US010627907B2

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

(10) **Patent No.: US 10,627,907 B2**
(45) **Date of Patent: *Apr. 21, 2020**

(54) **POSITION CONTROL OF A USER INPUT ELEMENT ASSOCIATED WITH A HAPTIC OUTPUT DEVICE**

(71) Applicant: **Immersion Corporation**, San Jose, CA (US)

(72) Inventors: **Srivatsav Venkatesan**, Sunnyvale, CA (US); **Kaniyalal Shah**, Fremont, CA (US); **Douglas George Billington**, Campbell, CA (US); **Aaron Kapelus**, Jamaica Plain, MA (US); **Stephen Rank**, San Jose, CA (US); **Daniel Parker**, San Jose, CA (US)

(73) Assignee: **Immersion Corporation**, San Jose, CA (US)

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

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/058,399**

(22) Filed: **Aug. 8, 2018**

(65) **Prior Publication Data**

US 2019/0041990 A1 Feb. 7, 2019

Related U.S. Application Data

(63) Continuation of application No. 14/979,321, filed on Dec. 22, 2015, now Pat. No. 10,073,523.
(Continued)

(51) **Int. Cl.**
A63F 13/00 (2014.01)
G06F 3/01 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06F 3/016*** (2013.01); ***A63F 13/218*** (2014.09); ***A63F 13/23*** (2014.09); ***A63F 13/285*** (2014.09); ***A63F 13/42*** (2014.09)

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

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,020,876 A * 2/2000 Rosenberg G06F 3/011 345/157
6,184,868 B1 * 2/2001 Shahoian A63F 13/06 345/161
(Continued)

FOREIGN PATENT DOCUMENTS

JP 2008000345 A 1/2008
JP 2008015679 A 1/2008
(Continued)

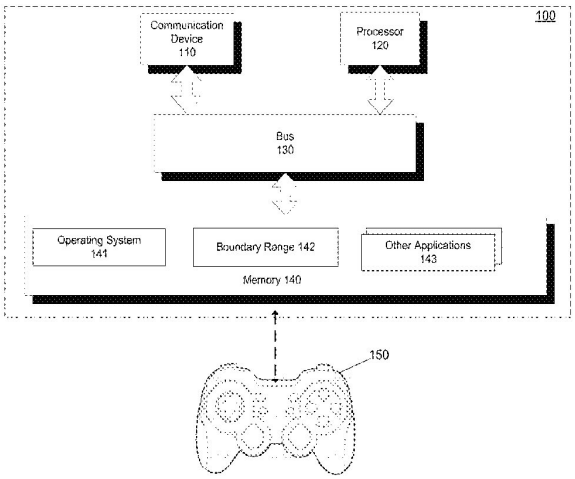
OTHER PUBLICATIONS

Anonymous: "Getting Started With XInput", Dec. 16, 2014 (Dec. 16, 2014), XP055458537, retrieved from the Internet: URL:https://web.archive.org/web/20141216120515/http://msdn.microsoft.com:80/en-us/library/windows/desktop/ee417001(v=vs.85).aspx [retrieved on Mar. 12, 2018] p. 1-3.
(Continued)

Primary Examiner — Paul A D'Agostino
(74) *Attorney, Agent, or Firm* — Medler Ferro Woodhouse & Mills PLLC

(57) **ABSTRACT**

Systems and methods for rendering a haptic effect at a user input element associated with a haptic output device are provided. A primary range and a secondary range of positions are defined for the user input element associated with the haptic output device. In addition, a boundary range of positions is defined for the user input element associated with the haptic output device, the boundary range partially overlapping each of the primary and secondary ranges. A position of the user input element is monitored, and the
(Continued)



Valve Exhibit 1001
Valve v. Immersion

haptic effect rendered in response to an entry of the user input element to positions within the boundary range.

20 Claims, 10 Drawing Sheets

Related U.S. Application Data

(60) Provisional application No. 62/096,251, filed on Dec. 23, 2014.

(51) **Int. Cl.**

A63F 13/285	(2014.01)
A63F 13/23	(2014.01)
A63F 13/42	(2014.01)
A63F 13/218	(2014.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,490,530	B2	2/2009	Ishikawa et al.	
8,622,833	B2	1/2014	Kake	
9,778,743	B2	10/2017	Grant et al.	
2005/0156892	A1	7/2005	Grant	
2006/0142657	A1*	6/2006	Quaid	A61B 17/1703 600/424
2006/0290662	A1*	12/2006	Houston	A63F 13/06 345/156
2011/0118032	A1	5/2011	Zalewski	
2011/0260990	A1*	10/2011	Ali	G06F 3/016 345/173
2014/0043228	A1	2/2014	Grant et al.	
2014/0315642	A1	10/2014	Grant et al.	
2014/0320406	A1	10/2014	Nishizawa	
2015/0130706	A1	5/2015	Lacroix et al.	

FOREIGN PATENT DOCUMENTS

JP	2014215850	A	11/2014
JP	2014216017	A	11/2014

OTHER PUBLICATIONS

Any information that are not included with this Information Disclosure Statement can be found in U.S. Appl. No. 14/979,321.

* cited by examiner

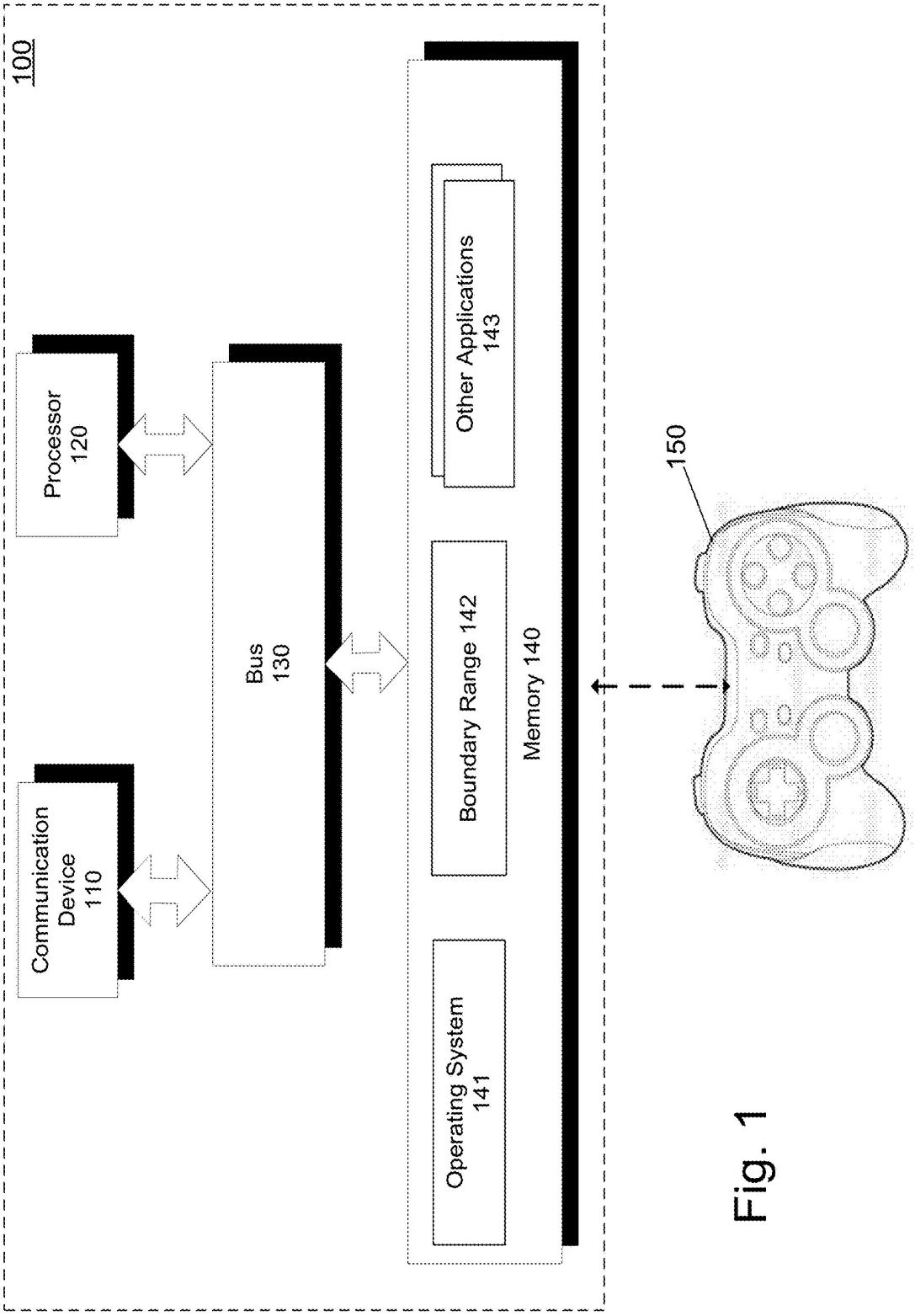

100
Processor 120
Bus 130
Communication Device 110
Other Applications 143
Boundary Range 142
Memory 140
Operating System 141
150

