



US010234945B2

(12) **United States Patent**  
**Levesque et al.**

(10) **Patent No.:** **US 10,234,945 B2**  
(45) **Date of Patent:** **Mar. 19, 2019**

(54) **COMPENSATED HAPTIC RENDERING FOR FLEXIBLE ELECTRONIC DEVICES**

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/261,447**

(22) Filed: **Sep. 9, 2016**

(65) **Prior Publication Data**

US 2018/0074585 A1 Mar. 15, 2018

(51) **Int. Cl.**  
**G06F 3/01** (2006.01)  
**G06F 3/041** (2006.01)  
**G06F 3/0487** (2013.01)

(52) **U.S. Cl.**  
CPC ..... **G06F 3/016** (2013.01); **G06F 3/017** (2013.01); **G06F 3/0414** (2013.01); **G06F 3/0487** (2013.01); **G06F 2203/04102** (2013.01)

(58) **Field of Classification Search**  
None  
See application file for complete search history.

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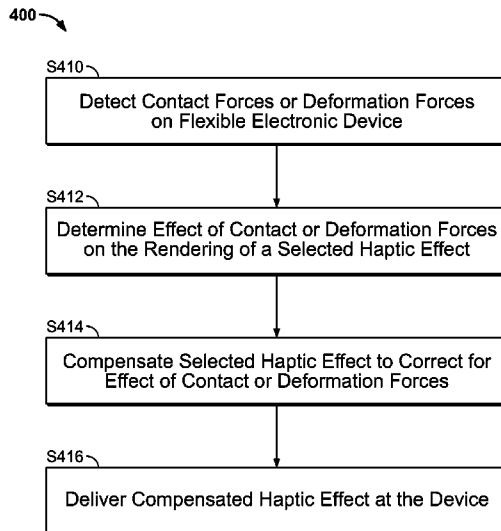
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(57) **ABSTRACT**

A device comprises a housing, a sensor, a controller and an actuator. The sensor is configured to detect a contact force exerted on the housing. The controller is communicatively coupled to the sensor and is configured to determine a change in a haptic effect caused by the contact force. The controller is additionally configured to generate an output instruction to deliver the haptic effect in a compensated form that is operable to correct the change. The actuator is configured to receive the output instruction and deliver the compensated haptic effect at the housing.

**18 Claims, 8 Drawing Sheets**



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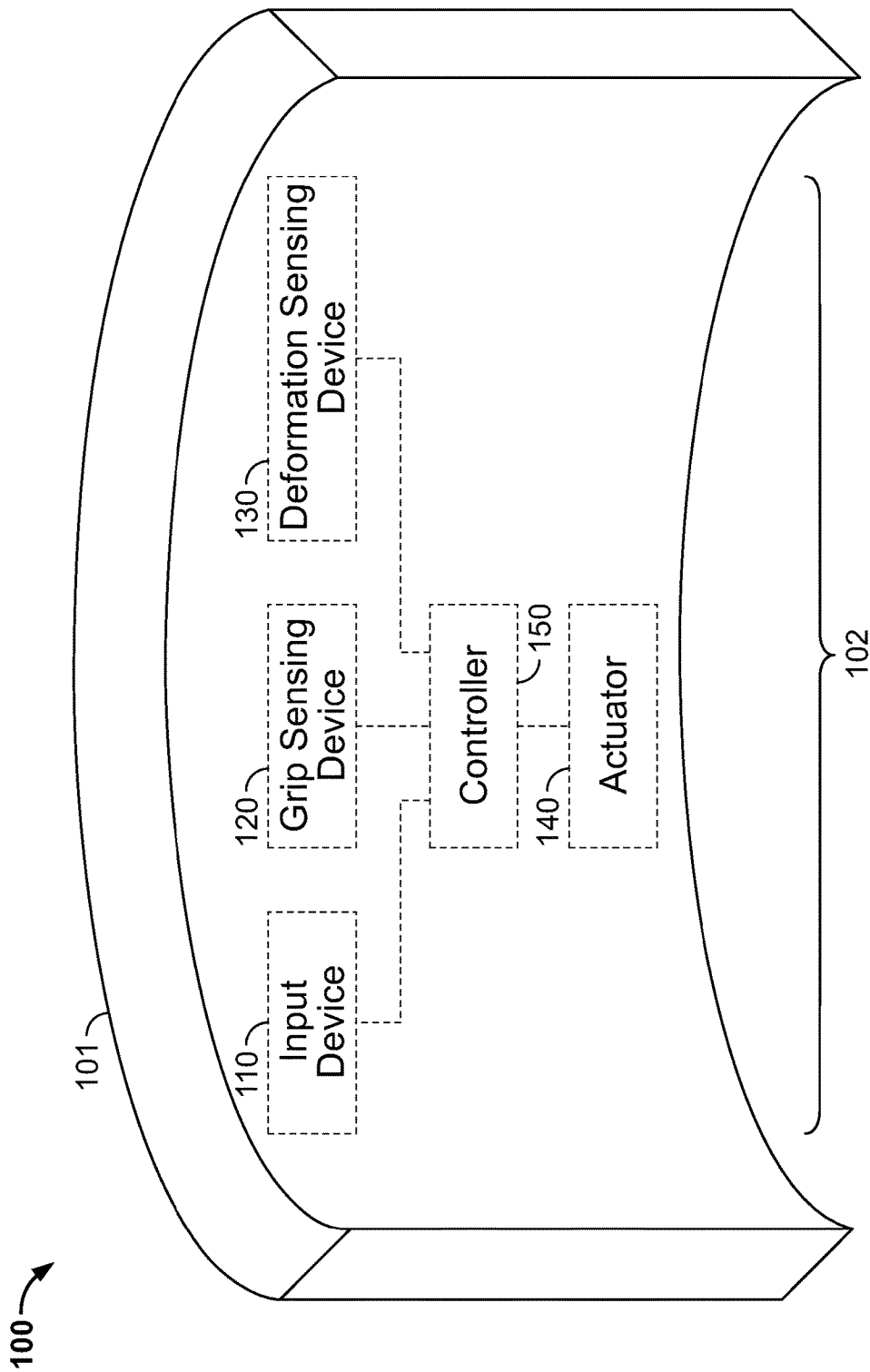


