciated that one or more features of the input device **100** may advantageously be incorporated into input devices for many applications in the fields of consumer, industrial, medical, and other electronics. It is contemplated that input devices similar to those described herein may be useful in translating user intent to a form interpretable by any type of computing device, including, but not limited to, personal computers, entertainment systems, industrial computing systems, stenography devices, medical computing systems, and other computing devices. By way of example, when an input device according to the present disclosure is used in a medical application (specifically, radiology), the force applied by a user to a force sensitive input key of the input device may control how fast a computerized tomography system changes between the displayed slices.

As shown in FIG. **2**, the game pad **100** includes a number of force sensitive input keys **110** and a number of binary input keys **160**. In particular, the illustrative embodiment of the game pad **100** includes six force sensitive input keys **110** that are arranged near the center of the game pad **100** and sixteen binary input keys **160** that surround the force sensitive input keys **110** (not all binary input keys **160** are labeled in FIG. **2**). It is contemplated that, in other embodiments, the game pad **100** may include any number of force sensitive input keys **110** and any number of binary input keys **160** (including no binary input keys **160**). As described below, an arrangement of at least four force sensitive input keys **110** may be advantageous for certain applications. The game pad **100** also includes a cover **150** to protect the internal electronic components of the game pad **100**. The game pad **100** is shown in FIG. **3** with the cover **150** removed to expose several internal components of the game pad **100**. It is contemplated that, in other embodiments, the game pad **100** may contain additional or different components to those illustrated in FIGS. **2** and **3**.

Except as noted below, each of the force sensitive input keys **110** of the game pad **100** has a similar configuration and operation to the force sensitive input device **10** described above (with reference to FIG. **1**). In the illustrative embodiment shown in FIGS. **2** and **3**, the force sensitive input keys **110** (and the binary input keys **160**) of the game pad **100** are each embodied in the form factor of a standard keyswitch. In particular, the button **112** of each force sensitive input key **110** has a two-part construction that includes a keycap **134** configured to be pressed by a user and a plunger **136** that engages a spring **114** within a housing **118**. The housing **118**, plunger **136**, and spring **114** of each force sensitive input key **110** are illustratively embodied as an MX Series Desktop Profile 0.60 Inch Keyswitch (with linear actuation), commercially available from Cherry Corporation of Pleasant Prairie, Wis. The button **162** of each binary input key **160** has a similar two-part construction that includes a key cap **184** and a plunger **186** that engages a spring **164** within a housing **168**. The housing **168**, plunger **186**, and spring **164** of each binary input key **160** are illustratively embodied as an MX Series Desktop Profile 0.60 Inch Keyswitch (with pressure point click), also commercially available from Cherry Corporation. The housing **118** of each force sensitive input key **110** and the housing **168** of each binary input key **160** are secured to a PCB **120**.

The majority of the keycaps **134**, **184** have been removed in FIG. **3** to expose the housings **118**, **168** and the plungers **136**, **186** of the input keys **110**, **160**. One keycap **134** and one keycap **184** are shown in the partially-exploded view of FIG. **3** to indicate their relationships to the plunger **136** and the plunger **186**, respectively. When the keycap **134** is coupled to the plunger **136**, the plunger **136** supports the keycap **134**. When assembled, the keycap **134** and plunger **136** move together along an axis **124** as the button **112** of the force sensitive input key **110**. Similarly, when the keycap **184** is coupled to the plunger **186**, the plunger **186** supports the keycap **184**. When assembled, the keycap **184** and plunger **186** move together along an axis **174** as the button **162** of the binary input key **160**.

As shown in FIG. **3**, for each of the force sensitive input keys **110**, the reflectance sensor **116** is positioned outside the housing **118** (rather than within the housing, like the illustrative embodiment of the force sensitive input device **10** shown in FIG. **1**). In particular, the reflectance sensor **116** of each of the force sensitive input keys **110** is soldered to the PCB **120** in a position adjacent the housing **118**. In the illustrative embodiment, the keycap **134** of each of the force sensitive input keys **110** includes a reflective surface **128**. As shown in FIG. **3**, the reflective surface **128** extends outwardly from the keycap **134** above the reflectance sensor **116**. In the illustrative embodiment, the reflective surface **128** is integrally formed with the keycap **134** (i.e., the reflective surface **128** is a surface of the keycap **134**). In other embodiments, the reflective surface **128** may be coupled to the keycap **134** after the keycap **134** has been formed. As the button **112** (including the keycap **134**) moves along the axis **124**, the reflective surface **128** will move along an axis that is generally parallel to the axis **124**. In the illustrative embodiment, the reflective surface **128** is generally perpendicular to the axis **124** (and the axis of its travel).