Fig. 1

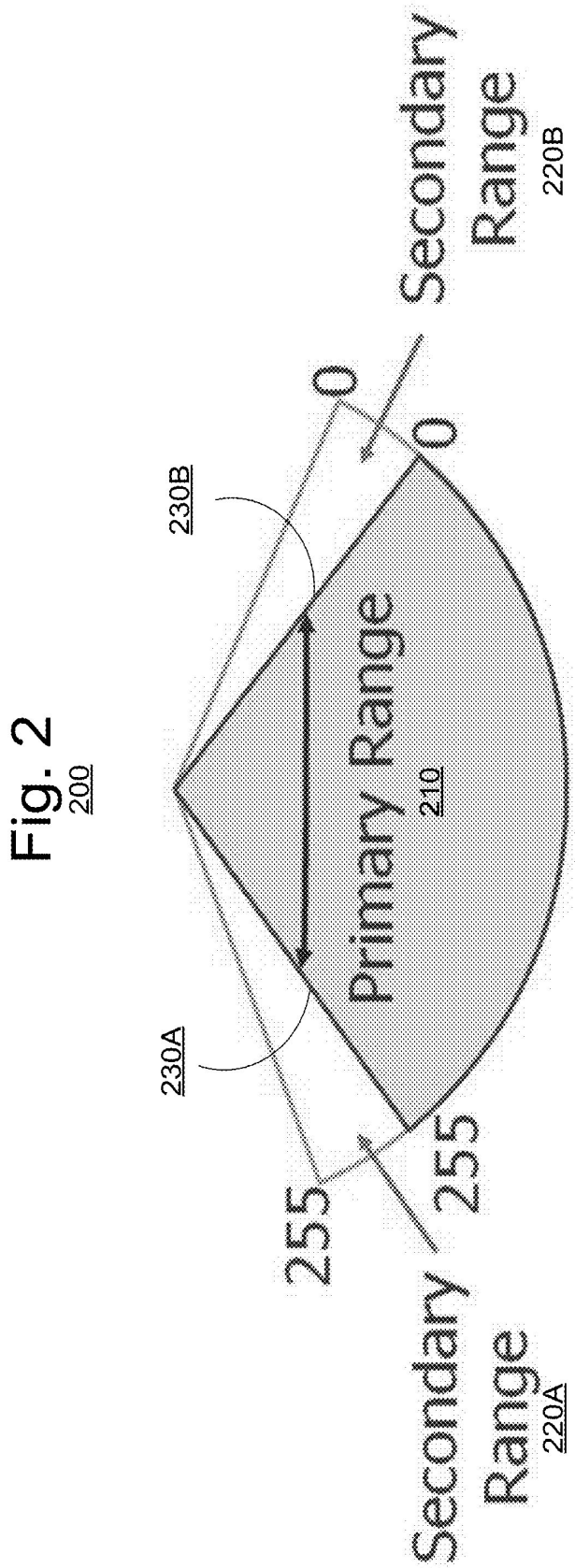

Secondary Range
220B
0
0
230B
Primary Range
210
230A
255
255
Secondary Range
220A

Fig. 2
200

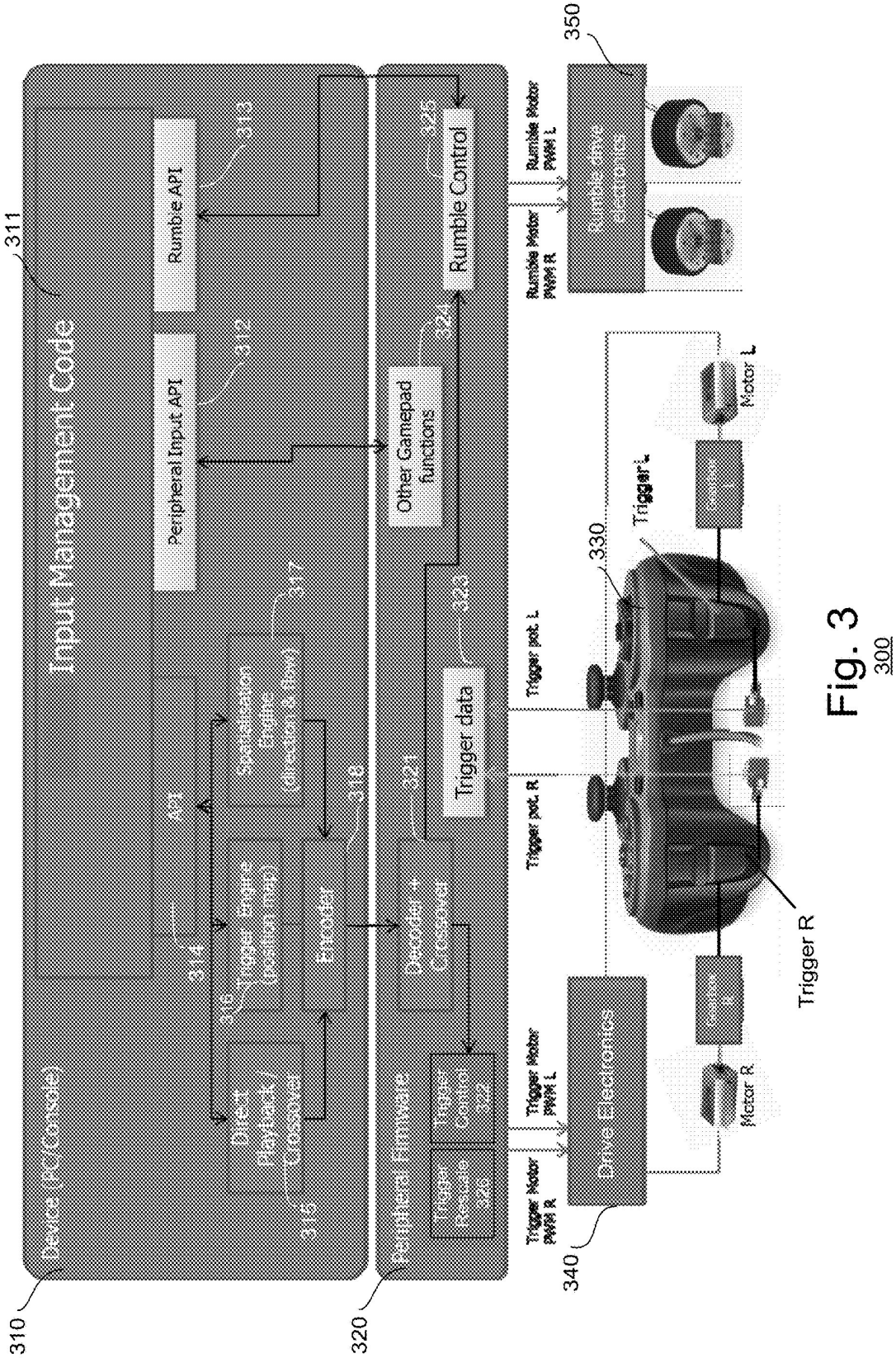

Input Managment Code
Device (PC/Console)
Peripheral Firmware
Rumble API
Peripheral Input API
Other Gamepad functions
Rumble Control
Trigger data
Trigger Motor PWM L
Trigger Motor PWM R
Rumble Motor PWM L
Rumble Motor PWM R
Drive Electronics
Rumble drive electronics
Trigger pot. L
Trigger pot. R
Motor L
Motor R
Trigger L
Trigger R
310
311
312
313
314
316
317
318
320
321
322
323
324
325
330
340
350

Fig. 3
300

Fig. 4
400

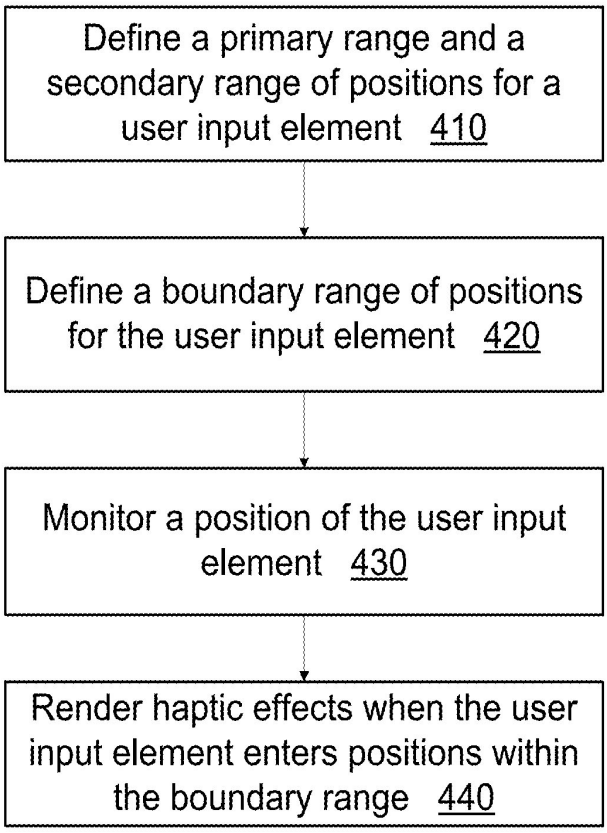
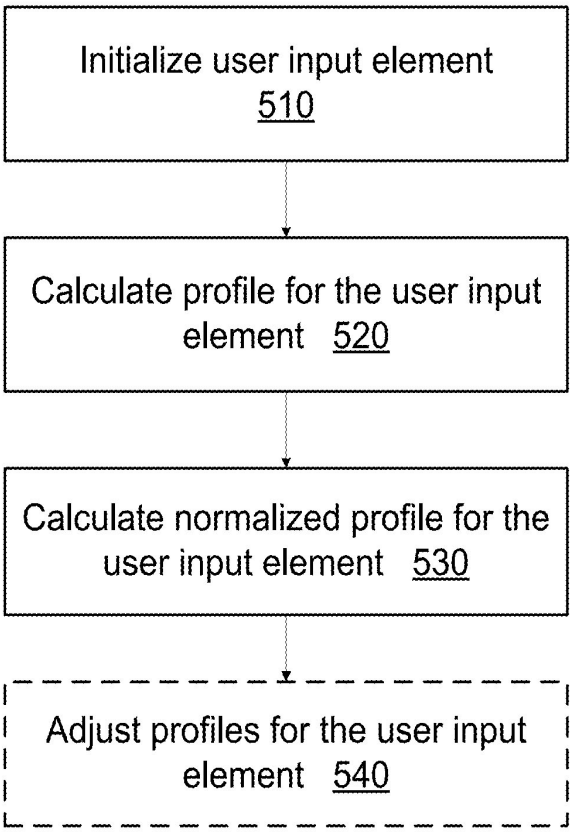