FIG. 1

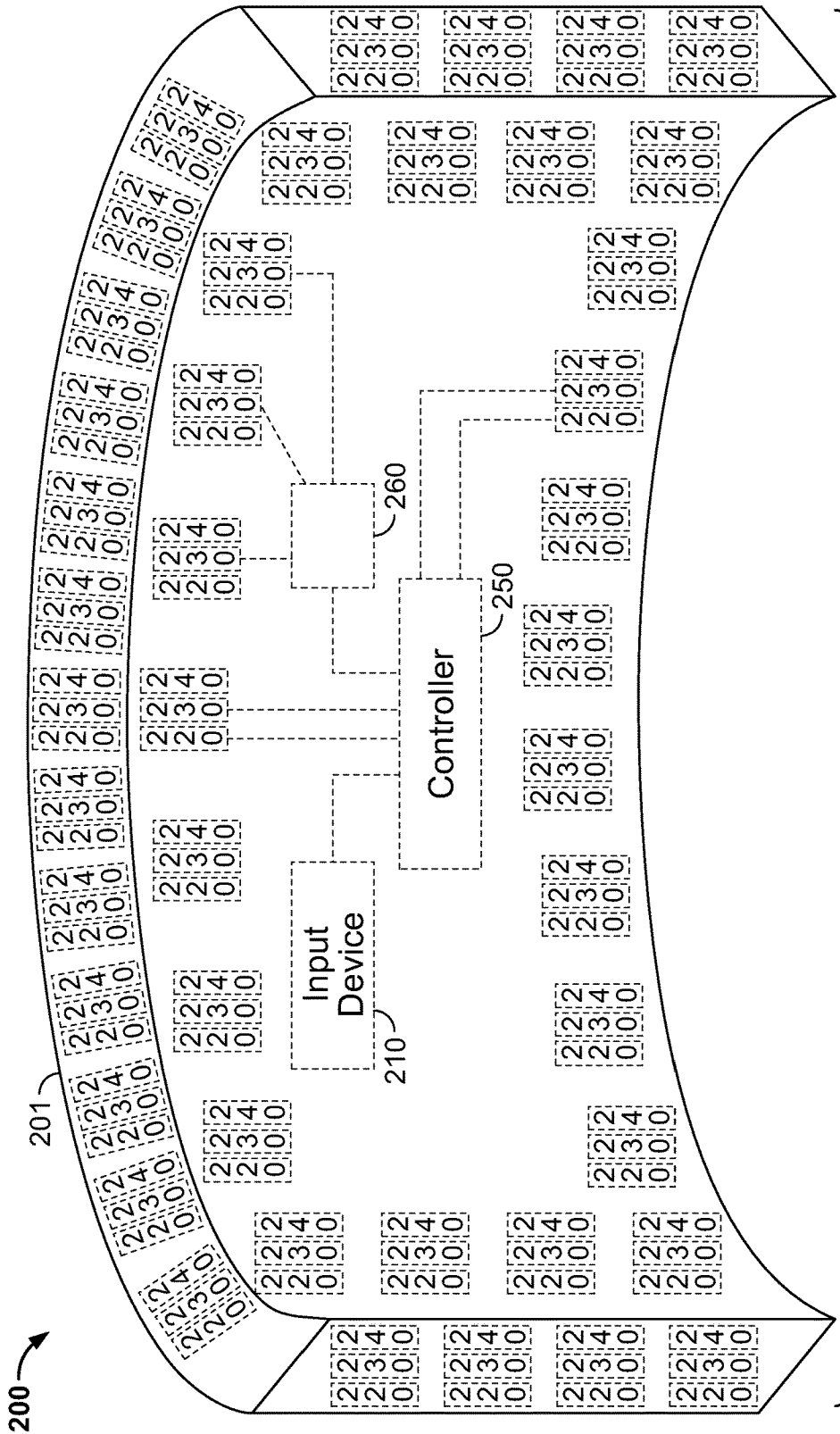


FIG. 2

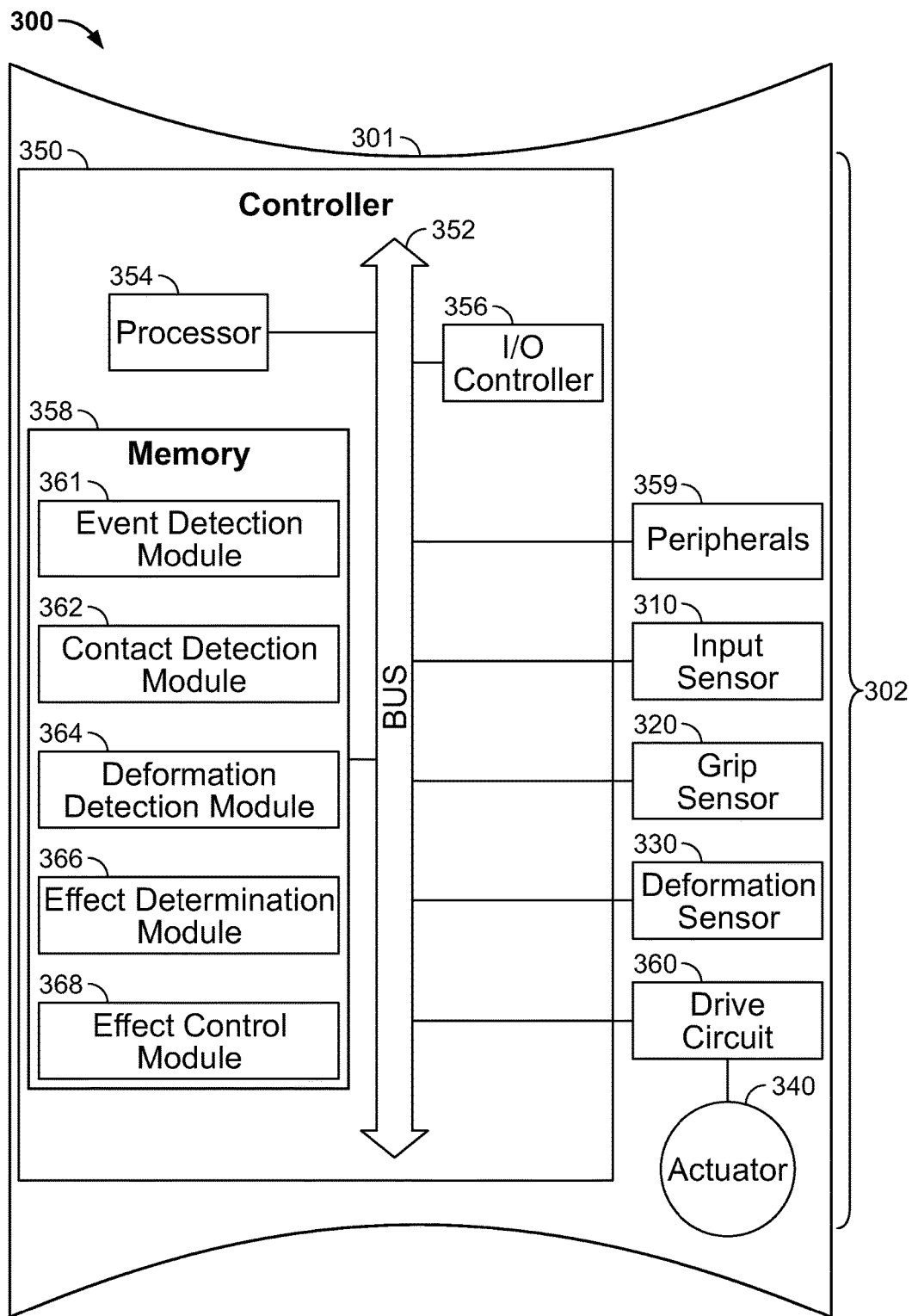


FIG. 3

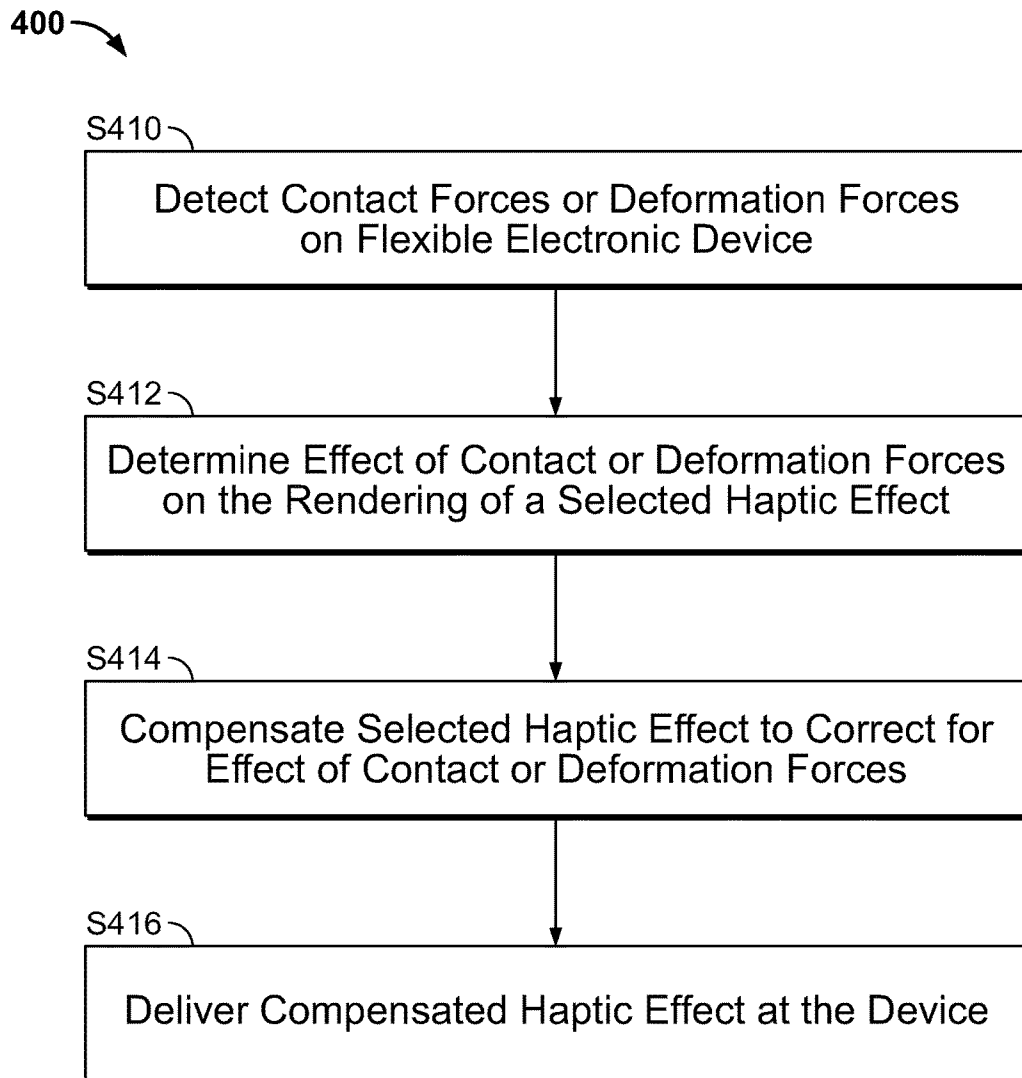


FIG. 4

500 →

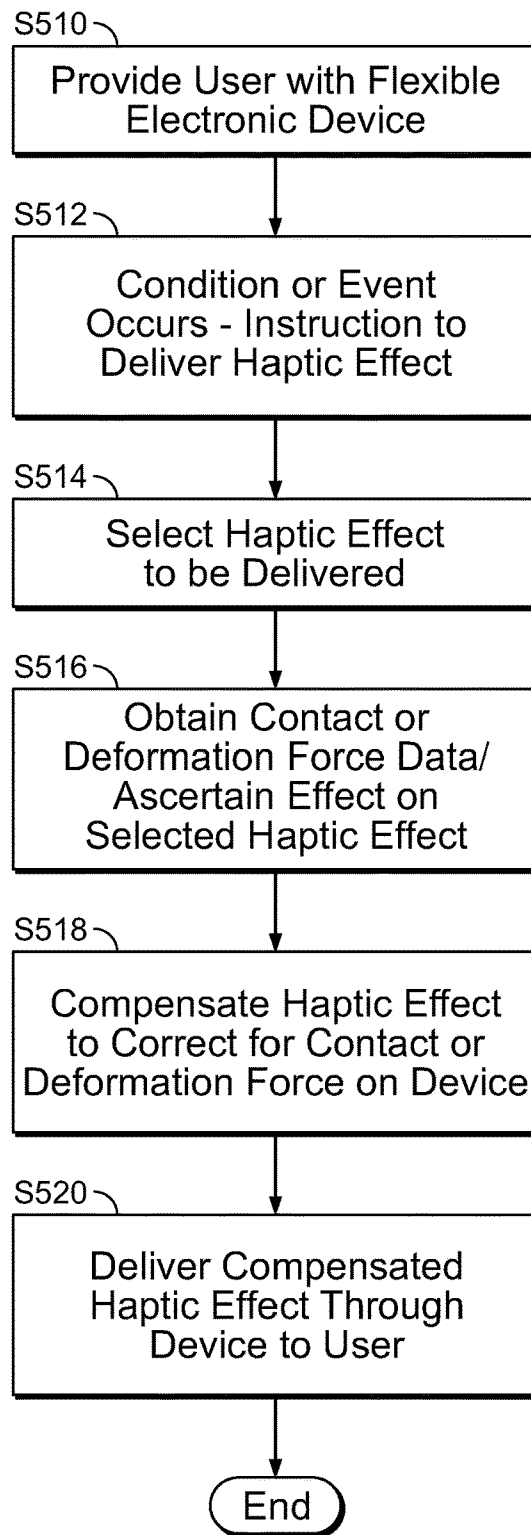


FIG. 5

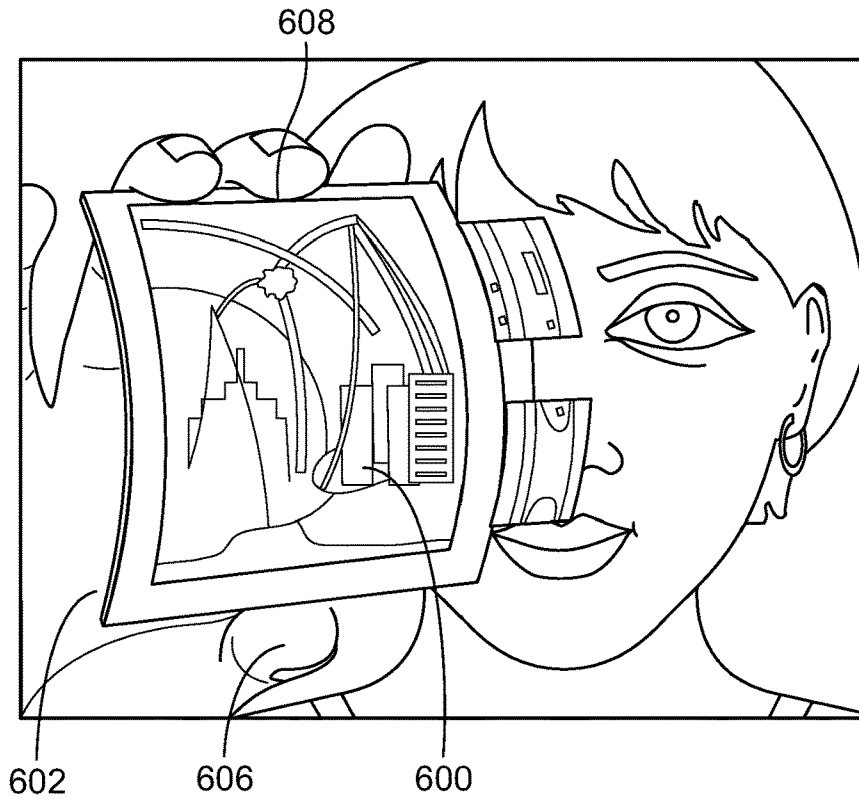


FIG. 6A

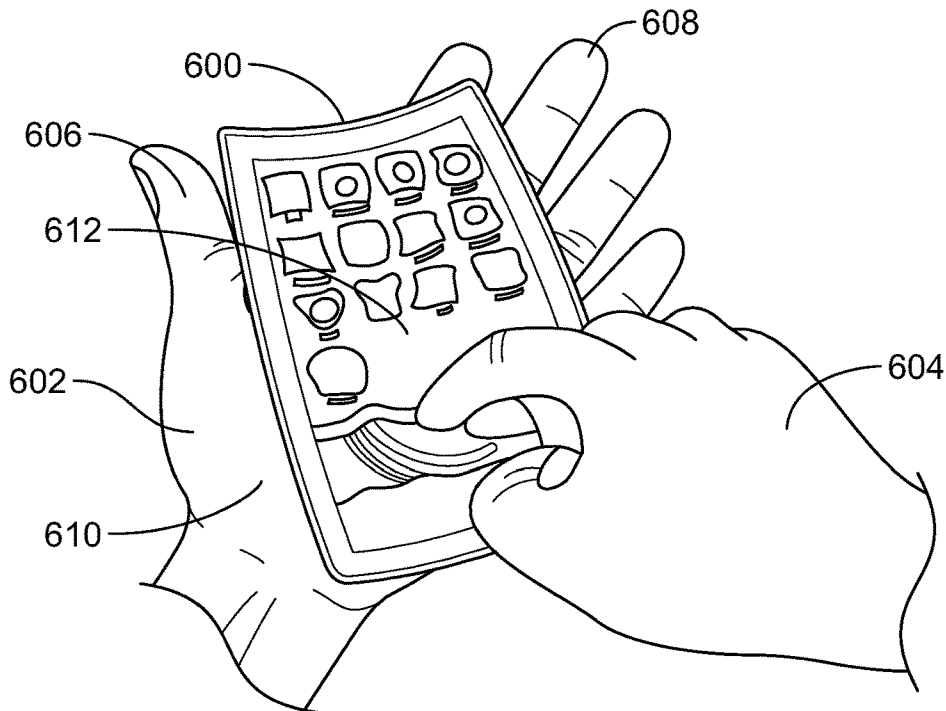


FIG. 6B



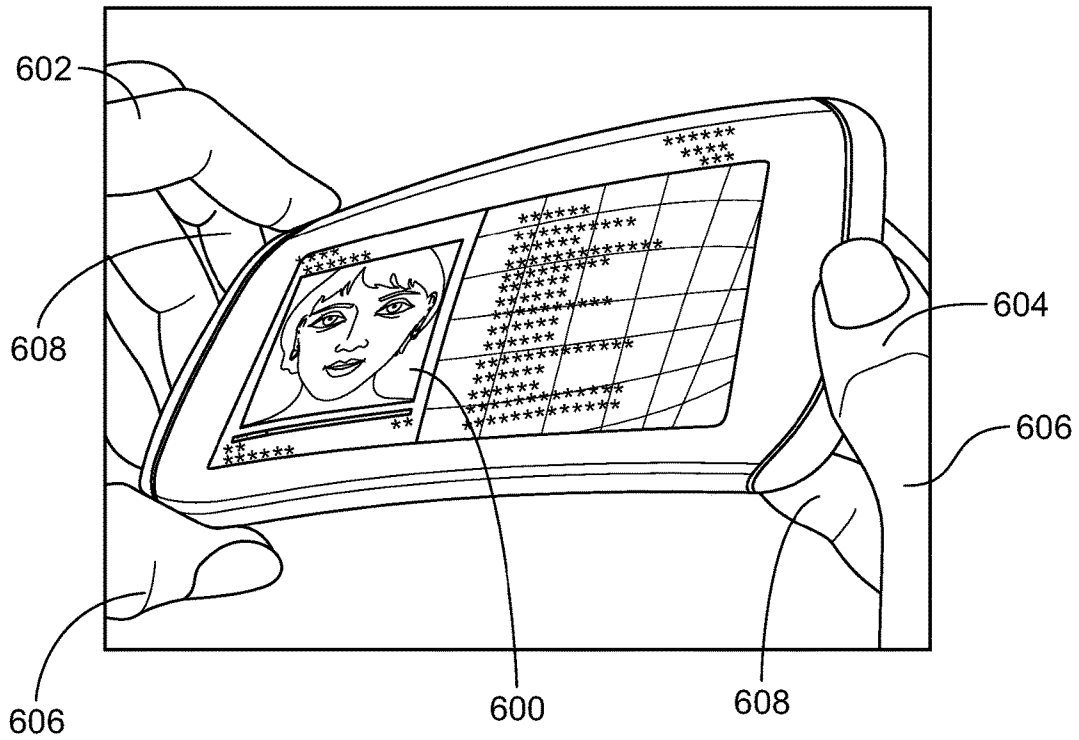


FIG. 6C

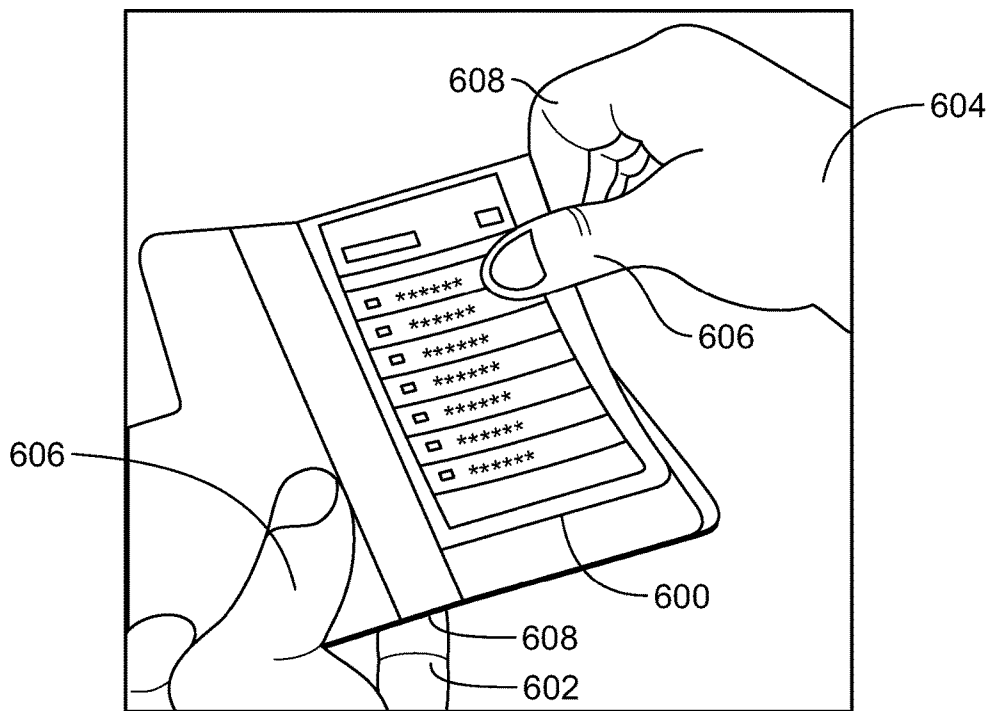


FIG. 6D

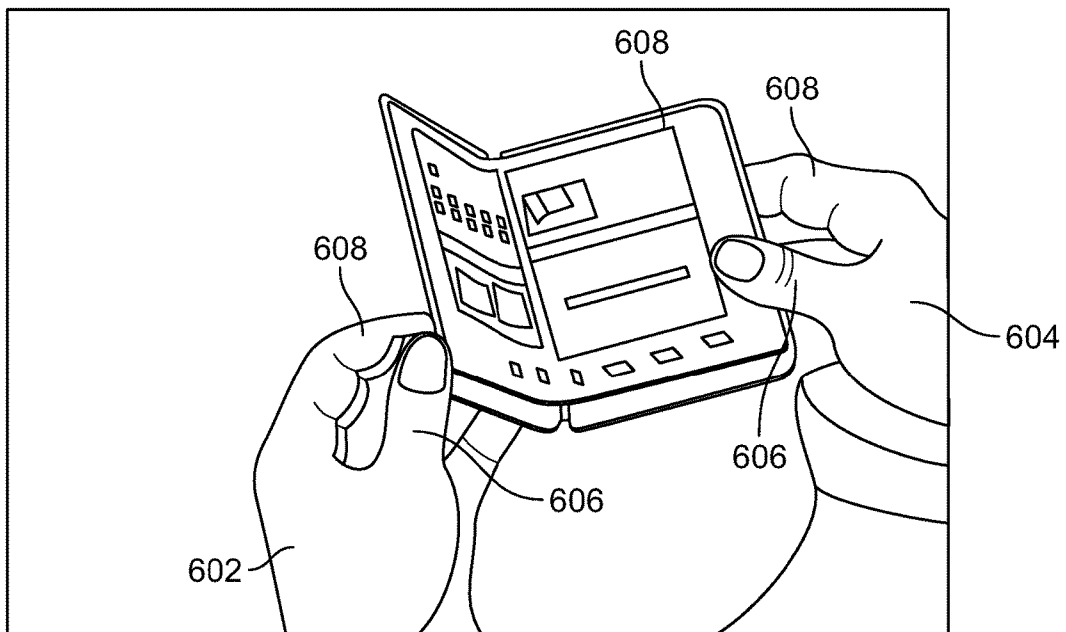


FIG. 6E

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# COMPENSATED HAPTIC RENDERING FOR FLEXIBLE ELECTRONIC DEVICES

## TECHNICAL FIELD

This patent document relates to haptic effects and, more particularly, to compensated haptic rendering for flexible electronic devices.

## BACKGROUND

The design of electronic devices continues to evolve including designs that enable the device to flex or bend in response to an applied force. A user's touch or grip on an electronic device will vary in accordance with the flexing and bending of the device as will various device parameters that are affected by the forces exerted by user's contact or the deformation. As such, the delivery of a desired haptic effect through