Like the force sensitive input device **10** described above, each of the force sensitive input keys **110** of the game pad **100** is configured to output an analog signal that is a function of the force applied to that input key **110**. In particular, the reflectance sensor **116** of each force sensitive input key **110** will generate an analog signal in response to the amount of reflected light measured. As described above, since the displacement of the button **112** (including the keycap **134** and its reflective surface **128**) is proportional to the force applied to the keycap **134** and the amount of light reflected from the reflective surface **128** is monotonically related to the displacement of the button **112**, the amount of the light that is reflected from the reflective surface **128** is also monotonically related to the force applied to the keycap **134**. As such, by measuring the amount of light that is reflected from the reflective surface **128**, the reflectance sensor **116** is also able to indirectly measure the force applied by a user.

The analog signal output by each of the force sensitive input keys **110** of the game pad **100** is transmitted to a controller **152** that determines a force applied to each of the force sensitive input keys **110** based on the respective analog signal. In the illustrative embodiment, the controller **152** of the game pad **100** is soldered to the PCB **120**. In other embodiments, the controller **152** may be external to the game pad **100**. The controller **152** is illustratively embodied as an ATmega16 U4 8-Bit AVR Microcontroller with 16K Bytes of ISP Flash and USB Controller, commercially available from Atmel Corporation of San Jose, Calif. The controller **152** includes an analog-to-digital converter (ADC) configured to convert the analog signals received from the force sensitive input keys **110** into digital signals. In other words, the ADC of the controller **152** is configured to output a digital signal based upon each analog signal received from the force sensitive input keys **110**. It is contemplated that, in other embodiments, the ADC may be separate from the controller **152** (i.e., a separate component soldered to the PCB **120**). In the illustrative embodiment, the game pad **100** also includes one or more low-pass filters soldered to a backside of the PCB **120** (not shown). These one or more low-pass filters are positioned between the force sensitive input keys **110** and the ADC of the controller **152** and are configured to reduce noise in one or more of the analog signals from the force sensitive input keys **110** before the analog signals are received by the ADC.

Once the analog signals from the force sensitive input keys **110** have been converted into digital signals, the controller **152** of the game pad **100** may determine a force applied to each of the force sensitive input keys **110**. As described above, the magnitude of each analog signal represents the amount of the light measured by each force sensitive input key **110**, which is monotonically related to the force applied to the keycap **134** of that input key **110**. As such, the controller **152** may calculate the force applied to one of the force sensitive input keys **110** using the value of the received analog signal (converted to a digital signal). The controller **152** may perform this calculation of the force applied using a mathematical function, a look-up table, or any other suitable calculation process. The controller **152** may then perform appropriate calibration, mapping, and/or scaling of the determined force into a format suitable for presentation to a driver of a computing device connected to the game pad **100**.

In the illustrative embodiment, the controller **152** is configured to output movement data including both direction and magnitude in response to analog signals received from four of the force sensitive input keys **110** of the game pad **100**. In particular, two of the force sensitive input keys **110** may be used to register user intent regarding movement along an x-axis (one input key **110** representing positive movement along the x-axis and one input key **110** representing negative movement along the x-axis). Likewise, two of the force sensitive input keys **110** may be used to register user intent regarding movement along a y-axis (one input key **110** representing positive movement along the y-axis and one input key **110** representing negative movement along the y-axis). Using the analog signals output by these four force sensitive input keys **110**, the controller **152** may generate movement data that includes an x-axis component and a y-axis component. When any one of the four force sensitive input keys **110** is pressed by a user, the controller **152** may calculate a vector in the corresponding direction, where a magnitude of the vector is proportional to the force applied to that input key **110** by the user. Where multiple (e.g., two) force sensitive input keys **110** are pressed simultaneously, the controller **152** may add the calculated vectors to determine the overall direction and magnitude of movement intended by the user. In an electronic gaming application (e.g., a computer game), this movement data may be used to accurately and precisely control the movement and/or actions of a character in the game.