Define a primary range and a secondary range of positions for a user input element 410
Define a boundary range of positions for the user input element 420
Monitor a position of the user input element 430
Render haptic effects when the user input element enters positions within the boundary range 440

Fig. 5
500


Initialize user input element 510
Calculate profile for the user input element 520
Calculate normalized profile for the user input element 530
Adjust profiles for the user input element 540

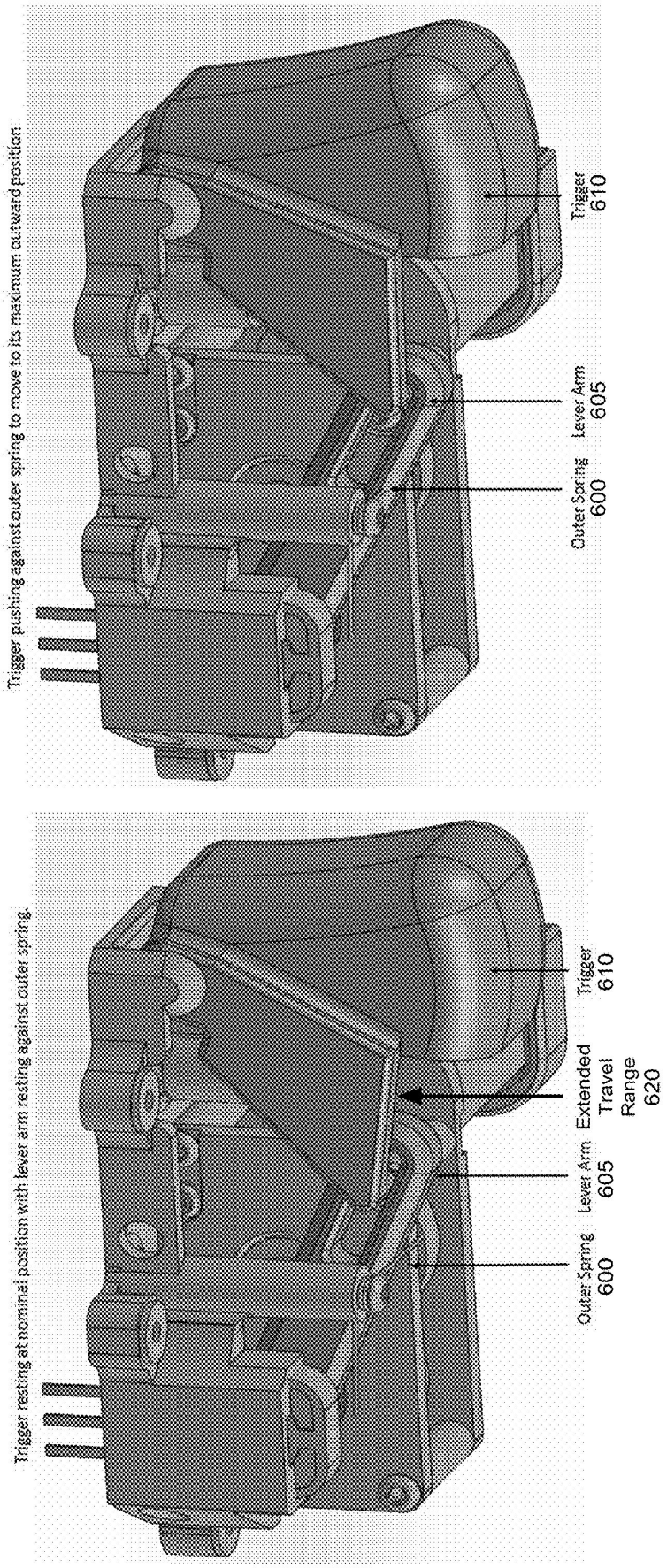

602
Trigger pushing against outer spring to move to its maximum outward position
Trigger 610
Lever Arm 605
Outer Spring 600
601
Trigger resting at nominal position with lever arm resting against outer spring.
Trigger 610
Extended Travel Range 620
Lever Arm 605
Outer Spring 600

Fig. 6

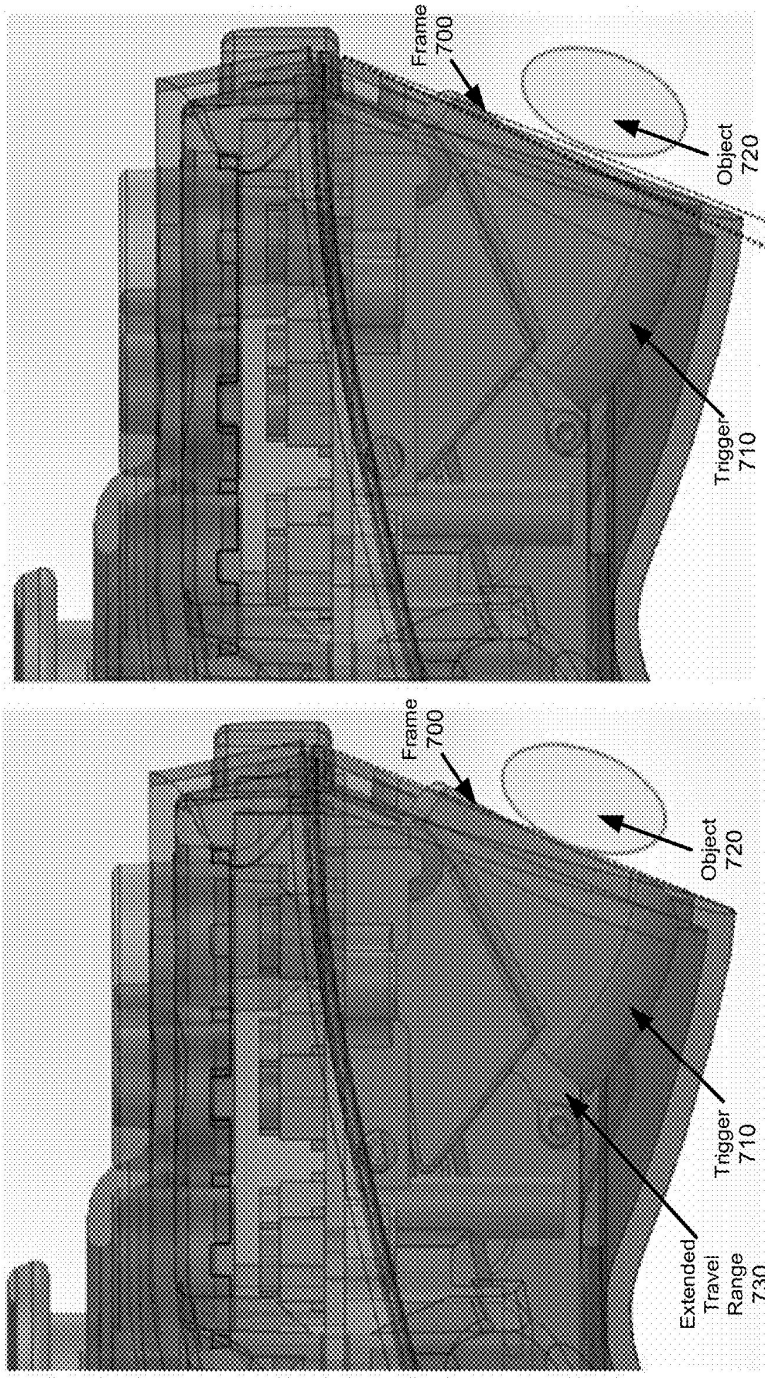

701
Frame 700
Object 720
Trigger 710
Extended Travel Range 730
View of trigger with user's finger bottoming out on the housing. The trigger can still rotate into the housing.
702
Frame 700
Object 720
Trigger 710
View of trigger with user's finger bottoming out on the housing and trigger bottoming out inside the casing.