the device to the user can be disrupted or altered by one or both of device contact and device deformation resulting in an unsatisfactory, or even undetectable, haptic sensation.

## SUMMARY

This patent document relates to compensated haptic rendering for flexible electronic devices.

In one aspect, this patent document is directed to a device comprising a housing, a sensor, a controller and an actuator. The sensor is configured to detect a contact force exerted on the housing. The controller is communicatively coupled to the sensor and is configured to determine a change in a haptic effect caused by the contact force. The controller is additionally configured to generate an output instruction to deliver the haptic effect in a compensated form that is operable to correct the change. The actuator is configured to receive the output instruction and deliver the compensated haptic effect at the housing.

In another aspect, this patent document is directed to a device comprising a housing, a first sensor, a second sensor, a controller and an actuator. The first sensor is configured to detect a contact force exerted on the housing. The second sensor is configured to detect a deformation force created by deformation of the housing. The controller is communicatively coupled to the first and second sensors, and is configured to determine a change in a haptic effect caused by both the contact force and the deformation force. The controller is additionally configured to generate an output instruction to deliver the haptic effect in a compensated form that is operable to correct the change. The actuator is configured to receive the output instruction and deliver the compensated haptic effect at the housing.

In still another aspect, this patent document is directed to a method for compensating haptic effects including: (a) detecting a contact force exerted on a housing; (b) determining a change in a haptic effect to be delivered at the housing caused by the contact force; (c) determining a compensation for the haptic effect, the compensation operable to correct the change; (d) applying the compensation to the haptic effect; and (e) delivering the compensated haptic effect at the housing.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of flexible electronic device configured to deliver haptic effects according to various embodiments disclosed herein.

