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(54) **HAPTIC TRIGGER CONTROL SYSTEM**
(71) Applicant: **Immersion Corporation**, San Jose, CA (US)
(72) Inventors: **Robert Lacroix**, Saint-Lambert (CA); **Danny Grant**, Laval (CA); **Henry Da Costa**, Montreal (CA); **Stephen D. Rank**, San Jose, CA (US); **David Birnbaum**, Oakland, CA (US); **William Rihn**, San Jose, CA (US)
(73) Assignee: **Immersion Corporation**, San Jose, CA (US)
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G06F 3/01 (2006.01)
(Continued)
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CPC **G06F 3/016** (2013.01); **A63F 13/22** (2014.09); **A63F 13/23** (2014.09); **A63F 13/285** (2014.09); **A63F 13/54** (2014.09); **A63F 13/60** (2014.09)
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CPC G06F 3/016; G06F 2203/013; G06F 2203/014; G06F 2203/015; G06F 3/0488;
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(56) **References Cited**

U.S. PATENT DOCUMENTS

5,473,126 A 12/1995 Wu
5,959,613 A 9/1999 Rosenberg et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 1983125 A 6/2007
CN 102822772 A 12/2012
(Continued)

OTHER PUBLICATIONS

Jamal Sabouné et al., U.S. Appl. No. 14/020,461, filed on Sep. 6, 2013.

(Continued)

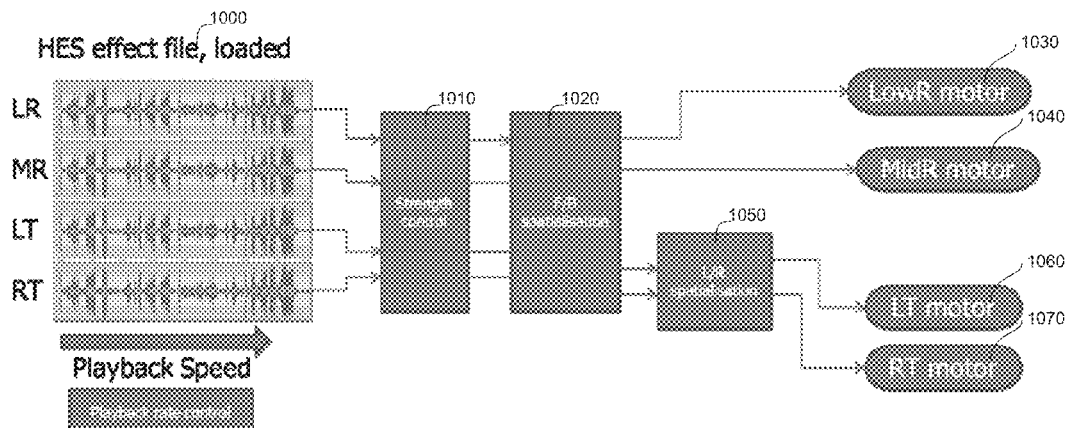
Primary Examiner — Duc Dinh

(74) *Attorney, Agent, or Firm* — Miles & Stockbridge P.C.

(57) **ABSTRACT**

A system that controls a haptic effect experienced at a trigger is provided. The system receives a haptic effect definition including haptic data. The system further receives trigger data including at least one of: a position of a trigger of a peripheral device; or a range of the trigger of the peripheral device. The system further determines whether a trigger condition is reached based on the received trigger data. The system further sends a haptic instruction and the haptic effect definition to the peripheral device when the trigger condition is reached. The system further causes a haptic output device (or multiple haptic output devices) to produce haptic effects that are based on the haptic effect definition at the peripheral device in response to the haptic instruction.

32 Claims, 33 Drawing Sheets



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A63F 13/22 (2014.01)
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- (58) **Field of Classification Search**
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 USPC 345/156, 169, 173, 174, 175, 161, 167, 345/168
- See application file for complete search history.

2011/0215913	A1	9/2011	Ullrich et al.
2011/0244963	A1	10/2011	Grant et al.
2012/0206246	A1	8/2012	Cruz-Hernandez et al.
2012/0206247	A1	8/2012	Bhatia et al.
2012/0306631	A1*	12/2012	Hughes 340/407.1
2013/0131851	A1	5/2013	Ullrich et al.
2013/0194085	A1	8/2013	Grant et al.
2013/0207917	A1	8/2013	Cruz-Hernandez et al.
2013/0222311	A1*	8/2013	Pesonen G06F 3/016 345/173
2013/0265286	A1	10/2013	Da Costa et al.
2013/0267321	A1	10/2013	Burgess et al.
2013/0324254	A1	12/2013	Huang et al.
2013/0335209	A1	12/2013	Cruz-Hernandez et al.
2014/0064516	A1	3/2014	Cruz-Hernandez et al.
2014/0118125	A1	5/2014	Bhatia
2014/0315642	A1	10/2014	Grant et al.