As mentioned above, the controller **152** may format the determined movement data for presentation to a driver of a computing device connected to the game pad **100**. For instance, the movement data may be formatted according to a Universal Serial Bus (USB) protocol (e.g., by a USB controller included in the controller **152**) where the game pad **100** is coupled to the computing device via a USB cable. In other embodiments, the controller **152** may format the movement data according to the Direct Input protocol, the X-Input protocol, or any other protocol expected by a driver of a particular computing device. In some embodiments, the formatting performed by the controller **152** may be adjustable by a user. For instance, the user may set how different forces applied to one of the force sensitive input keys **110** of the game pad **100** are mapped to a 256-value scale. This configurability may allow more users (e.g., of different abilities) to effectively use the game pad **100**. In some embodiments, the user may also be able to instruct the game pad **100** to interpret the analog signal(s) from one or more of the force sensitive input keys **110** like a binary input key **160** (i.e., treat any force exceeding an adjustable threshold as a binary “on” and treat all other forces applied as a binary “off”). In the illustrative embodiment, the binary input keys **160** of the game pad **100** are configured to output a digital signal that indicates whether or not the binary input key has been pressed.

Referring now to FIG. **4**, another illustrative embodiment of a force sensitive input key **110** that may be used in the game pad **100** (or other input devices **100**) is shown in cross-section. The illustrative embodiment of the force sensitive input key **110** shown in FIG. **4** is similar in configuration and operation to the force sensitive input keys **110** shown in FIGS. **2** and **3**, except that (like the force sensitive input device **10** of FIG. **1**) the reflectance sensor **116** is disposed in a chamber **132** defined within the housing **118**. As shown in FIG. **4**, the button **112** of the force sensitive input key **110** has a two part construction that includes a keycap **134** (with a surface **122** configured to be pressed by a user) and a plunger **136** that engages a spring **114** within the housing **118**. The plunger **136** is movable along an axis **124** when a force is applied to the keycap **134** by a user. The plunger **136** is illustrated in FIG. **4** in a top end position. When the surface **122** of the keycap **134** is pressed by a user, the keycap **134** and the plunger **136** may both move along the axis **124** (downward in FIG. **4**) until the button **112** reaches a bottom end position.

In the illustrative embodiment of FIG. **4**, the plunger **136** includes a plunger arm **138** that extends into the chamber **132** defined in the housing **118**. The reflective surface **128** of the button **112** is included on the plunger arm **138** and faces the reflectance sensor **116**. In the illustrative embodiment, the reflective surface **128** is integrally formed with the plunger **136** (i.e., the reflective surface **128** is a surface of the plunger **136**). In other embodiments, the plunger arm **138** and/or the reflective surface **128** may be coupled to the plunger **136** after the plunger **136** has been formed. As the button **112** (including the plunger **136**) moves along the axis **124**, the reflective surface **128** will move along an axis **130** that is generally parallel to the axis **124**. In the illustrative embodiment, the reflective surface **128** is generally perpendicular to the axis **130** (as well as the axis **124**). In the illustrative embodiment, the housing **118** may be formed of an opaque material, such that light is not able to escape and/or enter the chamber **132**.

Referring now to FIG. **5**, one illustrative embodiment of a force sensitive input method **200** is shown as a simplified flow diagram. The method **200** may be used with the force sensitive input device **10** of FIG. **1**, with the force sensitive input keys **110** of FIGS. **2-4**, and/or with any other suitable force sensitive input device(s). The method **200** begins with block **202** in which a button **12** that is movable along an axis **24** between two end positions is biased toward one of the two end positions using a resilient component **14**. As described above, the button **12** may be biased toward one of the two end positions using a spring **14**. While the spring **14** allows displacement of the button **12** along the axis **24** (as described below), the spring **14** continually biases the button **12** toward one of the two end positions (i.e., the block **202** is performed throughout the method **200**).

The method **200** continues with block **204** in which a reflective surface **28** of the button **12** is illuminated with light that travels generally parallel to the axis **24**. In some embodiments, block **204** may involve illuminating the reflective surface **28** of the button **12** by emitting light from an LED of a reflectance sensor **16** that faces the reflective surface **28**. In particular, block **204** may involve emitting infrared light from the LED of the reflectance sensor **16**. It is contemplated that, in other embodiments, other types of light sources and/or other types of light may be used to illuminate the reflective surface **28** of the button **12**. The block **204** may be performed either continuously or intermittently throughout the method **200**.