Fig. 7

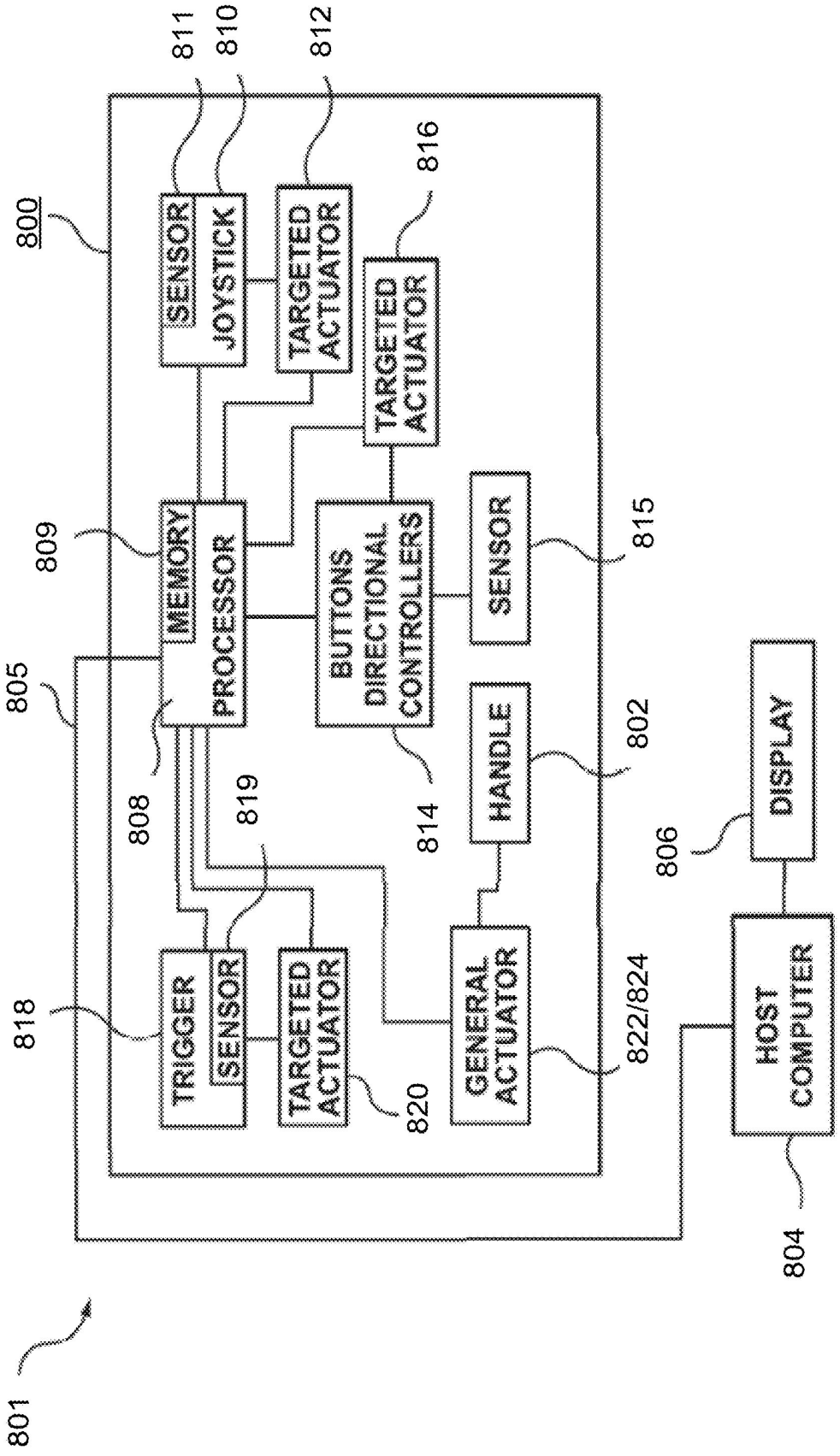

801
800
SENSOR
JOYSTICK
811
810
TARGETED ACTUATOR
812
816
TARGETED ACTUATOR
809
MEMORY
PROCESSOR
BUTTONS DIRECTIONAL CONTROLLERS
SENSOR
815
805
808
819
814
HANDLE
802
806
DISPLAY
818
TRIGGER
SENSOR
TARGETED ACTUATOR
820
GENERAL ACTUATOR
822/824
HOST COMPUTER
804

Fig. 8

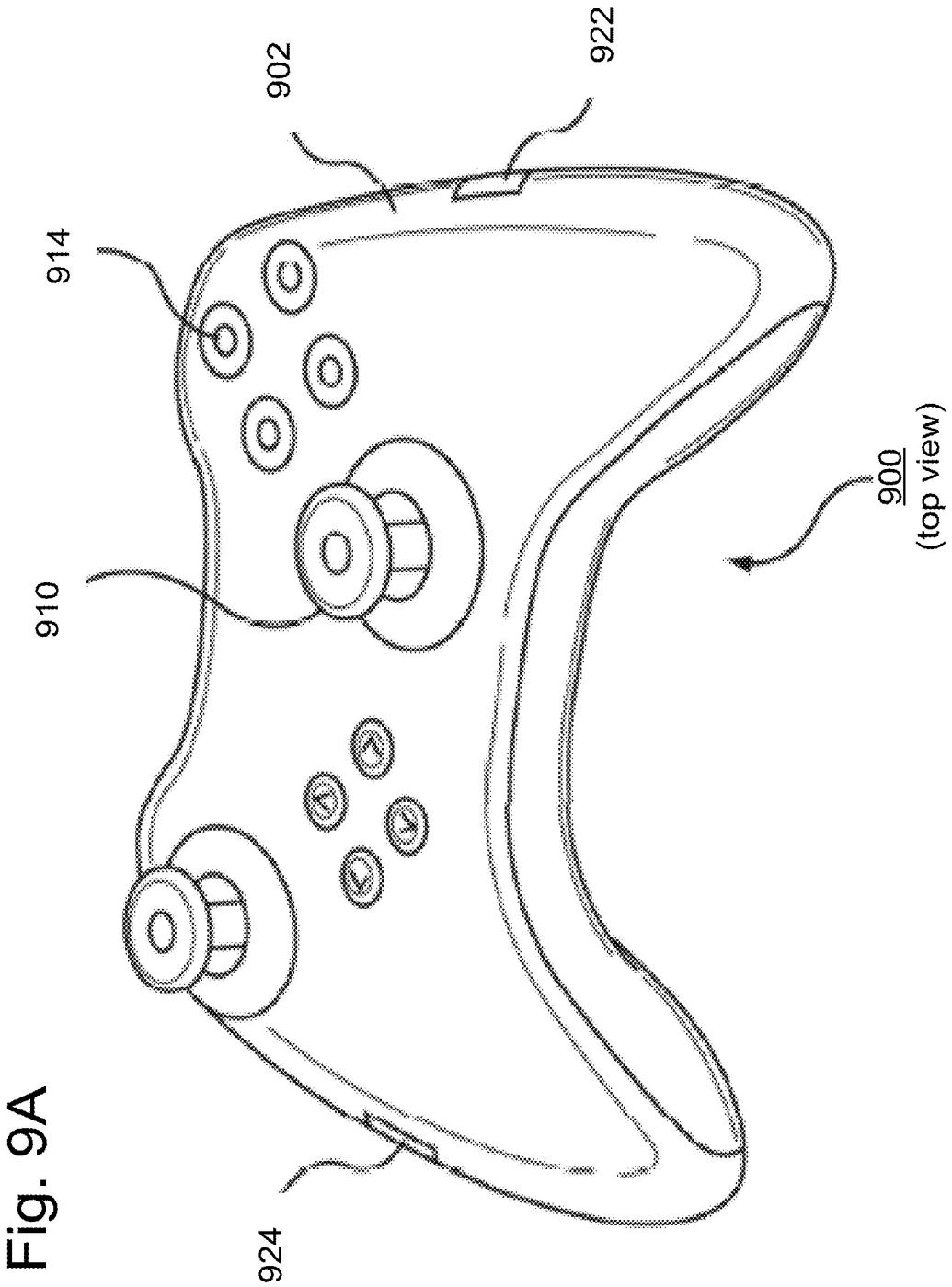


Fig. 9A

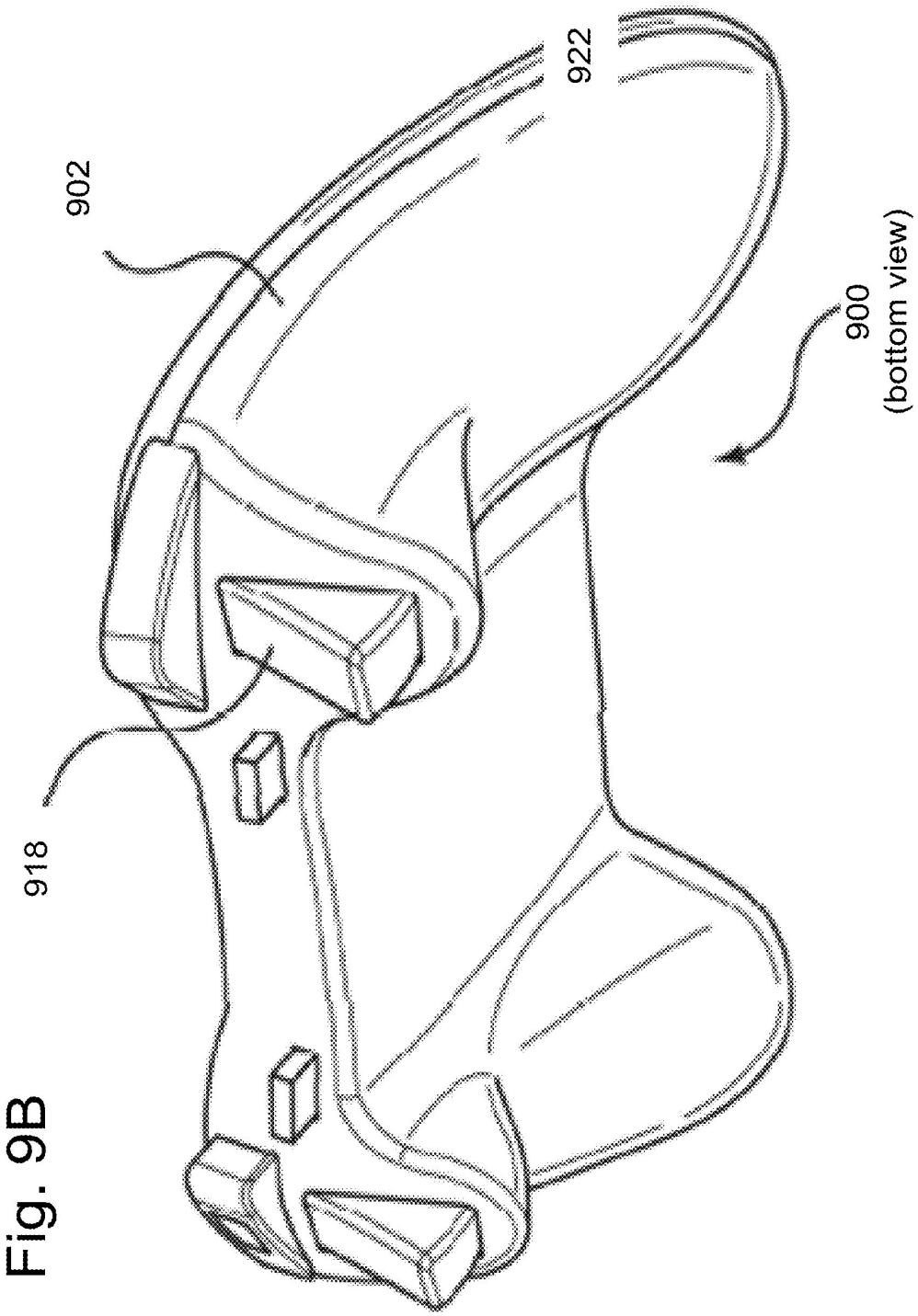


Fig. 9B

POSITION CONTROL OF A USER INPUT ELEMENT ASSOCIATED WITH A HAPTIC OUTPUT DEVICE

PRIORITY APPLICATION

This application is a continuation of U.S. patent application Ser. No. 14/979,321, filed on Dec. 22, 2015, which claims the benefit of U.S. Provisional Patent Application No. 62/096,251, filed on Dec. 23, 2014, both of which have been incorporated herein by reference in their entirety.