FOREIGN PATENT DOCUMENTS

- (56) **References Cited**
 U.S. PATENT DOCUMENTS

6,005,551	A	12/1999	Osborne et al.
6,169,540	B1	1/2001	Rosenberg et al.
6,343,349	B1	1/2002	Braun et al.
6,424,356	B2	7/2002	Chang et al.
6,710,764	B1	3/2004	Burgel et al.
7,336,260	B2	2/2008	Martin et al.
7,791,588	B2	9/2010	Tierling et al.
7,808,488	B2	10/2010	Martin et al.
7,965,276	B1	6/2011	Martin et al.
7,979,146	B2	7/2011	Ullrich et al.
7,979,797	B2	7/2011	Schena
8,000,825	B2	8/2011	Ullrich et al.
8,159,461	B2	4/2012	Martin et al.
8,164,573	B2	4/2012	Dacosta et al.
8,210,942	B2	7/2012	Shimabukuro et al.
8,378,964	B2	2/2013	Ullrich et al.
8,384,316	B2	2/2013	Houston et al.
8,723,820	B1*	5/2014	Han 345/173
8,754,757	B1	6/2014	Ullrich et al.
8,754,758	B1	6/2014	Ullrich et al.
2002/0024503	A1	2/2002	Armstrong
2002/0080112	A1	6/2002	Braun et al.
2004/0056840	A1	3/2004	Goldenberg et al.
2005/0134561	A1	6/2005	Tierling et al.
2006/0109256	A1	5/2006	Grant et al.
2007/0013677	A1	1/2007	Rosenberg et al.
2008/0223627	A1*	9/2008	Lacroix et al. 178/18.01
2008/0294984	A1	11/2008	Ramsay et al.
2009/0033624	A1	2/2009	Rosenberg et al.
2009/0088659	A1	4/2009	Graham et al.
2009/0122006	A1	5/2009	Nielsen et al.
2009/0297328	A1	12/2009	Slocum, III
2010/0122006	A1	5/2010	Kanaya
2010/0148943	A1	6/2010	Rosenberg et al.
2010/0173686	A1*	7/2010	Grant et al. 463/2
2010/0231541	A1	9/2010	Cruz-Hernandez et al.
2011/0202155	A1	8/2011	Ullrich et al.

CN	103365415	A	10/2013
EP	0864144	A2	9/1998
EP	2648071	A1	10/2013
EP	2796965	A2	10/2014
JP	20030199974	A	7/2003
JP	20130218327	A	10/2013
WO	03032289	A1	4/2003
WO	2010065207	A1	6/2010
WO	20130116247	A1	8/2013

OTHER PUBLICATIONS

Jamal Saboune et al., U.S. Appl. No. 14/020,502, filed on Sep. 6, 2013.

Juan Manuel Cruz-Hernandez et al., U.S. Appl. No. 14/051,933, filed on Oct. 11, 2013.

Juan Manuel Cruz-Hernandez et al., U.S. Appl. No. 14/078,438, filed on Nov. 12, 2013.

Juan Manuel Cruz-Hernandez et al., U.S. Appl. No. 14/078,442, filed on Nov. 12, 2013.

Juan Manuel Cruz-Hernandez et al., U.S. Appl. No. 14/078,445, filed on Nov. 12, 2013.

Robert Lacroix et al., U.S. Appl. No. 14/277,870, filed on May 15, 2014.

Satvir Singh Bhatia, U.S. Appl. No. 14/1467,184, filed on Aug. 25, 2014.

Danny Grant et al., U.S. Appl. No. 14/538,976, filed on Nov. 12, 2014.

William Rihn, U.S. Appl. No. 14/538,955, filed on Nov. 12, 2014.

Henry Da Costa et al., U.S. Appl. No. 14/539,122, filed on Nov. 12, 2014.

Conan Hughes, "Turn Off Wii Remote's Rumble Feature", Apr. 9, 2011, XP055172295, <http://www.conanhughes.com/2011/04/turn-off-wii-remotes-rumble-feature.html>.

Mkwone, "Move FAQ—Playstation Forum", Sep. 3, 2010, XP055172297, <http://community.eu.playstation.com/t5/PlayStation-Move/Move-FAQ/td-p/11447251>.