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FIG. 2 is a schematic of another possible embodiment of the flexible electronic device.

FIG. 3 is a schematic of another possible embodiment of the flexible electronic device.

FIG. 4 is a flowchart illustrating a method for compensating a haptic effect.

FIG. 5 is a flow chart illustrating a method for compensating a haptic effect.

FIG. 6A-6E illustrate various grip configurations on a flexible electronic device.

## DETAILED DESCRIPTION

Various embodiments will be described in detail with reference to the drawings, wherein like reference numerals represent like parts and assemblies throughout the several views. Reference to various embodiments does not limit the scope of the claims attached hereto. Additionally, any examples set forth in this specification are not intended to be limiting and merely set forth some of the many possible embodiments for the appended claims.

Whenever appropriate, terms used in the singular also will include the plural and vice versa. The use of "a" herein means "one or more" unless stated otherwise or where the use of "one or more" is clearly inappropriate. The use of "or" means "and/or" unless stated otherwise. The use of "comprise," "comprises," "comprising," "include," "includes," "including," "has," and "having" are interchangeable and not intended to be limiting. The term "such as" also is not intended to be limiting. For example, the term "including" shall mean "including, but not limited to."

In general terms, this patent document relates to compensated haptic rendering for flexible electronic devices.

Referring to FIG. 1, a flexible electronic device **100** presents a housing **101** that includes a haptic effect system **102** that has an input device **110**, a contact sensing device **120**, a deformation sensing device **130**, an actuator **140** and a controller **150**. As used herein, the term "flexible electronic device" is any electronic device capable of changing shape from its original shape by flexing, bending, expanding, contracting, stretching, or otherwise yielding to an external force resulting in an alteration of original shape. Examples of flexible electronic devices include computers, tablets, smartphones, e-readers, keyboards, trackpads, medical devices, pens/stylus, remote controls, gaming controllers, joysticks, steering wheels, gear shifters, home appliances.

The input device **110** is any device that inputs a signal into the controller **150**. An example of an input device **110** is a control device such as a switch. Another example of the input device **110** includes a transducer that inputs a signal to the controller **150**. Examples of transducers that can be used as input device **110** include antennas and sensors. Various embodiments can include a single input device or two or more input devices of the same or different type. Further, while FIG. 1 shows the input device **110** as internal to the flexible electronic device **100**, in various other embodiments the input device **110** may be external to the flexible electronic device **100**.

The contact sensing device **120** can be any device that senses or otherwise detects a force exerted by a user on the flexible electronic device **100** through either direct or indirect contact with the device **100**. The contact sensing device **120** provides notification of that detection as an input to the controller **150**. Examples of contact forces exerted by the user on the flexible electronic device **100** include forces exerted through direct contact with the device (e.g., a user's single-handed or dual-handed grip on the device, a single

finger touch of the device, a multi-finger touch of the device, or touching the device with other user body parts). Examples of contact forces exerted by the user on the flexible electronic device **100** further include forces exerted through indirect contact with the device such as forces transferred from a user through an interfacing medium to the device (e.g., the flexing of a user's wrist transfers a force through a watch band to the watch housing mounted on the band; the watch housing is experiencing indirect user contact). Examples of sensors that can be used as the contact sensing device **120** include pressure sensors, vibration sensors and other sensors described herein. Various embodiments can include a single contact sensing device **120** or a plurality of contact sensing devices **120** that may be presented individually or in an array configuration; the plurality of contact sensing devices **120** can be spread equidistantly about the flexible electronic device **100** or can be spread non-equidistantly about the device **100**.

The deformation sensing device **130** can be any device that senses or otherwise detects a force caused by the deformation, e.g., flexing, bending, and twisting, of the flexible electronic device **100** itself and provides notification of that detection as an input to the controller **150**. Various types of sensors may be used as the deformation sensing device **130** including pressure sensors, vibration sensors and other sensors described herein. Various embodiments can include a single deformation sensing device **130** or a plurality of deformation sensing devices **130** that may be presented individually or in an array configuration; the plurality of deformation sensing devices **130** can be spread equidistantly about the flexible electronic device **100** or can be spread non-equidistantly about the device **100**. In various example embodiments, a contact sensing device **120** or, alternatively, a deformation sensing device **130** may perform both functions of contact sensing and deformation sensing. Further, in some example embodiments, the deformation sensing device **130** is eliminated and only the contact sensing device **120** is used to provide data to the controller **150** while in other example embodiments the contact sensing device **120** is eliminated and only the deformation sensing device **130** is used to provide data to the controller **150**.

The actuator **140** can be any controlled mechanism or other structure that initiates movement for deliverance of a haptic effect. The haptic effect can be any type of tactile sensation delivered from the flexible electronic device **100** to the user. Examples of actuators **140** include mechanisms such as motors, linear actuators (e.g. solenoids), magnetic or electromagnetic mechanisms. Additional examples of actuators **140** include smart materials such as shape memory alloys, piezoelectric materials, electroactive polymers, and materials containing smart fluids. The actuator **140** can comprise a single actuator or a plurality of actuators provided within the flexible electronic device **100**. In the instance of a plurality of actuators **140**, the actuators can be provided in an actuator array, or individually positioned, with the actuators **140** equidistantly spaced or non-equidistantly spaced. The haptic effect can, for example, be delivered as a vibrotactile haptic effect, an electrostatic friction (ESF) haptic effect, or a deformation haptic effect.

The controller **150** is any type of circuit that controls operation of the actuator **140** based on receiving a signal or data from the input device **110**, the contact sensing device **120**, and the deformation sensing device **130**. Data can be any type of parameters (e.g., conditions, events, contact-related parameters, and deformation-related parameters),

instructions, flags, or other information that is processed by the processors, program modules and other hardware disclosed herein.

In operation, the input device **110**, the contact sensing device **120**, and the deformation sensing device **130** are stimulated, and each provides an input signal to the controller **150**. In response, the controller **150** operates the actuator **140** to deliver a haptic effect to the user via the flexible electronic device **100**. The delivered haptic effect is configured to compensate for user contact forces or deformation forces on the device **100**. The haptic effect can be any type of tactile sensation delivered directly or indirectly to a user. The haptic effect embodies a message such as a cue, notification, or more complex information.

FIG. 2 illustrates a more detailed schematic of a possible embodiment of a flexible electronic device **200** having a housing **201** and haptic effect system **202**. In this embodiment, the haptic effect system **202** of the flexible electronic device **200** includes an input sensor **210**, a plurality of contact sensors **220**, a plurality of deformation sensors **230**, a plurality of actuators **240** and a controller **250**. The contact sensors **220**, the deformation sensors **230**, and the actuators **240** are positioned throughout the device **200**. The input sensor **210**, the contact sensors **220**, and the deformation sensors **230** are in electrical communication with the controller **250**. One or more actuator drive circuits **260** are in electrical communication with the controller **250** and with one or more actuators **240**. Note that only a few exemplary connections between components have been provided to simplify the diagram; other connections between components are to be considered as included in the schematic.

The input sensor **210** can be any instrument or other device that outputs a signal in response to receiving a stimulus; the input sensors can be used to detect or sense a variety of different conditions or events. The input sensor **210** can be hardwired to the controller **250** or can be connected to the controller wirelessly. Further, the input sensor **210** can comprise a single sensor or a plurality of sensors that are included within, or external to, the flexible electronic device **200**.

The contact sensors **220** can be any instrument or other device that outputs a signal in response to sensing or detecting a contact force exerted by direct or indirect contact of the user with the flexible electronic device **200**; the contact sensors **220** can be used to detect or sense a variety of contact-related parameters. The contact sensors **220** can be hardwired to the controller **250** or can be connected to the controller **250** wirelessly. In various example embodiments, the contact sensors **220** comprise a plurality of touch sensors (e.g., capacitive sensors or force-sensitive resistors) that lie behind substantially all of the surfaces of the flexible electronic device **200**. The surfaces of the flexible electronic device **200** can include, for example, the surfaces of a device housing, the surfaces of a device touchscreen, the surfaces of a device display screen and the surfaces of a device button or switch.