FIELD OF INVENTION

The embodiments are generally directed to electronic devices, and more particularly, to electronic devices that produce haptic effects.

BACKGROUND

Video games and video game systems have become extremely popular. Video game devices or controllers typically use visual and auditory cues to provide feedback to a user. In some interface devices, kinesthetic feedback (e.g., active and resistive force feedback) and/or tactile feedback (e.g., vibration, texture, temperature variation, and the like) may be provided to the user. In general, such feedback is collectively known as "haptic feedback" or "haptic effects." Haptic feedback provides cues that enhance and simplify a user's interaction with a video game controller, or other electronic device. For example, haptic effects may provide cues to users of video game controllers or other electronic devices to alert the user to specific events, or provide realistic feedback to create greater sensory immersion within a simulated or virtual environment.

Other devices in which a user interacts with a user input element to cause an action also may benefit from haptic feedback or haptic effects. For example, such devices may include medical devices, automotive controls, remote controls, and other similar devices.

SUMMARY OF THE INVENTION

Embodiments of the present invention are directed toward electronic devices configured to produce haptic effects that substantially improve upon the related art.

Features and advantages of the embodiments are set forth in the description which follows, or will be apparent from the description, or may be learned by practice of the invention.

In one example, functionality for rendering a haptic effect at a user input element associated with a haptic output device is provided. A primary range and a secondary range of positions are defined for the user input element associated with the haptic output device. In addition, a boundary range of positions is defined for the user input element associated with the haptic output device, the boundary range partially overlapping each of the primary and secondary ranges. A position of the user input element is monitored, and the haptic effect is rendered in response to an entry of the user input element to positions within the boundary range.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not intended to limit the invention to the described examples.

BRIEF DESCRIPTION OF THE DRAWINGS

Further embodiments, details, advantages, and modifications will become apparent from the following detailed description of the preferred embodiments, which is to be taken in conjunction with the accompanying drawings.

FIG. **1** illustrates a block diagram of a system according to an example embodiment of the present invention.

FIG. **2** is a simplified schematic illustrating a range of motion for a user input element according to an example embodiment of the present invention.

FIG. **3** illustrates a block diagram of a haptic effect software stack according to an example embodiment of the present invention.

FIG. **4** illustrates a flow diagram of functionality for controlling a user input element associated with a haptic output device according to an example embodiment of the present invention.

FIG. **5** illustrates a flow diagram of functionality for controlling a user input element associated with a haptic output device according to another example embodiment of the present invention.

FIG. **6** illustrates a controller that includes an outer spring that creates an open extended travel range for a trigger to move within when the trigger is in a maximum open position outside of the open extended travel range, according to an example embodiment of the present invention.

FIG. **7** illustrates a controller that includes an extended frame that that creates a closed extended travel range for a trigger to move within when the trigger is in a maximum closed position outside of the closed extended travel range, according to an example embodiment of the invention.

FIG. **8** illustrates a functional block diagram of a controller suitable for use with the embodiments of the present invention.

FIGS. **9**A and **9**B illustrate different views of a controller suitable for use with the embodiments of the present invention.

DETAILED DESCRIPTION

Example embodiments are directed toward systems and methods for controlling a boundary range of a user input element associated with a haptic output device. For example, a haptic effect may be rendered when the user input element is positioned in the boundary range. The boundary range of positions is defined for the user input element so as to partially overlap each of a primary and secondary range of positions. As the position of the user input element is monitored, the haptic effect may be rendered in response the user input element entering positions within the boundary range.

In the various embodiments, a variety of user interfaces and methods for using a device are described. In some embodiments, the device is a portable electronic device (e.g., a game controller, console, mobile phone, smartphone, tablet, etc.). It should be understood, however, that the user interfaces and associated methods may be applied to numerous other devices, such as personal computers, medical devices, laptops, and the like that may include one or more other physical user-interface devices, such as a keyboard, mouse, trackball and the like.

FIG. **1** illustrates a block diagram of a system **100** according to an example embodiment of the present invention.

System **100** may include a communication device **110** configured to transmit and/or receive data from remote sources. Communication device **110** may enable connectivity between a processor **120** and other devices by encoding data to be sent from processor **120** to another device over a

network (not shown) and decoding data received from another system over the network for processor **120**.

For example, communication device **110** may include a network interface card that is configured to provide wireless network communications. A variety of wireless communication techniques may be used including infrared, radio, Bluetooth, Wi-Fi, and/or cellular communications. Alternatively, communication device **110** may be configured to provide wired network connection(s), such as an Ethernet connection.

Processor **120** may comprise one or more general or specific purpose processors to perform computation and control functions of system **100**. Processor **120** may include a single integrated circuit, such as a micro-processing device, or may include multiple integrated circuit devices and/or circuit boards working in cooperation to accomplish the functions of processor **120**. In addition, processor **120** may execute computer programs, such as an operating system **141**, boundary range module **142**, and other applications **143**, stored within memory **140**.

System **100** may include memory **140** for storing information and instructions for execution by processor **120**. Memory **140** may contain various components for retrieving, presenting, modifying, and storing data. For example, memory **140** may store software modules that provide functionality when executed by processor **120**. The modules may include operating system **141** that provides operating system functionality for system **100**. The modules may further include the boundary range module **142** that controls the boundary range of user input elements of controller **150**. For example, boundary range module **142** may monitor the position of user input elements and render haptic effects in response the user input elements entering positions within respective boundary ranges. System **100** also may include one or more additional application modules **143** that include additional functionality, such as peripheral firmware configured to provide control functionality for a peripheral device, such as controller **150** (e.g., a gamepad, wearable device, etc.).

Non-transitory memory **140** may include a variety of computer-readable media that may be accessed by processor **120**. In the various embodiments, memory **140** may include volatile and nonvolatile media, removable and non-removable media. For example, memory **140** may include any combination of random access memory ("RAM"), dynamic RAM ("DRAM"), static RAM ("SRAM"), read only memory ("ROM"), flash memory, cache memory, and/or any other type of non-transitory computer-readable media. Alternatively, or additionally, memory **140** may include one or more network or cloud accessible storage media.

Although shown as a single system, the functionality of system **100** may be implemented as a distributed system. For example, memory **140** and processor **120** may be distributed across multiple different computers that collectively comprise system **100**. In one embodiment, system **100** may be part of a device (e.g., personal computer, console, video game console, etc.), and system **100** provides haptic effect functionality for the device. In another embodiment, system **100** may be separate from the device, and may remotely provide the aforementioned functionality for the device.

System **100** may be operably connected to controller **150**. Controller **150** may be a peripheral device configured to provide input to the system **100**. Controller **150** may be operably connected to system **100** using either a wireless connection or a wired connection. Controller **150** also may include a local processor configured to communicate with system **100** using either a wireless connection or a wired connection. Alternatively, controller **150** may be configured to not include a local processor, and all input signals and/or output signals associated with controller **150** may be processed by the components of system **100**. In embodiments in which controller **150** has a local processor, additional functionality, such as boundary range modules and peripheral firmware configured to provide control functionality may reside within controller **150**.

Controller **150** may further include one or more digital buttons, one or more analog buttons, one or more bumpers, one or more directional pads, one or more analog or digital sticks, one or more driving wheels, and/or one or more user input elements that can be interacted with by a user, and that can provide input to system **100**. Controller **150** may also include one or more analog or digital trigger buttons (or "triggers") that can further be interacted with by the user, and that can further provide input to system **100**. As is described below in greater detail, controller **150** can further include a motor, or another type of actuator or haptic output device, configured to exert a bi-directional push/pull force on at least one trigger of controller **150**.

Controller **150** can also include one or more actuators, or other types of haptic output devices. The local processor of controller **150**, or processor **120** in embodiments where controller **150** does not include a local processor, may transmit a haptic signal associated with a haptic effect to at least one actuator of controller **150**. The actuator, in turn, outputs haptic effects such as vibrotactile haptic effects, kinesthetic haptic effects, or deformation haptic effects, in response to the haptic signal. The haptic effects can be experienced at a user input element (e.g., a digital button, analog button, bumper, directional pad, analog or digital stick, driving wheel, or trigger) of controller **150**. Alternatively, the haptic effects can be experienced at an outer surface of controller **150**.

An actuator is an example of a haptic output device, where a haptic output device is a device configured to output haptic effects, such as vibrotactile haptic effects, electrostatic friction haptic effects, temperature variation, and/or deformation haptic effects, in response to a drive signal. In alternate embodiments, the one or more actuators within controller **150** can be replaced by some other type of haptic output device. The haptic output device may be, for example, an electric motor, an electro-magnetic actuator, a voice coil, a shape memory alloy, an electro-active polymer, a solenoid, an eccentric rotating mass motor ("ERM"), a harmonic ERM motor ("HERM"), a linear resonant actuator ("LRA"), a piezoelectric actuator, a high bandwidth actuator, an electroactive polymer ("EAP") actuator, an electrostatic friction display, or an ultrasonic vibration generator. In some instances, the haptic output device may include haptic output drive circuit. In some embodiments, the haptic output device may be unidirectional or bidirectional.

Controller **150** may further include one or more speakers. The local processor of controller **150**, or processor **120** in embodiments where controller **150** does not include a local processor, may transmit an audio signal to at least one speaker of controller **150**, which in turn outputs audio effects. The speaker may be, for example, a dynamic loudspeaker, an electrodynamic loudspeaker, a piezoelectric loudspeaker, a magnetostrictive loudspeaker, an electrostatic loudspeaker, a ribbon and planar magnetic loudspeaker, a bending wave loudspeaker, a flat panel loudspeaker, a heil air motion transducer, a plasma arc speaker, and a digital loudspeaker.