* cited by examiner

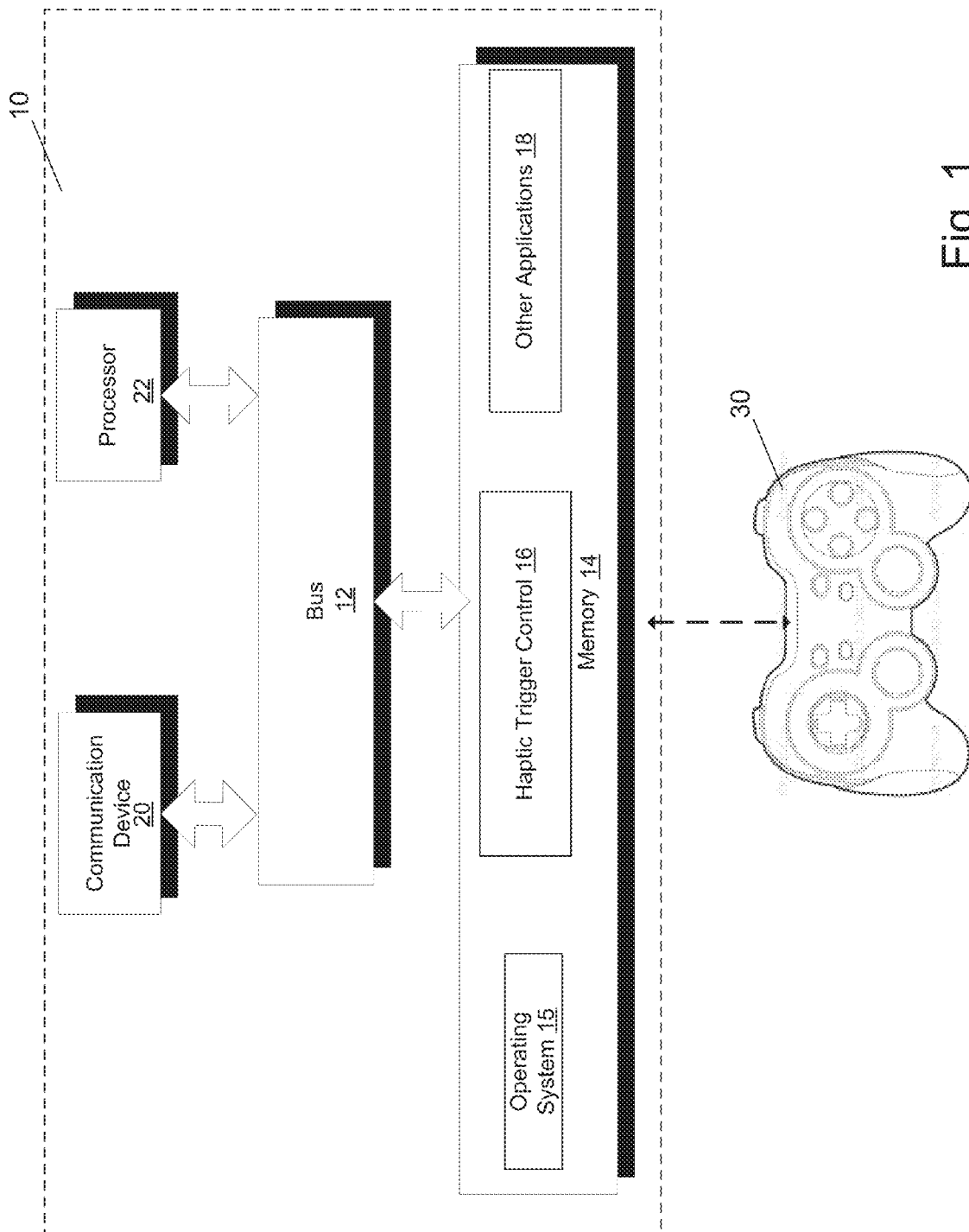


Fig. 1