The deformation sensors **230** can be any instrument or other device that outputs a signal in response to sensing a force caused by a deformation, e.g., flexing, bending, and twisting, of the housing **201** of flexible electronic device **200**; the deformation sensors **230** can be used to detect or sense a variety of deformation-related parameters. The deformation sensors **230** can be hardwired to the controller **250** or can be connected to the controller **250** wirelessly. In various example embodiments, the deformation sensors **230** comprise strain gauges, force-sensitive resistors or piezoelectric sensors that lie behind substantially all of the

surfaces of the flexible electronic device **200**. In various example embodiments, a sensor may perform both the functions of contact force sensing and deformation force sensing. Further, in some example embodiments, the deformation sensors **230** are eliminated and only the contact sensors **220** are used to provide data to the controller **250** while in other embodiments the contact sensors **220** are eliminated and only the deformation sensors **230** are used to provide data to the controller.

Various other examples of input sensors **210**, contact sensors **220**, and deformation sensors **230** include acoustical or sound sensors such as microphones; vibration sensors; chemical and particle sensors such as breathalyzers, carbon monoxide and carbon dioxide sensors, and Geiger counters; electrical and magnetic sensors such as voltage detectors or hall-effect sensors; flow sensors; navigational sensors or instruments such as GPS receivers, altimeters, gyroscopes, or accelerometers; position, proximity, and movement-related sensors such as piezoelectric materials, rangefinders, odometers, speedometers, shock detectors; imaging and other optical sensors such as charge-coupled devices (CCD), CMOS sensors, infrared sensors, and photodetectors; pressure sensors such as barometers, piezometers, and tactile sensors; force sensors such as piezoelectric sensors and strain gauges; temperature and heat sensors such as thermometers, calorimeters, thermistors, thermocouples, and pyrometers; proximity and presence sensors such as motion detectors, triangulation sensors, radars, photo cells, sonars, and hall-effect sensors; biochips; biometric sensors such as blood pressure sensors, pulse/ox sensors, blood glucose sensors, and heart monitors. Additionally, the sensors can be formed with smart materials, such as piezo-electric polymers, which in some embodiments function as both a sensor and an actuator.

The controller **250** is any type of circuit that controls operation of the actuators **240** based on receiving a signal or data from the input sensor **210**, the contact sensors **220**, and the deformation sensors **230**. Data can be any type of parameters (e.g., conditions, events, contact-related parameters, and deformation-related parameters), instructions, flags, or other information that is processed by the processors, program modules and other hardware disclosed herein.

The one or more actuator drive circuits **260** are circuits that receive a haptic signal from the controller **250**. The haptic signal embodies haptic data, and the haptic, data defines parameters that the actuator drive circuit **260** uses to generate a haptic drive signal. Examples of parameters that can be defined by the haptic data include frequency, amplitude, phase, inversion, duration, waveform, attack time, rise time, fade time, and lag or lead time relative to an event. The haptic drive signal is applied to the actuators **240** causing motion within the actuators **240**.

In operation, the input sensor **210** detects an event or condition, the contact sensors **220** detect forces exerted via direct or indirect user contact with the housing **201**, and the deformation sensors **230** detect forces exerted by the actual deformation of the housing **201**. In response to the detected event or condition, the controller **250** determines: (a) the appropriate haptic effect to deliver; and (b) the change in the haptic effect caused by the contact forces and by the deformation forces. The controller **250** then operates to modify the haptic effect to correct, or compensate, for the contact forces and deformation forces on the haptic effect. The controller **250** then provides the instruction for delivering the compensated haptic effect to the one or more drive circuits **260** to initiate the desired actuation of the actuators **240**. Due to the compensation, the haptic effect delivered to

the user feels to the user as though the contact forces or the deformation forces on the device have had substantially no effect on the delivered haptic effect.

FIG. 3 illustrates a more detailed schematic of a possible embodiment of a flexible electronic device **300** with a housing that includes a haptic effect system **302**. In this embodiment, the haptic effect system **302** of the flexible electronic device **300** includes an input sensor **310**, a contact sensor **320**, a deformation sensor **330**, an actuator **340** and a controller **350**. The input sensor **310**, the contact sensor **320**, and the deformation sensor **330** are in electrical communication with the controller **350**. An actuator drive circuit **360** is in electrical communication with the controller **350** and the actuator **340**.

The input sensor **310**, contact sensor **320**, deformation sensor **330**, and actuator **340**, correspond to input sensors **210**, contact sensors **220**, deformation sensors **230**, and actuators **240**, respectively, as described herein.

The controller **350** generally includes a bus **352**, a processor **354**, an input/output (I/O) controller **356** and a memory **358**. The bus **352** couples the various components of the controller **350**, including the I/O controller **356** and memory **358**, to the processor **354**. The bus **352** typically comprises a control bus, address bus, and data bus. However, the bus **352** can be any bus or combination of buses suitable to transfer data between components in the controller **350**.

The processor **354** can comprise any circuit configured to process information and can include a suitable analog or digital circuit. The processor **354** can also include a programmable circuit that executes instructions. Examples of programmable circuits include microprocessors, microcontrollers, application specific integrated circuits (ASICs), programmable gate arrays (PGAs), field programmable gate arrays (FPGAs), or any other processor or hardware suitable for executing instructions. In the various embodiments the processor **354** can comprise a single unit, or a combination of two or more units, with the units physically located in a single controller **350** or in separate devices.

The I/O controller **356** comprises circuitry that monitors the operation of the controller **350**, and peripheral or external devices such as the input sensor **310**, the force exertion sensor **320**, the deformation sensor **330**, and the actuator drive circuit **360**. The I/O controller **356** further manages data flow between the controller **350** and the peripheral devices, and frees the processor **354** from details associated with monitoring and controlling the peripheral devices. Examples of other peripheral or external devices **359** with which the I/O controller **356** can interface include external storage devices, monitors, input devices such as keyboards, mice or pushbuttons, external computing devices, mobile devices, and transmitters/receivers.

The memory **358** can comprise volatile memory such as random access memory (RAM), read only memory (ROM), electrically erasable programmable read only memory (EEPROM), flash memory, magnetic memory, optical memory or any other suitable memory technology. The memory **358** can also comprise a combination of volatile and nonvolatile memory.

The memory **358** is configured to store a number of program modules for execution by the processor **354**, including an event detection module **361**, a contact detection module **362**, a deformation detection module **364**, an effect determination module **366**, and an effect control module **368**. Each program module is a collection of data, routines, objects, calls and other instructions that perform one or more particular task. Although certain program modules are dis-

closed herein, the various instructions and tasks described for each module can, in various embodiments, be performed by a single program module, a different combination of modules, modules other than those disclosed herein, or modules executed by remote devices that are in communication with the controller 30.

The event detection module 361 is programmed to receive event data from the input sensor 310 and evaluate the received event data to determine if the event data is associated with a haptic effect. In the instance that the input sensor 310 is internal to the flexible electronic device 300, the event data from input sensor 310 can comprise data generated by an event occurring at or in the device 300. Alternatively, in the instance that the input sensor 310 is external to the flexible electronic device 300, the event data from input sensor 310 can comprise data generated by a device or system that is separate from the flexible electronic device 300. An event can, for example comprise, an individual input (e.g., a button press, the manipulation of a joystick, user interaction with a touch sensitive surface, or any other interaction with a user interface). In another example, the event can comprise a system status (e.g., low battery, low memory, and an incoming call), a sending of data, a receiving of data, or a program event (e.g., a game program producing the explosions, gunshots, collisions, interactions between characters, bumpy terrains).

The contact detection module 362 is programmed to receive contact data from the contact sensor 320 within the flexible electronic device 300 and evaluate that data to establish parameters related to the direct or indirect contact of the by device 300 by the user. Examples of contact-related parameters include the location, area and applied pressure at the contact points between the user and the device 300. Further examples of contact-related parameters include, for example, the number of fingers being used to grip or touch the device 300; the position of the user's grip or touch (direct or indirect) on the device 300 regardless of, or in relation to, the orientation of the device 300, the pressure being exerted by the user's grip or touch (direct or indirect) on the device 300; the heat being transferred from the user's grip or touch (direct or indirect) to the device 300; the temperature change caused by the user's grip or touch (direct or indirect) on the device 300; the electrical conductivity of the user's grip or touch (direct or indirect) on the device 300; the vibration of the user's grip or touch (direct or indirect) on the device 300; or the deformation of a surface of the device 300 caused by the user's grip or touch (direct or indirect) on the device 300.