Controller **150** can further include one or more sensors. A sensor may be configured to detect a form of energy, or other

physical property, such as, but not limited to, sound, movement, acceleration, bio signals, distance, flow, force/pressure/strain/bend, humidity, linear position, orientation/inclination, radio frequency, rotary position, rotary velocity, manipulation of a switch, temperature, vibration, or visible light intensity. The sensor may further be configured to convert the detected energy, or other physical property, into an electrical signal, or any signal that represents virtual sensor information, and controller **150** can send the converted signal to the local processor of controller **150**, or processor **120** in embodiments where controller **150** does not include a local processor.

FIG. **2** is a simplified schematic illustrating a range of motion **200** for a user input element according to an example embodiment of the present invention. Although range of motion **200** relates to a trigger input element, the embodiments of the invention may be readily applied to a variety of user input element types.

As shown in FIG. **2**, range of motion **200** may include a primary range **210** and secondary ranges **220**A, **220**B. In addition, boundary ranges **230**A, **230**B may be defined so as to partially overlap primary range **210** and secondary ranges **220**A, **220**B. In some instances, primary range **210** may be extended to render haptic effects within secondary ranges **220**A, **220**B and/or boundary ranges **230**A, **230**B. For example, the user input elements may be pulled further in and/or pushed further out while haptic output devices render the haptic effects.

In some embodiments, primary range **210** and secondary ranges **220**A, **220**B may be fixed or variable. For example, secondary range **220**A may have a range of motion of 7 degrees from a maximum outward position to a nominal position, primary range **210** may have a range of motion of 29 degrees from the nominal position to a finger grounding position, and secondary range **220**B may have a range of motion of 3 degrees from the finger grounding position to a trigger grounding position. In this example, range of motion **200** may total 39 degrees (7+29+3).

When no haptic effect is being applied, movement of the user input element may be limited to primary range **210**. However, when haptic effects are applied, movement of the user input element may be extended to secondary ranges **220**A, **220**B and/or boundary ranges **230**A, **230**B. In either case, the position of the user input element may be represented as analog to digital conversion ("ADC") data, such as 8 bit ADC data having a range of values between 0 and 255. Although 8 bit position data is provided as an example, the embodiments are not so limited. Higher resolution position data, such as 16 bit position data, may also be used.

FIG. **3** illustrates a block diagram of a haptic effect software stack **300** according to an example embodiment of the present invention. As shown in FIG. **3**, software stack **300** includes device modules **310**, peripheral firmware modules **320**, controller modules **330**, drive modules **340**, and rumble drive modules **350**. Haptic effect software stack **300** is implemented on a system, such as system **100** of FIG. **1**.

Device modules **310** may include a variety of modules such as input management code **311**, peripheral input application programming interface ("API") **312**, rumble API **313**, haptic effect API **314**, direct playback/crossover **315**, trigger engine **316**, spatialization engine **317**, and encoder **318**.

Input management code **311** may include a set of computer-readable instructions that manage input provided by controller **330** in the context of a game application, or other type of application, executed within a device.

Peripheral input API **312** may include a set of computer-readable functions or routines that enable game input management code **311** to interact with peripheral firmware **320** in order to receive and manage input provided by controller **330**.

Rumble API **313** may include a set of computer-readable functions or routines that enable input management code **311** to interact with peripheral firmware **320** in order to transmit rumble instructions to one or more rumble motors or rumble actuators of controller **330** (e.g., rumble motors L and R of FIG. **3**). In addition, a rumble instruction may cause a rumble motor or rumble actuator of controller **330** to produce a general or rumble haptic effect.

Haptic effect API **314** (identified in FIG. **3** as "API") may include a set of computer-readable functions or routines that are accessible to input management code **311**, and that enable input management code **311** to interact with peripheral firmware **320** in order to transmit haptic instructions to controller **330**. In addition, a haptic instruction may cause one or more targeted motors or targeted actuators of controller **330** to produce a haptic effect at one or more user input elements of controller **330**.

Haptic effect API **314** also may store one or more haptic effect definitions. A haptic effect definition is a data structure that includes haptic data, such as a haptic signal, that is pre-defined and that can be stored within a storage, such as a haptic file or haptic stream, and that can be sent to one or more rumble motors, rumble actuators, targeted motors, or targeted actuators, to produce a haptic effect at a component, or user input element, of controller **330**. The haptic data can include one or more attributes of the corresponding haptic effect, where the attributes can be stored as parameters. Example parameters of a haptic effect definition may include an amplitude parameter, a frequency parameter, a waveform parameter, an envelope parameter, a magnitude (or strength) parameter, and a duration parameter.

Haptic effect API **314** may enable game input management code **311** to interact with direct playback/crossover **315**, trigger engine **316**, and spatialization engine **317**, and may further manage direct playback/crossover **315**, trigger engine **316**, and spatialization engine **317** according to requests invoked by game input management code **311**. Further, haptic effect API **314** may store data used for communication with peripheral firmware **320**, and used for generation of one or more haptic effects.

Direct playback/crossover **315** may receive haptic data as input, produce haptic data as output, and transmit haptic data to one or more targeted motors, or targeted actuators, of controller **330** (e.g., motors L and R of FIG. **3**). In some embodiments, direct playback/crossover **315** may output the input haptic data directly, without modifying a format of the input haptic data. This results in an "as-is" playback of the input haptic data. In other embodiments, direct playback/crossover **315** may convert the haptic data that is input from a first format to a second format, and can further output the converted haptic data. Depending on the type of playback, direct playback/crossover **315** may optionally use a programmable crossover to convert the haptic data. By converting the haptic data, device modules may deconstruct the haptic effect and playback the haptic effect at multiple actuators.

The format of the haptic data may be a haptic elementary stream ("HES") format. A HES format is a file or data format for representing haptic data that may be streamed to a device. The haptic data can be represented in a manner that is identical or similar to how uncompressed sound is represented, although the haptic data can be encrypted within the HES format.

Trigger engine **316** may receive haptic data, such as a haptic effect definition, and may modify the haptic data based on user input data, such as trigger data **323**. Trigger data is data that includes one or more parameters that indicate a position and/or range of one or more triggers of controller **330** (e.g., triggers L and R of FIG. **3**). Trigger engine **316** may further transmit haptic instructions to controller **330**. For example, trigger engine **316** may transmit haptic instructions to a variety of user-input elements of controller **330**. As previously described, a haptic instruction may cause one or more targeted motors or targeted actuators of controller **330** to produce a haptic effect at one or more user-input elements of controller **330**.

Spatialization engine **317** may receive haptic data and may modify the haptic data based on spatialization data. Spatialization data may include data that indicates a desired direction and/or flow of a haptic effect, such as an ordering of haptic effects on respective user input elements. In certain embodiments, spatialization engine **317** may receive spatialization data that includes a direction and/or flow from input management code **311**.

Spatialization engine **317** may modify the haptic data so that a haptic effect, such as a trigger haptic effect, is scaled for one or more rumble motors, or rumble actuators, of controller **330** (e.g., rumble motors L and R of FIG. **3**), and that the haptic effect is also scaled for one or more targeted motors, or targeted actuators, of controller **330** (e.g., motors L and R, as illustrated in FIG. **3**). In other words, spatialization engine **317** may modify the haptic data that is sent to each motor or actuator, and thus, modify the haptic effect that is experienced at each motor or actuator, in order to convey a sense of direction and flow of an overall haptic effect. For example, in order to emphasize a haptic effect experienced at a motor or actuator, spatialization engine **317** may scale one or more portions of the haptic effect. For example, spatialization engine **317** may scale haptic data that is sent to the motor or actuator that causes the haptic effect to be experienced, causing the haptic effect to be more pronounced (e.g., increased magnitude, duration, etc.). Additionally, spatialization engine **317** may scale haptic data that is sent to other motors or actuators, causing other haptic effects that are experienced at those motors or actuators to be less pronounced (e.g., decreased magnitude, duration, etc.). In some embodiments, spatialization engine **317** may modify the haptic data in real-time or substantially in real time. Further, in some embodiments, spatialization engine **317** may have non-linear relationships between inputs and motor, or actuator, outputs in order to exaggerate an overall haptic effect.

Encoder **318** encodes haptic data received from direct playback/crossover **315**, trigger engine **316**, and/or spatialization engine **317** into a format. In one embodiment, the format may be an HES format. Encoder **318** may transmit the encoded haptic data to peripheral firmware **320**.

Peripheral firmware **320** is firmware for one or more peripheral devices (e.g., controllers). Peripheral firmware **320** may include a variety of modules such as decoder and crossover **321**, trigger control **322**, trigger data **323**, other functions **324**, and rumble control **325**.

Decoder and crossover **321** may receive the encoded haptic data from encoder **318** and decodes the encoded haptic data. In some embodiments, decoder and crossover **321** computes a programmable crossover in order to decode the encoded haptic data. Decoder and crossover **321** may compute the programmable crossover in real-time.

Trigger control **322** is a low-level control API for one or more targeted motors or targeted actuators of controller **330** (e.g., motors L and R of FIG. **3**). Trigger control **322** may receive a trigger instruction and may convert the trigger instruction into a low-level trigger instruction for a specified targeted motor or targeted actuator of controller **330**, and may transmit the low-level trigger instruction to the specified targeted motor or targeted actuator of controller **330**. The low-level trigger instruction may cause the specified targeted motor or targeted actuator to produce a trigger haptic effect at a specified trigger of controller **330**.

Trigger data **323**, as previously described, is data that includes one or more parameters that indicate a position and/or range of one or more triggers of controller **330** (e.g., triggers L and R of FIG. **3**). Trigger data **323** may be received from controller **330** by peripheral firmware **320**. Peripheral firmware **320** may further store trigger data **323**, and may further transmit trigger data **323** to device modules **310**.