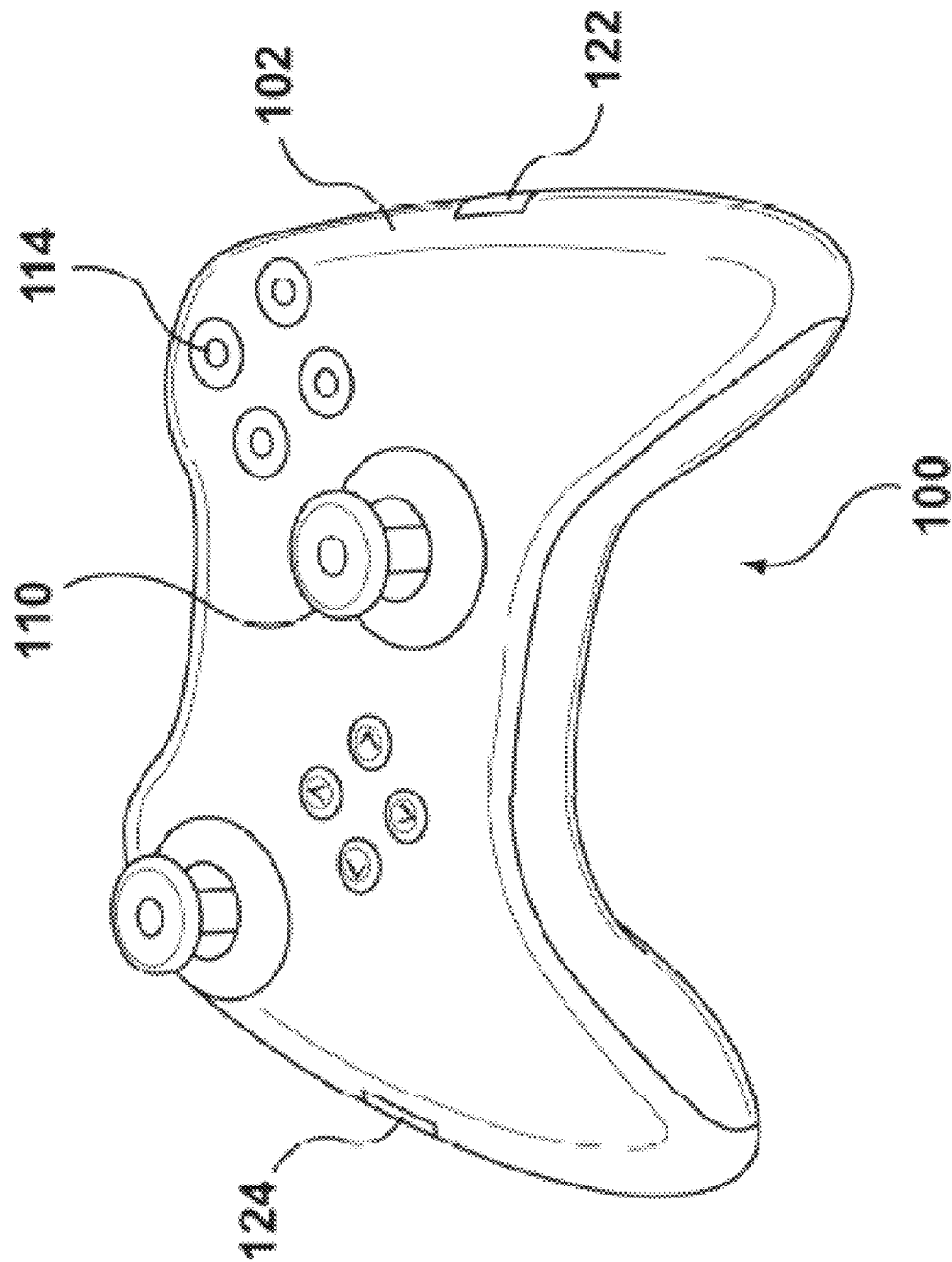


Fig. 2

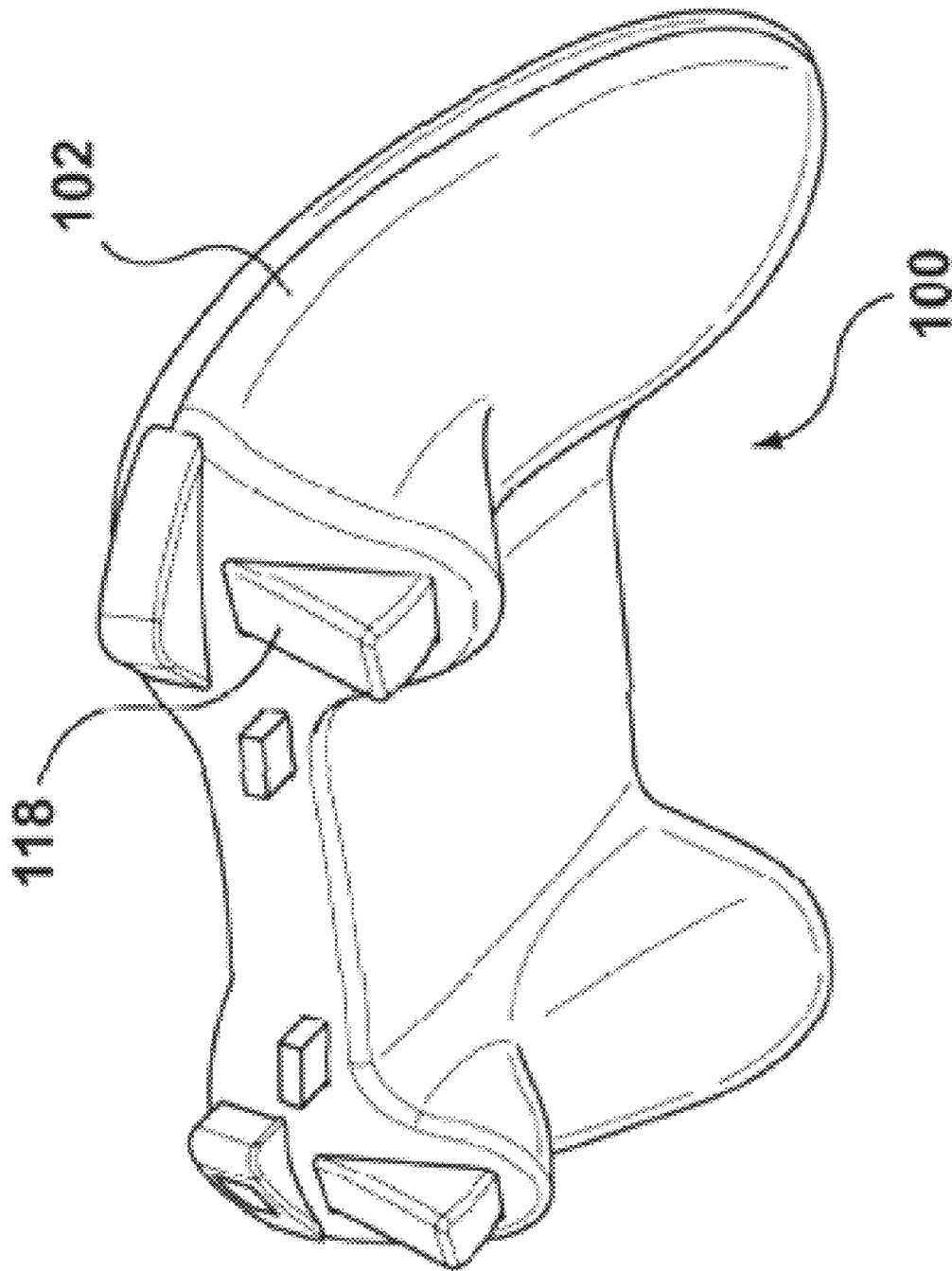


Fig. 3