The contact data may be obtained on a sensor-by-sensor basis or may be representative of a plurality contact sensors 320. For example, a plurality of contact sensors 320 can be defined as identifying a region of the surface of the flexible electronic device 300 to provide contact data on a region-by-region basis. In other examples, the contact data can be obtained from a plurality of contact sensors 320 where the contact data is obtained on a finger-by-finger basis. In various example embodiments, the contact detection module 362 can use the contact data to infer the posture of a user's hand, for example, based on a model of the mechanical constraints of the hand and the relative area of different finger pads. The contact detection module 362 can determine, for example, based on the contact data, whether the flexible device 300 is held in one or two hands, whether the device 300 is being touched by the thumb or other fingers, or whether the device 300 is being directly or indirectly touched by the user.

The deformation detection module 364 is programmed to receive deformation data from the deformation sensor 330

within the flexible electronic device 300 and evaluate the deformation data to determine parameters relating to the deformation of the device. Examples of deformation-related parameters include the amount or angle of flex/bend of the device 300, the pressure created by the flex/bend of the device 300, or the change in temperature caused by the flex/bend of the device 300.

Upon the event detection module 361 determining that event data is associated with a haptic effect, the effect determination module 366 selects a haptic effect to deliver through the actuator 340. An example technique that the effect determination module 366 can use to select a haptic effect includes rules programmed to make decisions on the selection of a haptic effect. Another example technique that can be used by the effect determination module 366 to select a haptic effect includes lookup tables or databases that relate the haptic effect to the event data.

The effect determination module 366 additionally determines how the contact data and the deformation data will affect the delivery of the selected haptic effect. In various embodiments, for example, the effect determination module 366 is programmed to realize that the contact-related parameters or deformation-related parameters will affect the amplitude and frequency of the delivered haptic effect by changing vibration transmission properties of the actuators 340 and vibration transmission properties of the flexible electronic device 300 itself.

Accordingly, in various example embodiments, the effect determination module 366 is programmed to map the contact data or deformation data (e.g., grip or touch force, grip or touch location, deformation, etc.) to a model of vibration transmissions to ascertain the effects of the data. In various example embodiments, the vibration transmission model is in the form of a transfer function indicating how different frequencies of vibrations of the actuator 340 are attenuated or amplified by the contact with or deformation of the housing 301. In various example embodiments, this model of vibration transmission additionally takes into account the starting point of haptic effect vibrations (e.g., the location at which actuator 340 the delivery of the haptic effect will begin) as well as the location of the contact sensor 320 (e.g., location of contact or touch input). In the instance of a multi-actuator 340 configuration, a model of vibration transmission can be developed for each actuator 340 or grouping of actuators 340 to ascertain the effects of the contact or deformation on the selected haptic effect. In various example embodiments, other manners of ascertaining the effects of the user contact or deformation on the selected haptic effect are used, for example, by using alternative system models or look-up tables.

Upon the effect determination module 366 selecting a haptic effect for delivery and ascertaining the effect of user contact and deformation on the selected haptic effect, the effect control module 368 operates to determine how to modify the selected haptic effect to correct, or compensate, for the effects of that contact or deformation such that the haptic effect that is ultimately delivered to the user feels unaffected by contact or deformation. In the case of a single actuator, for example, the vibration transmission model, described herein, can be inverted and used as filter on the haptic signal. To further explain, if the contact with the device 300 or the deformation force of the device 300 operates to attenuate the vibrations of the actuator 340 at 50 Hz, for example, the effect control module 368 can amplify the actuator 340 at the same frequency of 50 Hz to correct for the attenuation and produce a compensated haptic effect for rendering to the user.

Additionally, or alternatively, in various example embodiments, the effect control module **368** can include one or more smart algorithms to analyze the vibration transmission model, described herein, and apply corrective measures. For example, if vibrations of 50 Hz are known to be attenuated, the effect control module **368** can correct the attenuation by changing actuator operation to 100 Hz resulting in improved transmission of vibrations. As such, correction can comprise one-to-one off-set compensation or other manners of dealing with contact or deformation effects by, for example, changing the frequency of operation of the actuator **340**. Any correction that results in the rendering of a haptic effect for which the effects of contact or deformation are substantially unnoticed can be used as and deemed a form of compensation.

Upon the effect control module **368** determining appropriate compensation to the selected haptic effect, the controller **350** generates a haptic instruction signal to direct activation of the one or more actuators **340** to deliver the compensated haptic effect, via the actuator drive circuit **360**, through the device **300**. The actuator drive circuit **360** generates a corresponding actuator drive signal that is delivered to the actuator **340** initiating actuator operation. The result is the delivery of a compensated haptic effect to the user that feels to the user as though the current contact with or deformation of the device **300** has had no effect on the haptic rendering.

FIG. **4** provides a flowchart illustrating a simplified method **400** for compensated haptic effect rendering in a flexible electronic device that incorporates a haptic effect system. The method **400** can be utilized with any of the various embodiments or combinations of embodiments described above. In the method **400**, the contact with or the deformation of the electronic device are detected, **S410**. Then the effect of the contact or deformation on a selected haptic effect is ascertained, **S412**. The selected haptic effect is then compensated to correct for the effect(s), **S414**. And, subsequently, the compensated haptic effect is delivered at the device, **S416**. The steps of the method **400** can be performed in any appropriate order to achieve the final result of the delivery of the desired haptic effect.

FIG. **5** provides a more detailed flowchart illustrating a method **500** for compensated haptic effect rendering in a flexible electronic device. The method **500** can be utilized with any of the various embodiments or combinations of embodiments described above. In the method **500**, the user is provided with a flexible electronic device, **S510**; the device may already incorporate a deformation from its original shape or the user may deform the device from its original shape by flexing, bending or otherwise deforming the device. The flexible device is instructed to deliver a haptic effect based on the occurrence of a condition or an event, **S512**. Next, based on the condition or event, a haptic effect is selected for delivery, **S514**. Subsequently, contact-related data or deformation-related data of the device is determined, and the effect of the contact or deformation on the selected haptic effect is determined based on the data, **S516**. The selected haptic effect is then compensated to correct for the contact with or deformation of the device, **S518**. Finally the compensated haptic effect is delivered to the user via the device, **S520**. The compensated haptic effect is rendered to the user such that any change in delivery of the haptic effect that would have been caused by the contact with or deformation of the device is now substantially undetectable by the user. The steps of the method **500** can be performed in any appropriate order to achieve the final result of the delivery of the desired haptic effect.

The various embodiments of flexible electronic devices having haptic effect systems as described herein include the ability to detect user contact with or deformation of the device. Further, the various embodiments include the ability to determine the impact of that contact or deformation on the rendering of a haptic effect and the ability to modify the rendering of that haptic effect to compensate for the contact or deformation. The various embodiments described herein have numerous applications. Consider an example application where a user bends their flexible phone to control the volume on a television. As the user bends the phone, the user feels distinct detents as the volume increases. Every detent feels the same to the user. The user is not aware of the correction but the controller within the flexible phone is actually adjusting the intensity of vibrations as the user bends the phone such that the vibration pulses delivered through the flexible phone feel the same to the user despite changes in the stiffness of the phone caused by the flexing.

Consider another example application wherein a user changes their grip on a flexible tablet to enable accomplishment of a task. As the user types on the tablet, the user holds the back of the tablet with one hand and types with the other. As the user plays a game, however, the user holds the tablet with two hands so that the user can more easily bend the tablet. The haptic feedback provided through the tablet feels consistent; the user does not notice that different actuators are activated with different intensities to correct or compensate for how the user holds the tablet.

Various examples of flexible electronic devices **600** in relation to user contact or deformation, e.g., a user's grip, are illustrated in FIGS. **6A-6E**. Each of the figures illustrates a unique grip or deformation of the device **600** for which the haptic effect system (e.g., **102**, **202**, **302**) of the device **600** operates to correct when delivering a haptic effect to the user. Of course, numerous other types of contact with or deformations of the device **600** for which the haptic effect system may correct are possible.

The various grips illustrated in FIGS. **6A-6E** include single-handed grips, e.g., using only a first hand **602** to support the device **600**, and dual-handed grips, e.g., using both the first hand **602** and a second hand **604** to support the device **600**. FIG. **6A** illustrates an example of a single-handed grip, e.g., only the first hand **602** is used to hold the device **600**. The thumb **606** of the hand **602** supports a lower edge of the device **600** while fingertips **608** of the hand **602** grasp the upper edge of the device **600**. FIG. **6A** also illustrates a deformation of the device **600** comprising an outward bowing of the device from the user's hand **602**. The various embodiments of the haptic effect system disclosed herein are configured to haptically correct for the noted grip or deformation of the device **600** when delivering a haptic effect to the user.