Other gamepad functions **324** may be functions of controller **330** managed by peripheral firmware **320**. Such functions may include such functions as wired/wireless communications, input reporting, protocol implementation, power management, etc.

Rumble control **325** is a low-level control API for one or more rumble motors or rumble actuators of controller **330** (e.g., rumble motors L and R of FIG. **3**). Rumble control **325** may receive a rumble instruction, may convert the rumble instruction into a low-level rumble instruction for a specified rumble motor or rumble actuator of controller **330**, and may transmit the low-level trigger instruction to the specified rumble motor or rumble actuator of controller **330**.

Trigger rescale module **326** is a modular firmware module that monitors the positions of user input elements and the status of their respective haptic output devices in controller **330**. For example, trigger rescale module **326** rescales the user inputs to a range expected by the host device. In some instances, trigger rescale module **326** may rescale the user inputs to a range [0,127]. In other instances, trigger rescale module **326** may rescale the user inputs to a range [0,255]. In the various configurations, trigger rescale module **326** may be applied to any analog input. In some instances, sections of firmware that are hardware independent may be separated from the sections that are hardware dependent. Here, hardware independent firmware may interact with the hardware dependent firmware by using function pointers.

Controller **330** may include triggers L and R. Controller **330** may further include gear boxes L and R and motors L and R. Motor L and gearbox L are operably coupled to trigger L within controller **330**. Likewise, motor R and gearbox R are operably coupled to trigger R within controller **330**. When motor L receives a trigger instruction, motor L and gearbox L may collectively cause a trigger haptic effect to be experienced at trigger L. Likewise, when motor R receives a trigger instruction, motor R and gearbox R may collectively cause a trigger haptic effect to be experienced at trigger R. Peripheral firmware **320** may send trigger instructions to motors L and R of controller **330** using drive electronics **340**.

Controller **330** may further include potentiometers L and R. Potentiometer L may detect a position and/or range of trigger L, and may further send the detected position and/or range of trigger L to peripheral firmware **320** as trigger data. Likewise, potentiometer R may detect a position and/or range of trigger R, and may further send the detected position and/or range of trigger R to peripheral firmware **320** as trigger data.

Controller **330** may further include rumble motors L and R. When rumble motor L receives a rumble instruction,

rumble motor L causes a haptic effect to be experienced along a left component of controller **330**. Likewise, when rumble motor R receives a rumble instruction, rumble motor R causes a haptic effect to be experienced along a right component of controller **330**. Peripheral firmware **320** may send rumble instructions to rumble motors L and R using rumble drive electronics **350**.

FIG. **4** illustrates a flow diagram of functionality **400** for controlling a user input element associated with a haptic output device according to an example embodiment of the present invention. In some instances, the functionality of the flow diagram of FIG. **4** (and FIG. **5** below) may be implemented by software stored in memory or other computer readable or tangible media, and executed by a processor. In other embodiments, the functionality may be performed by hardware (e.g., through the use of an application specific integrated circuit ("ASIC"), a programmable gate array ("PGA"), a field programmable gate array ("FPGA"), etc.), or any combination of hardware and software.

At the outset, functionality **400** may define a primary range and a secondary range of positions for the user input element associated with the haptic output device, at **410**. Next, at **420**, functionality **400** may define a boundary range of positions for the user input element associated with the haptic output device, the boundary range partially overlapping each of the primary and secondary ranges. After the various ranges are defined, functionality **400** monitors the position of the user input element, at **430**. Lastly, haptic effect(s) may be rendered when the user input element enters positions within the boundary range, at **440**. Here, the haptic effect(s) may extend the position of the user input element into one of the secondary ranges. In addition, haptic instructions to render the haptic effect(s) may be generated by a software application, such as a gaming application. By employing functionality **400**, the range and capabilities of the user input elements are extended, and a wider range of haptic effects can be experienced by an end user.

FIG. **5** illustrates a flow diagram of functionality **500** for controlling a user input element associated with a haptic output device according to another example embodiment of the present invention.

At the outset, the user input elements of the controller may be initialized, at **510**. Here, functionality **500** may initially set position and range information for the user input elements. For example, primary range, secondary range(s), and boundary range(s) may be initially set. In some instances, these values may be calculated based on the movement of the user input device from the maximum out position to the grounding position.

Next, functionality **500** calculates profiles for the user input elements, at **520**. The calculated profiles may map each position of the user input device to an ADC value. For example, the calculated profiles of **520** may map each position of the user input device to an ADC value between 0 and 255.

The calculated profiles may utilize either an increasing or a decreasing profile. For example, an increasing profile will produce a value [0,255] when the position of the user input value is read from 8 bit ADC data. Similarly, a decreasing profile will produce a value [255,0] when read from 8 bit ADC data.

Subsequently, at **530**, functionality **500** calculates a normalized profile. The normalized profile may be calculated by removing secondary and/or boundary ranges from the ADC data. For example, the calculated normalized profile of **530** may map each position of the user input device, excluding secondary and/or boundary positions, to an ADC value between 0 and 255.

In some instances, the resting position of the user input elements may vary at different times. For example, after use of the various user input devices, some of the user input devices may not return to the same resting position when the user interaction is removed. In such instances, functionality **500** may adjust the calculated profile and the calculated normalized profiles for such user input elements, at **540**. Accordingly, the changed resting position(s) may be accounted for while monitoring the position of the user input elements.

FIG. **6** illustrates a controller that includes an outer spring **600** that creates an open extended travel range **620** for a trigger **610** to move within when trigger **610** is in a maximum open position outside of open extended travel range **620**, according to an embodiment of the invention. More specifically, FIG. **6** illustrates a controller that includes outer spring **600** that holds trigger **610** in a maximum open position outside of open extended travel range **620**. When a force is applied to trigger **610**, outer spring **600** can allow trigger **610** to rotate, or otherwise move, to open extended travel range **620**. FIG. **6** includes views **601** and **602**. In view **601**, trigger **610** is in a maximum open position outside of open extended travel range **620**, as trigger **610** can be pulled or pushed along an axis that is perpendicular to the illustrated plane of FIG. **6**. In view **602**, trigger **610** is in a maximum open position that is inside open extended travel range **620**, where trigger **610** is further extended within open extended travel range **620**, as trigger **610** can be pulled back in, but cannot be pushed out further along an axis that is perpendicular to the illustrated plane of FIG. **6**. In the illustrated embodiment, outer spring **600** is an example of a haptic diminishment prevention component, and is positioned between trigger **610** and an outer rotational hard stop, or an outer portion of a housing of the controller. A maximum open position outside of an extended travel range can be important for spatialization as a user can be lightly resting their fingers on triggers of a controller when receiving spatialization haptic effects. In order to increase a magnitude of a trigger haptic effect when a trigger (such as trigger **610**) is in a maximum open position outside of an open extended travel range (such as open extended travel range **620**), the trigger can be offset with an outer spring (such as outer spring **600**) so that, when in the maximum open position outside of an open extended travel range, the trigger is able to move within the extended travel range in response to a force that is applied to the trigger.

View **601** is a view of the controller where outer spring **600** holds trigger **610** in a position such that trigger **610** is not resting at, or otherwise making contact with, an outer rotational hard stop, or an outer portion of a housing of the controller, when trigger **610** is in a maximum open position outside of open extended travel range **620**. In other words, outer spring **600** creates open extended travel range **620**, where open extended travel range **620** is a range that trigger **610** can rotate, or otherwise move, within, in response to a force that is produced by a targeted motor or actuator and applied to trigger **610**. By creating open extended travel range **620**, outer spring **600** can prevent trigger **610** from grounding on the outer rotational hard stop, or the outer portion of the housing, when trigger **610** rotates, or otherwise moves, in response to the force that is applied to trigger **610**. This can increase a magnitude of a trigger haptic effect (e.g., kinesthetic haptic effect) experienced at trigger **610**. In the illustrated embodiment, outer spring **600** is a cantilever

spring that includes lever arm **605**, where lever arm **605** pushes against, or otherwise makes contact with, trigger **610** to hold trigger **610** in the aforementioned position. In an alternate embodiment, outer spring **600** can be a compression spring, bias spring, or some other type of spring, that pushes against, or otherwise makes contact with, trigger **610**. Although various spring types may be used, the embodiments are not so limited, and other deformation mechanisms may be used.

View **602** is a view of the controller where a targeted motor or actuator applies a force to trigger **610**, and trigger **610** rotates, or otherwise moves, in response to the force. As illustrated in view **602** of FIG. **6**, trigger **610** rotates, or otherwise moves, into open extended travel range **620**, and occupies at least a portion of open extended travel range **620**. In the illustrated embodiment, trigger **610** pushes against, or otherwise makes contact with, lever arm **605**. This moves lever arm **605** so that trigger **610** can rotate, or otherwise move, into extended travel range **620**. In an alternate embodiment where outer spring **600** is a compression spring, bias spring, or another type of spring, trigger **610** can push against, or otherwise make contact with, outer spring **600**, which can move outer spring **600** so that trigger **610** can rotate, or otherwise move, into open extended travel range **620**.

In an alternate embodiment, outer spring **600** can be replaced with an inner spring. The inner spring can be positioned between trigger **610** and an inner rotational hard stop, or an inner portion of a housing of the controller. Further, the inner spring can pull trigger **610** such that trigger **610** is not resting at, or otherwise making contact with, an outer rotational hard stop, or an outer portion of a housing of the controller (i.e., such that extended travel range **620** is created). In this alternate embodiment, a stiffness of inner spring can be calculated in order to avoid pulling trigger **610** so that trigger **610** is resting at, or otherwise making contact with, an inner rotational hard stop, or an inner portion of a housing of the controller.