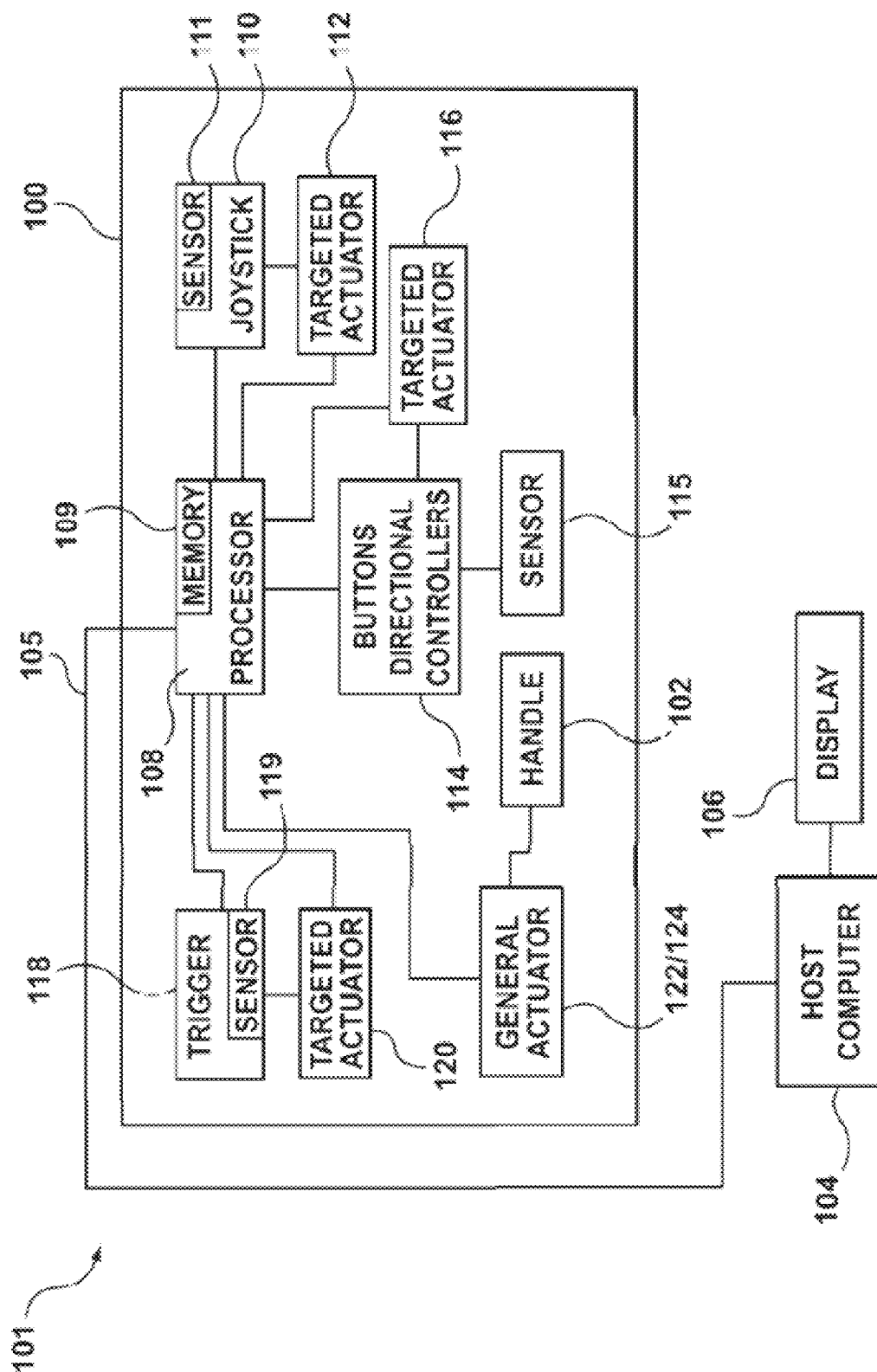
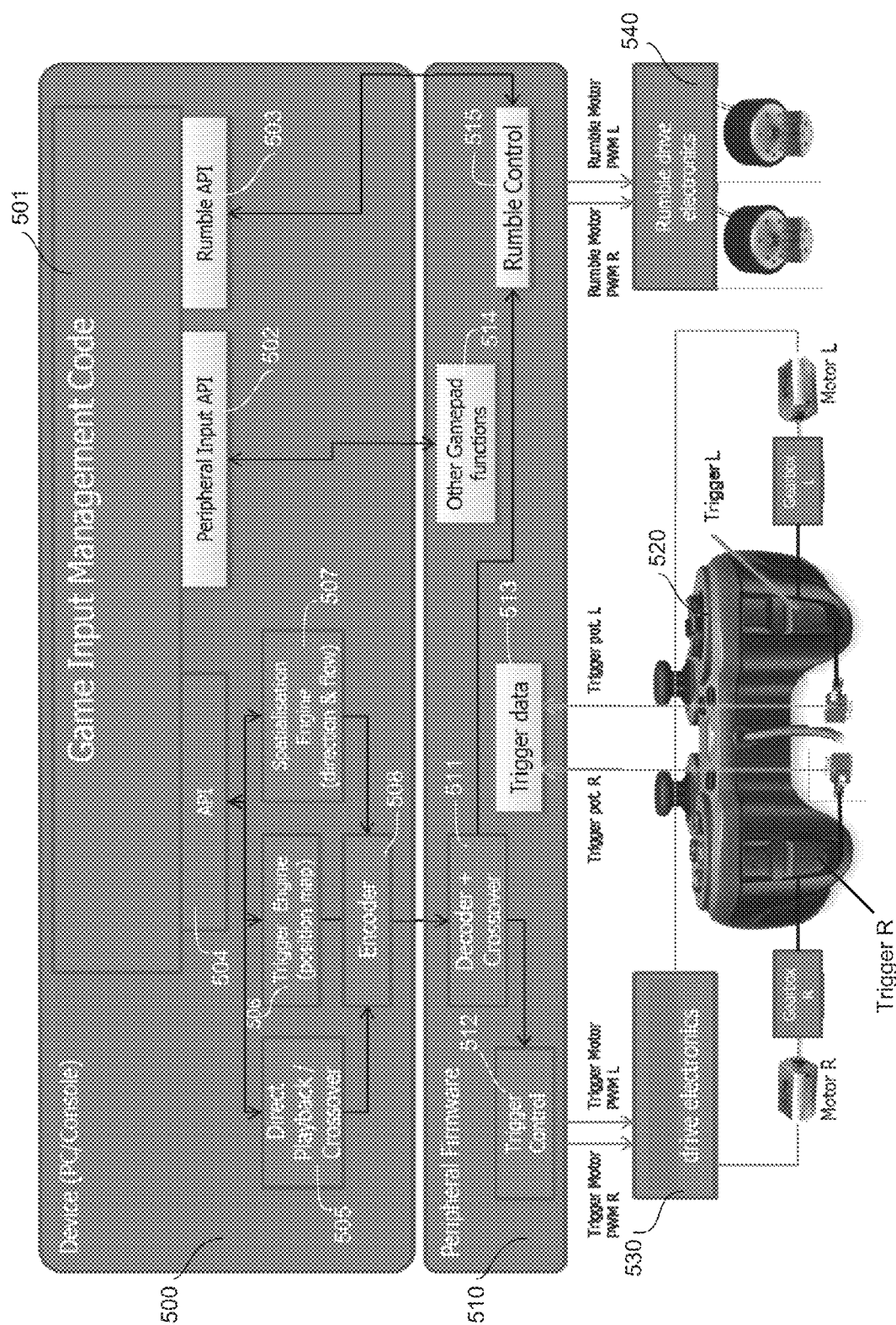