FIG. **6B** illustrates another singled handed grip of a flexible electronic device **600**. In this example, a back surface of the device **600** is supported in the palm **610** of the first hand **602** while the thumb **606** and the fingertips **608** support side edges of the device **600**. The user's second hand **604** is used to interact with a user interface **612** of the device **600**. FIG. **6B** also illustrates a deformation of the device **600** with the device bowed inward to the user's hand **602**. The various embodiments of the haptic effect system disclosed herein are configured to haptically correct for the noted grip or deformation of the device **600** when delivering a haptic effect to the user.

FIG. **6C** illustrates an example of a dual-handed grip, where both the first hand **602** and the second hand **604** operate in conjunction to support and hold the device **600**.

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As shown the thumb 606 of the first hand is used to support a bottom edge of the device 600 while the fingertips 608 of the first hand grasp an upper and side edge of the device 600. Further, the fingertips 608 of the second hand 604 support a back surface of the device 600 while the thumb 606 of the second hand grasps a front edge of the device 600. FIG. 6C also illustrates a deformation of the device 600 in the form a twist as the upper rear corner of the device 600 is farther back from the plane defined by the lower front corner of the device. The various embodiments of the haptic effect system disclosed herein are configured to haptically correct for the noted grip or deformation of the device 600 when delivering a haptic effect to the user.

FIG. 6D illustrates an example of a dual-handed grip, where the first hand 602 supports the device 600 and the second hand 604 grasp and twists an upper corner of the device 600. As shown, the fingertips of the first hand 602 support a back surface of the device 600 while the thumb 606 of the first hand grasps a front surface of the device 600. The thumb 606 and the fingertips of the second hand 604 are used to grasp a front and back surface of the device, and to twist a corner of the device. The various embodiments of the haptic effect system disclosed herein are configured to haptically correct for the noted grip or deformation of the device 600 when delivering a haptic effect to the user.

FIG. 6E illustrates an example of a dual-handed grip, where the first hand 602 supports a first half of the device 600 and the second hand 604 supports an unfolded second half of the device 600. As shown, the fingertips 608 of the first hand 602 support a surface of the unfolded second half of the device 600 while the thumb 606 of the first hand 602 grasps a side edge of the unfolded second half of the device 600. The fingertips 608 of the second hand 604 support a back surface of the first half of the device 600 while the thumb grasps a front surface of the first half of the device 600. FIG. 6E illustrates a deformation of the device 600 in the form of a centerfold with a portion of the device 600 unfolded. The various embodiments of the haptic effect system disclosed herein are configured to haptically correct for the noted grip or deformation of the device 600 when delivering a haptic effect to the user.

The various embodiments of the haptic effect system described herein can additionally, or alternatively, correct for natural haptic feedback in the delivery of a haptic effect through a flexible electronic device. Natural haptic feedback occurs when the flexible device produces force to oppose deformation. By way of example, a user bends a flexible electronic device to control scrolling in the device. As the user bends the device, the device itself opposes the bending. The opposition force produced by the flexible device depends on the amount of bending or flexing of the device as well as the properties of the flexible material, e.g., stiffness. This opposition force, or natural haptic feedback, produced by the flexible device is not programmable but rather is a consequence of the physical properties of the design.

Compensation of a selected haptic effect to correct for the natural haptic feedback of the device can be achieved by using one or more deformation sensors, such as those described herein, to detect the deformation of the device. The deformation sensor can then provide a signal representative of the deformation to the haptic effect system controller whereby the controller can utilize a model, e.g., vibration transmission model as described herein, or look-up table to determine the natural haptic feedback that the device is expected to produce. After, learning the expected natural haptic feedback and ascertaining its effect on the selected

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haptic effect, the controller can compensate the selected haptic effect. The compensation of the selected haptic effect corrects for the expected natural haptic feedback such that when the compensated haptic effect is delivered to the user, the user is substantially unaware of the effect of the natural haptic feedback forces on the flexible device and its haptic effect system.

For example, as a request for a specific force in the delivery of a haptic effect is received, the forces produced by the natural haptic feedback can be subtracted from it and a model can be used to determine what signal to send to the actuator to produce the remaining forces. An application could, for example, request that a force of 1 N be applied to the user via haptic effect by bending the device outwards. Based on data provided by the deformation sensors, the controller is able to determine that the current deformation of the device should already produce a force of 0.2 N through natural haptic feedback. Therefore, the output instruction from the controller to the actuator instructs the actuator to produce only an additional 0.8 N of force. The compensated haptic effect delivered to the user feels to the user as though the device has had no resistance to the user's input forces.

The various embodiments described above are provided by way of illustration only and should not be construed to limit the claims attached hereto. Those skilled in the art will readily recognize various modifications and changes that may be made without following the example embodiments and applications illustrated and described herein, and without departing from the true spirit and scope of the following claims.

The invention claimed is:

1. A device comprising:
  - a housing;
  - a sensor configured to detect a contact force exerted on the housing;
  - a controller communicatively coupled to the sensor, the controller configured to:
    - determine a change in a haptic effect delivered at the housing caused by the contact force,
    - determine a vibration compensation for the haptic effect to correct the change in the haptic effect delivered at the housing caused by the contact force,
    - apply the vibration compensation to the haptic effect to create a compensated haptic effect, and
    - generate an output instruction to deliver the compensated haptic effect; and
  - an actuator configured to receive the output instruction and deliver the compensated haptic effect at the housing,
  - wherein the vibration compensation is based on a vibration transmission model that is operable to evaluate changes in vibration transmission between the actuator and the sensor caused by the contact force.
2. The device of claim 1, wherein the sensor comprises a touch sensor.
3. The device of claim 2, wherein the touch sensor comprises a capacitive sensor, a force-sensitive resistor, a strain gauge or a piezoelectric sensor.
4. The device of claim 1, wherein the contact force indicates a location on the housing.
5. A device comprising:
  - a housing;
  - a first sensor configured to detect a contact force exerted on the housing;
  - a second sensor configured to detect a deformation force created by deformation of the housing;



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a controller communicatively coupled to the first and second sensors, the controller configured to determine a change in a haptic effect caused by both the contact force and the deformation force, the controller additionally configured to generate an output instruction to deliver the haptic effect as a compensated haptic effect, the compensated haptic effect operable to correct the change; and

an actuator configured to receive the output instruction and deliver the compensated haptic effect at the housing.

6. The device of claim 5, wherein the deformation force indicates an amount of deformation of the housing, an angle of deformation of the housing, a pressure created by the deformation, or a change in temperature within the housing.

7. The device of claim 5, wherein the compensated haptic effect is additionally operable to correct the change in the haptic effect caused by natural haptic feedback of the housing.

8. The device of claim 5, wherein the first sensor comprises a touch sensor.

9. The device of claim 8, wherein the touch sensor comprises a capacitive sensor, a force-sensitive resistor, a strain gauge or a piezoelectric sensor.

10. The device of claim 5, wherein the contact force indicates a location on the housing.

11. The device of claim 5, wherein the compensated haptic effect includes vibration compensation.

12. The device of claim 11, where the vibration compensation is based on a vibration model operable to evaluate the change in frequency of vibration on the haptic effect caused by the contact force.

13. The device of claim 12, wherein the vibration model is operable to consider a starting point of the haptic effect in determining vibration compensation.

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14. The device of claim 12, wherein the vibration model is operable to consider a location of the first sensor in determining vibration compensation.

15. A method for correcting haptic effects, comprising:  
 detecting a contact force exerted on a housing;  
 determining a first change in a haptic effect delivered at the housing caused by the contact force;  
 detecting a deformation force created by deformation of the housing;  
 determining a second change in the haptic effect to be delivered at the housing caused by the deformation force;  
 determining a compensation for the haptic effect to correct the first change in the haptic effect delivered at the housing caused by the contact force and the second change in the haptic effect delivered at the housing caused by the deformation force;  
 applying the compensation to the haptic effect to create a compensated haptic effect; and  
 delivering the compensated haptic effect at the housing.

16. The device of claim 1, wherein the vibration transmission model includes a transfer function that indicates attenuation or amplification of actuator vibration frequencies caused by the contact force.

17. The device of claim 1, wherein the vibration transmission model includes a lookup table that indicates attenuation or amplification of actuator vibration frequencies caused by the contact force.

18. The device of claim 1, further comprising a plurality of additional actuators delivering haptic effects at different locations, each additional actuator being associated with a different vibration transmission model.

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