After block **204**, the method **200** continues to block **206** in which the button **12** is displaced from one end position (specifically, the end position toward which it is biased in block **202**) toward the other end position. In some embodiments, block **204** may involve a user applying a force to the button **12** to cause movement of the button **12** along the axis **24**. During block **206**, the method **200** also involves block **208** in which an amount of the light that is reflected from the reflective surface **28** and that travels generally parallel to the axis **24** is measured by the reflectance sensor **16**. In some embodiments, block **204** may involve receiving and measuring the reflected light using a phototransistor of the reflectance sensor **16**. During block **208**, the phototransistor of the reflectance sensor **16** may output an analog signal that is a function of the amount of the light that is reflected from the reflective surface **28**. As described above, the amount of the light that is reflected from the reflective surface **28** (and, hence, the magnitude(s) of the generated analog signal) may be monotonically related to the force applied to the button **12** in block **206**.

After blocks **206** and **208**, the method **200** continues to block **210** in which the force applied to the button **12** in block **206** is determined as a function of the amount of light measured in block **208**. In some embodiments, block **210** may involve a controller **152** receiving the analog signal output by the phototransistor in block **208** and calculating the force applied to the button **12** using this analog signal, as described above. In such embodiments, block **210** may involve converting the analog signal output by the phototransistor into a digital signal using an ADC of the controller **152**. In some embodiments, block **210** may also involve reducing noise in the analog signal using a low-pass filter, prior to the analog signal being converted by the ADC.

After block **210**, the method **200** may continue to block **212** in which the controller **152** generates movement data in response to the force determined in block **210**. As described above, where the method **200** is used with one or more force sensitive input devices **10** and/or force sensitive input keys **110**, the movement data generated by the controller **152** may include both direction and magnitude of movement. In some embodiments, block **212** may involve formatting the movement data for presentation to a driver of a computing device and transmitting the formatted data to the computing device.

While the disclosure has been illustrated and described in detail in the drawings and foregoing description, such an illustration and description is to be considered as exemplary and not restrictive in character, it being understood that only illustrative embodiments have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected. There are a plurality of advantages of the present disclosure arising from the various features of the apparatus, systems, and methods described herein. It will be noted that alternative embodiments of the apparatus, systems, and methods of the present disclosure may not include all of the features described yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may readily devise their own implementations of the apparatus, systems, and methods that incorporate one or more of the features of the present invention and fall within the spirit and scope of the present disclosure as defined by the appended claims.

The invention claimed is:

1. An input device comprising:
- a first input key configured to output a first analog signal as a function of force applied to the first input key;
- a second input key configured to output a second analog signal as a function of force applied to the second input key;
- a third input key configured to output a third analog signal as a function of force applied to the third input key;
- a fourth input key configured to output a fourth analog signal as a function of force applied to the fourth input key; and
- a controller configured to output movement data including both direction and magnitude in response to the first, second, third, and fourth analog signals;
- wherein the first, second, third, and fourth input keys each comprise:
- a button movable along a respective axis between a first end position and a second end position, the button including a reflective surface;
- a resilient component biasing the button toward the first end position; and
- a reflectance sensor configured to emit light that impinges upon the reflective surface, to measure an amount of the light that is reflected from the reflective surface, and to output the respective analog signal in response to the measured amount of the reflected light, wherein the light travels generally parallel to the respective axis.

2. The input device of claim **1**, wherein the controller comprises an analog-to-digital converter (ADC) configured to convert the first, second, third, and fourth analog signals into digital signals.

3. The input device of claim **2**, further comprising a low-pass filter configured to reduce noise in at least one of the first, second, third, and fourth analog signals before the analog signal is received by the ADC of the controller.

4. The input device of claim **1**, wherein the controller is configured to format the movement data for presentation to a driver of a computing device.

5. The input device of claim **1**, wherein the movement data includes an x-axis component and a y-axis component, the x-axis component being a function of the first and second analog signals, and the y-axis component being a function of the third and fourth analog signals.

6. The input device of claim **1**, further comprising a number of binary input keys, each of the binary input keys being configured to output a digital signal indicating whether or not the binary input key has been pressed.

7. The input device of claim **1**, wherein the button of each of the first, second, third, and fourth input keys comprises:
- a keycap configured to be pressed by a user to move the button along the first axis toward the second end position; and
- a plunger supporting the keycap, the plunger engaging the resilient component.