Fig. 4



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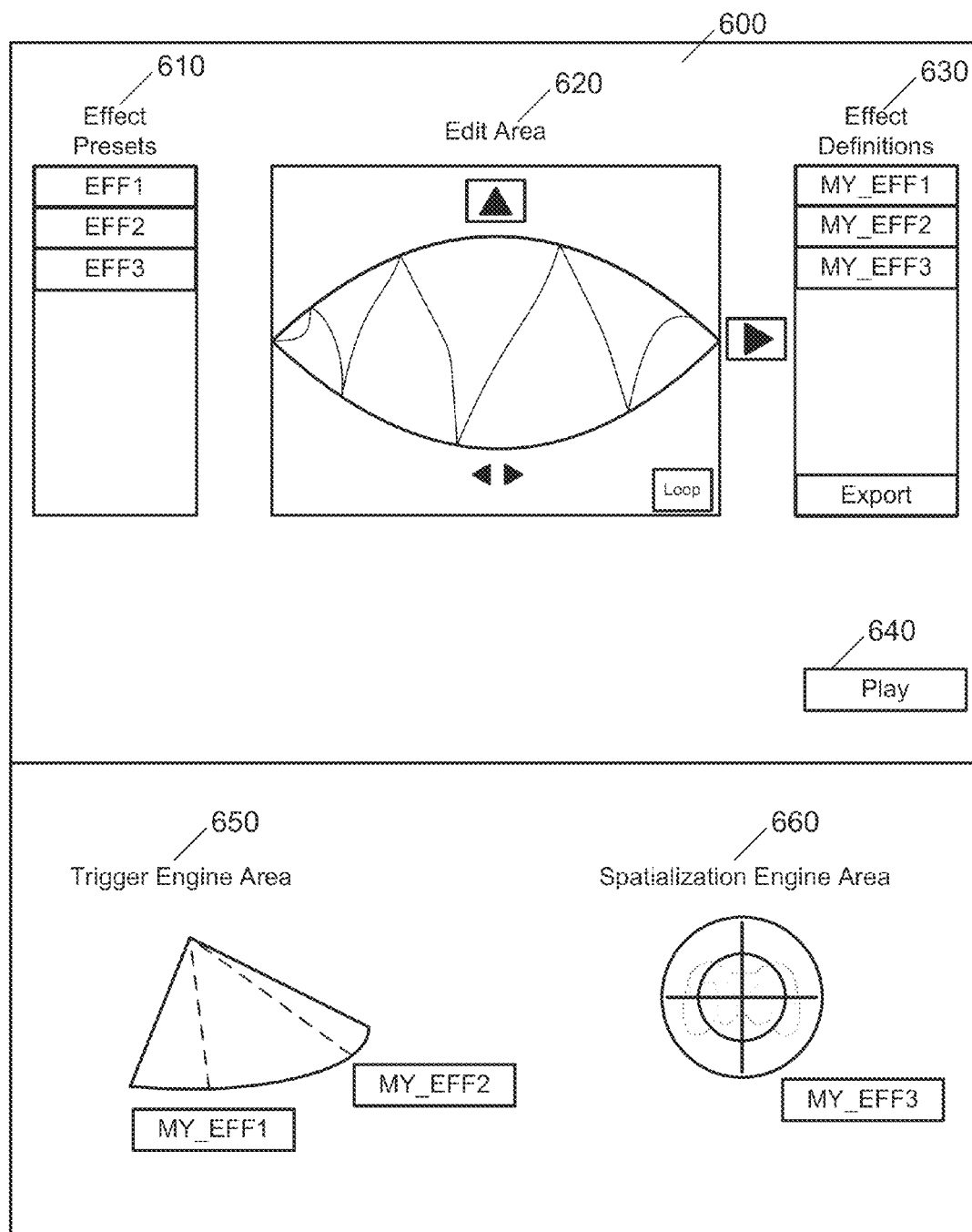


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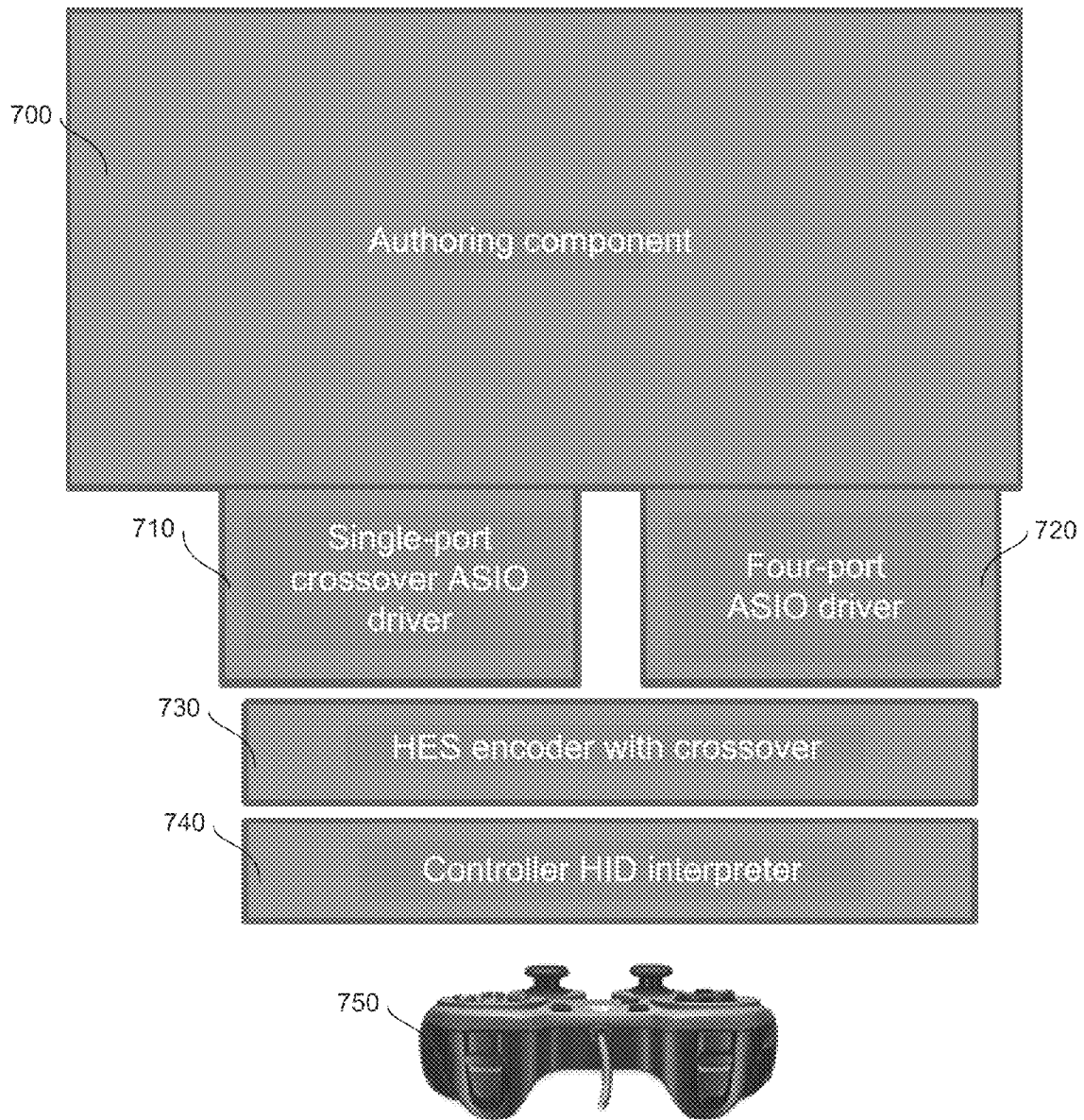