FIG. **7** illustrates a controller that includes an extended frame **700** that creates a closed extended travel range **730** for a trigger **710** to move within when trigger **710** is in a maximum closed position outside of closed extended travel range **730**, according to an embodiment of the invention. In the illustrated embodiment, extended frame **700** is an example of a haptic diminishment prevention component, and is an extension of an outer portion of a housing of the controller. As previously described, in a standard trigger design, a trigger haptic effect can be greatly diminished when a trigger (such as trigger **710**) is a maximum closed position (e.g., when a user fully presses the trigger so that the trigger is grounded to an inner portion of a housing). In order to increase a magnitude of a trigger haptic effect when the trigger is in a maximum closed position outside of a closed extended travel range, an extended frame (such as extended frame **700**) can be used as grounding for an object (such as object **720**) that moves the trigger. In this situation, even when the trigger has fully moved to a maximum closed position outside of the closed extended travel range, the trigger can still move against the object and a significant haptic feedback sensation can be generated at the trigger.

FIG. **7** includes views **701** and **702**. View **701** is a view of the controller where object **720** (e.g., a user's finger) has pushed, pulled, or otherwise moved trigger **710**, and where object **720** is grounded (i.e., bottomed out) on extended frame **700**. Because object **720** is grounded on extended frame **700**, trigger **710** is not resting at, or otherwise making contact with, an inner rotational hard stop, or an inner portion of a housing of the controller, when trigger **710** is in a maximum closed position outside of closed extended travel range **730**. In other words, extended frame **700** creates closed extended travel range **730**, where closed extended travel range **730** is a range that trigger **710** can rotate, or otherwise move, within, in response to a force that is produced by a targeted motor or actuator and applied to trigger **710**. By creating closed extended travel range **730**, extended frame **700** can prevent trigger **710** from grounding on the inner rotational hard stop, or the inner portion of the housing, when trigger **710** rotates, or otherwise moves, in response to the force that is applied to trigger **710**. This can increase a magnitude of a trigger haptic effect (e.g., kinesthetic haptic effect) experienced at trigger **710**.

View **702** is a view of the controller where a targeted motor or actuator applies a force to trigger **710**, and trigger **710** rotates, or otherwise moves, in response to the force. As illustrated in view **702** of FIG. **7**, trigger **710** rotates, or otherwise moves, into closed extended travel range **730**, and occupies at least a portion of closed extended travel range **730**.

In an alternate embodiment, extended frame **700** can be replaced with an inner spring. The inner spring can be positioned between trigger **710** and an inner rotational hard stop, or an inner portion of a housing of the controller. Further, the inner spring can push trigger **710** where object **720** has pushed, pulled, or otherwise moved trigger **710** such that trigger **710** is not resting at, or otherwise making contact with, an inner rotational hard stop, or an inner portion of a housing of the controller (i.e., such that closed extended travel range **730** is created). In this alternate embodiment, a stiffness of inner spring can be calculated in order to provide sufficient resistance to prevent trigger **710** from resting at, or otherwise making contact with, an inner rotational hard stop, or an inner portion of a housing of the controller.

FIG. **8** illustrates a functional block diagram of a controller **800** suitable for use with the embodiments of the present invention.

As illustrated in FIG. **8**, controller **800** may include one or more of a variety of user input elements. A user input element may refer to any interface device manipulated by the user to interact with host computer **804**. Example user input elements include analog or digital joy stick **810**, button **814**, trigger **818**, and the like. As understood by one of ordinary skill in the art, one or more of each user input element may be included on controller **800**. For example, the present description of trigger **818** does not limit controller **800** to a single trigger. Similarly, those skilled in the art understand that multiple analog or digital sticks, buttons, and other user input elements may be used.

Controller **800** may include local processor **808**. Local processor **808** may exchange commands and data with host computer **804** via connection **805**. Connection **805** may be a wired or wireless connection using one or more communication protocols known to those skilled in the art. In some instances, controller **800** may be alternatively configured to not include local processor **808**. Here, input/output signals from controller **800** may be handled and processed directly by host computer **804**. Host computer **804** may be a gaming device console and display device **806** may be screen which is operably coupled to the gaming device console. In some instances, host computer **804** and display device **806** may be combined into a single device.

Controller **800** may include targeted actuators **812**, **816**, **820** (e.g., motors) to directly drive each of the user input elements thereof as well as one or more general or rumble actuators **822**, **824** operably coupled to housing **802** in a

location where a hand of the user is generally located. More particularly, analog or digital stick **810** includes a targeted actuator or motor **812** operably coupled thereto, button **814** includes a targeted actuator or motor **816** operably coupled thereto, and trigger **818** includes a targeted actuator or motor **820** operably coupled thereto. In addition to a plurality of targeted actuators, controller **800** includes a position sensor operably coupled to each of the user input elements thereof. More particularly, analog or digital stick **810** includes a position sensor **811** operably coupled thereto, button **814** includes a position sensor **815** operably coupled thereto, and trigger **818** includes a position sensor **819** operably coupled thereto. Local processor **808** is operably coupled to targeted actuators **812**, **816**, **820** as well as position sensors **811**, **815**, **819** of analog or digital stick **810**, button **814**, and trigger **818**, respectively. In response to signals received from position sensors **811**, **815**, **819**, local processor **808** instructs targeted actuators **812**, **816**, **820** to provide directed or targeted kinesthetic effects directly to analog or digital stick **810**, button **814**, and trigger **818**, respectively. Such targeted kinesthetic effects are discernible or distinguishable from general or rumble haptic effects produced by general actuators **822**, **824** along the entire body of the controller. The collective haptic effects provide the user with a greater sense of immersion to the game as multiple modalities are being simultaneously engaged (e.g., video, audio, and haptics).

FIGS. **9**A and **9**B illustrate different views of a controller **900** suitable for use with the embodiments of the present invention. As shown in FIG. **9**A and FIG. **9**B, controller **900** may include a variety of components such as housing **902**, analog or digital joy stick **910**, button(s) **914**, trigger **918**, and rumble actuators **922** and **924**.

Housing **902** is shaped to easily accommodate user gripping of controller **900**. Controller **900** is an example embodiment of a controller, and the embodiments of the invention may be readily applied to other controller shapes.

Accordingly, the embodiments of the present invention extend the range and capabilities of user input elements. In addition, a wider range of haptic effects can be achieved by rendering the haptic effects at definable positions of the user input elements.

One having ordinary skill in the art will readily understand that the invention as discussed above may be practiced with steps in a different order, and/or with elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be apparent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. In order to determine the metes and bounds of the invention, therefore, reference should be made to the appended claims.

We claim:

1. A method for controlling a user input element associated with a haptic output device, the method comprising:

defining position and range information for the user input element associated with the haptic output device, including a primary range of positions, a secondary range of positions, and a boundary range of positions, wherein the boundary range of positions partially overlaps each of the primary range of positions and the secondary range of positions; and

rendering a haptic effect in response to an entry of the user input element to one or more positions within the boundary range of positions.

2. The method of claim **1**, wherein one of the primary range of positions, the secondary range of positions, and the boundary range of positions is calculated based on a movement of the user input element from a maximum out position to a grounding position.

3. The method of claim **1**, wherein a profile for the user input element is calculated by mapping each position of the user input element to an analog to digital conversion value.

4. The method of claim **3**, wherein the profile for the user input element is an increasing profile or a decreasing profile.

5. The method of claim **1**, wherein a normalized profile for the user input element is calculated by removing at least one of the secondary range of positions or the boundary range of positions from mapped analog to digital conversion values.

6. The method of claim **1**, further comprising monitoring a position of the user input element.

7. The method of claim **1**, further comprising adjusting a profile and a normalized profile of the user input element to adjust for a change to a resting position of the user input element.

8. A non-transitory computer readable storage medium storing a program configured to be executed by a processor, the program comprising instructions for:

defining position and range information for a user input element associated with the haptic output device, including a primary range of positions, a secondary range of positions, and a boundary range of positions, wherein the boundary range of positions partially overlaps each of the primary range of positions and the secondary range of positions; and

rendering a haptic effect in response to an entry of the user input element to one or more positions within the boundary range of positions.

9. The non-transitory computer readable storage medium of claim **8**, wherein one of the primary range of positions, the secondary range of positions, and the boundary range of positions is calculated based on a movement of the user input element from a maximum out position to a grounding position.

10. The non-transitory computer readable storage medium of claim **8**, wherein a profile for the user input element is calculated by mapping each position of the user input element to an analog to digital conversion value.

11. The non-transitory computer readable storage medium of claim **10**, wherein the profile for the user input element is an increasing profile or a decreasing profile.

12. The non-transitory computer readable storage medium of claim **8**, wherein a normalized profile for the user input element is calculated by removing at least one of the secondary range of positions or the boundary range of positions from mapped analog to digital conversion values.

13. The non-transitory computer readable storage medium of claim **8**, further comprising instructions for monitoring a position of the user input element.

14. The non-transitory computer readable storage medium of claim **13**, further comprising instructions for adjusting a profile and a normalized profile of the user input element to adjust for a change to a resting position of the user input element.

15. A device comprising:

a processor; and

a memory storing a program for execution by the processor, the program including instructions for:

defining position and range information for a user input element associated with the haptic output device, including a primary range of positions, a secondary

range of positions, and a boundary range of positions, wherein the boundary range of positions partially overlaps each of the primary range of positions and the secondary range of positions; and

rendering a haptic effect in response to an entry of the user input element to one or more positions within the boundary range of positions.

16. The device of claim **15**, wherein one of the primary range of positions, the secondary range of positions, and the boundary range of positions is calculated based on a movement of the user input element from a maximum out position to a grounding position.

17. The device of claim **15**, wherein a profile for the user input element is calculated by mapping each position of the user input element to an analog to digital conversion value.

18. The device of claim **15**, wherein a normalized profile for the user input element is calculated by removing at least one of the secondary range of positions or the boundary range of positions from mapped analog to digital conversion values.

19. The device of claim **15**, further comprising instructions for monitoring a position of the user input element.

20. The device of claim **19**, further comprising instructions for adjusting a profile and a normalized profile of the user input element to adjust for a change to a resting position of the user input element.

* * * * *