8. The input device of claim **1**, wherein each of the first, second, third, and fourth input keys further comprises an opaque housing defining a respective chamber, the reflective surface and the reflectance sensor being disposed in the respective chamber.

9. The input device of claim **1**, wherein the reflectance sensor of each of the first, second, third, and fourth input keys comprises:

a light-emitting diode (LED) configured to emit the light; and

a phototransistor configured to receive the amount of the light that is reflected from the reflective surface.

10. The input device of claim **1**, wherein the resilient component of each of the first, second, third, and fourth input keys is configured to allow a displacement of the button from the first end position that is proportional to a force applied to the button by a user.

11. The force sensitive input device of claim **10**, wherein, for each of the first, second, third, and fourth input keys, the amount of the light that is reflected from the reflective surface is monotonically related to the displacement of the button from the first end position.

12. A method comprising:

biasing a button that is movable along a first axis between a first end position and a second end position toward the first end position using a resilient component such that a force being applied to the button results in a displacement of the button from the first end position toward the second end position that is proportional to a magnitude of the force;

illuminating a reflective surface of the button with light that travels generally parallel to the first axis;

measuring, while the button is displaced from the first end position toward the second end position, an amount of the light that is reflected from the reflective surface and that travels generally parallel to the first axis;

determining the force applied to the button as a function of the measured amount of the light; and

outputting a value indicative of the magnitude of the force applied to the button.

13. The method of claim **12**, wherein illuminating the reflective surface of the button comprises emitting light from a light-emitting diode (LED) facing the reflective surface.

14. The method of claim **12**, wherein measuring the amount of the light that is reflected from the reflective surface comprises receiving light using a phototransistor.

15. The method of claim **14**, wherein the phototransistor outputs an analog signal that is a function of the amount of the light that is reflected from the reflective surface.

16. The method of claim **12**, wherein the amount of the light that is reflected from the reflective surface is monotonically related to the force applied to the button.

17. The method of claim **12**, further comprising generating movement data including both direction and magnitude in response to the determined force.

18. The method of claim **12**, wherein outputting the value indicative of the magnitude of the force applied to the button comprises further comprising mapping the determined force to a scale expected by a driver of a computing device.

19. The method of claim **15**, further comprising converting the analog signal into a digital signal that represents the amount of the light that is reflected from the reflective surface.

20. The method of claim **19**, wherein determining the force applied to the button comprises calculating the force using a mathematical function that takes a value of the digital signal as an input.

21. The method of claim **19**, wherein determining the force applied to the button comprises consulting a look-up table that relates a value of the digital signal to a force value.

22. The input device of claim **8**, wherein, for each of the first, second, third, and fourth input keys, when the button is in the second end position, the button contacts the opaque housing to block further movement of the button along the respective axis away from the first end position.

23. The input device of claim **7**, wherein, for each of the first, second, third, and fourth input keys, the reflective surface of the button is spaced apart from a portion of the plunger that engages the resilient component.

24. The input device of claim **23**, wherein, for each of the first, second, third, and fourth input keys, the portion of the plunger that engages the resilient component is configured to move along the respective axis and the reflective surface is configured to move along a parallel axis.

25. The input device of claim **24**, wherein, for each of the first, second, third, and fourth input keys, the reflective surface is perpendicular to the parallel axis.

26. The input device of claim **1**, wherein the controller is configured to:

calculate a first vector having a first magnitude based on a value of the first analog signal;

calculate a second vector having a second magnitude based on a value of the second analog signal;

calculate a third vector having a third magnitude based on a value of the third analog signal; and

calculate a fourth vector having a fourth magnitude based on a value of the fourth analog signal;

wherein the direction and the magnitude of the movement data represent a vector addition of the first, second, third, and fourth vectors.

27. The input device of claim **4**, wherein the controller is configured to format the movement data to a scale expected by the driver of the computing device.

28. The input device of claim **4**, wherein the controller is configured to format the movement data according to either the DirectInput protocol or the XInput protocol.

29. The input device of claim **5**, wherein:

the x-axis component represents a first distance from a resting point, the first distance being proportional to a force applied to one of the first and second input keys; and

the y-axis component represents a second distance from the resting point, the second distance being proportional to a force applied to one of the third and fourth input keys.

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