Fig. 7

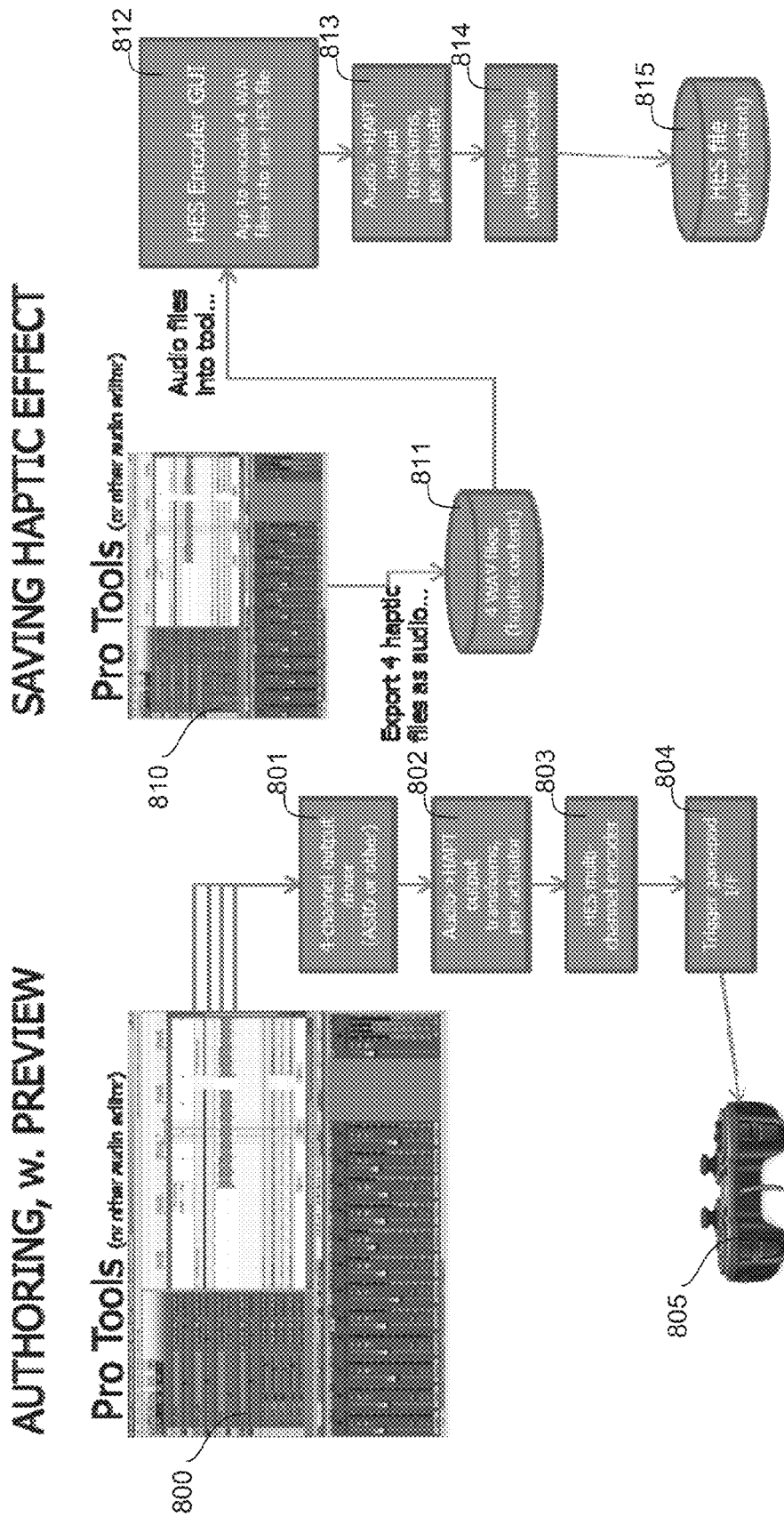


Fig. 8

AUTHORING, w. PREVIEW

SAVING HAPTIC EFFECT

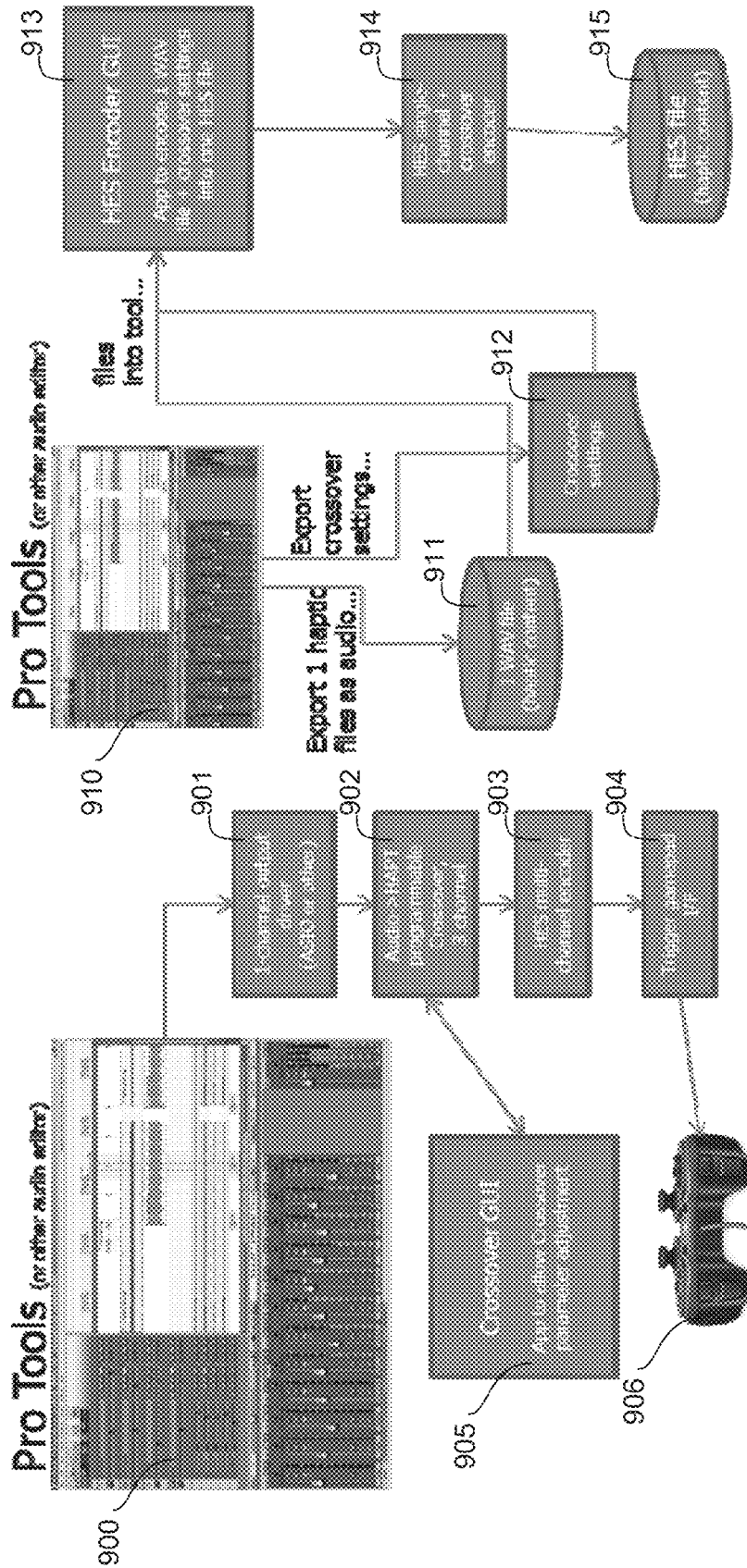


Fig. 9

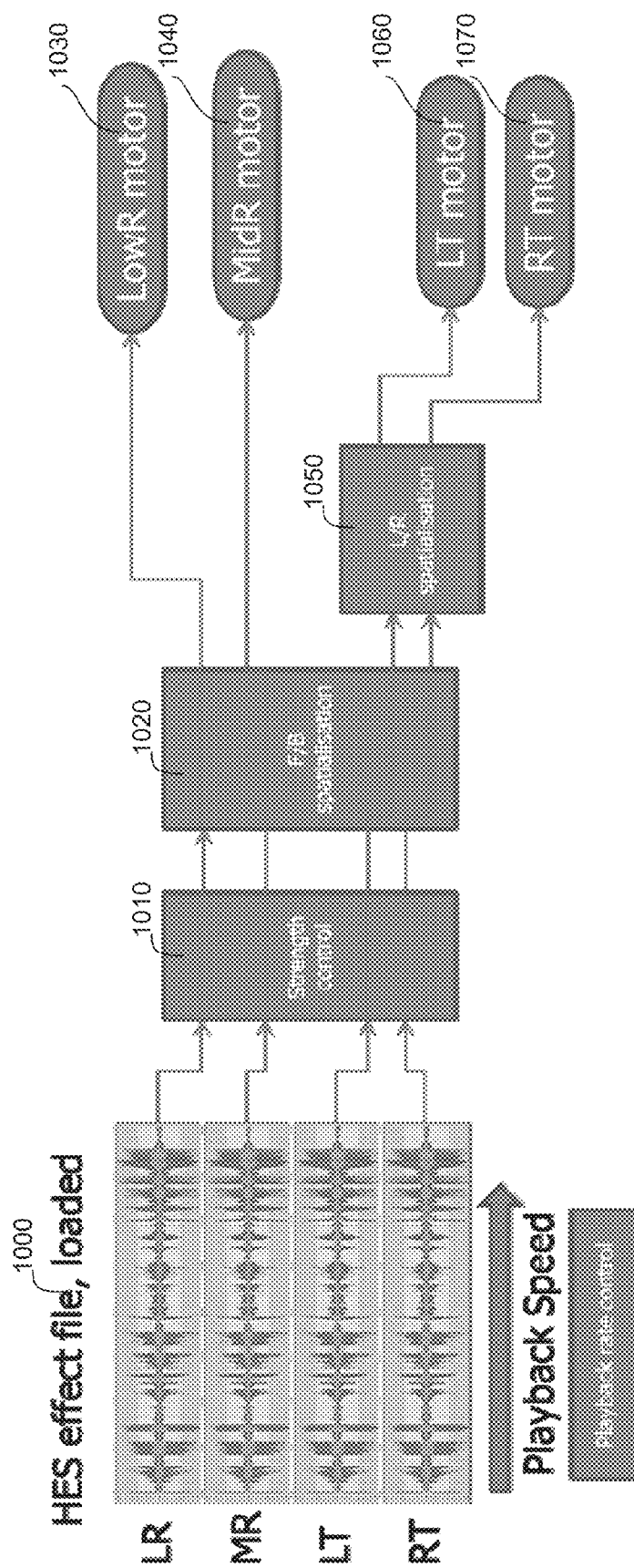


Fig. 10

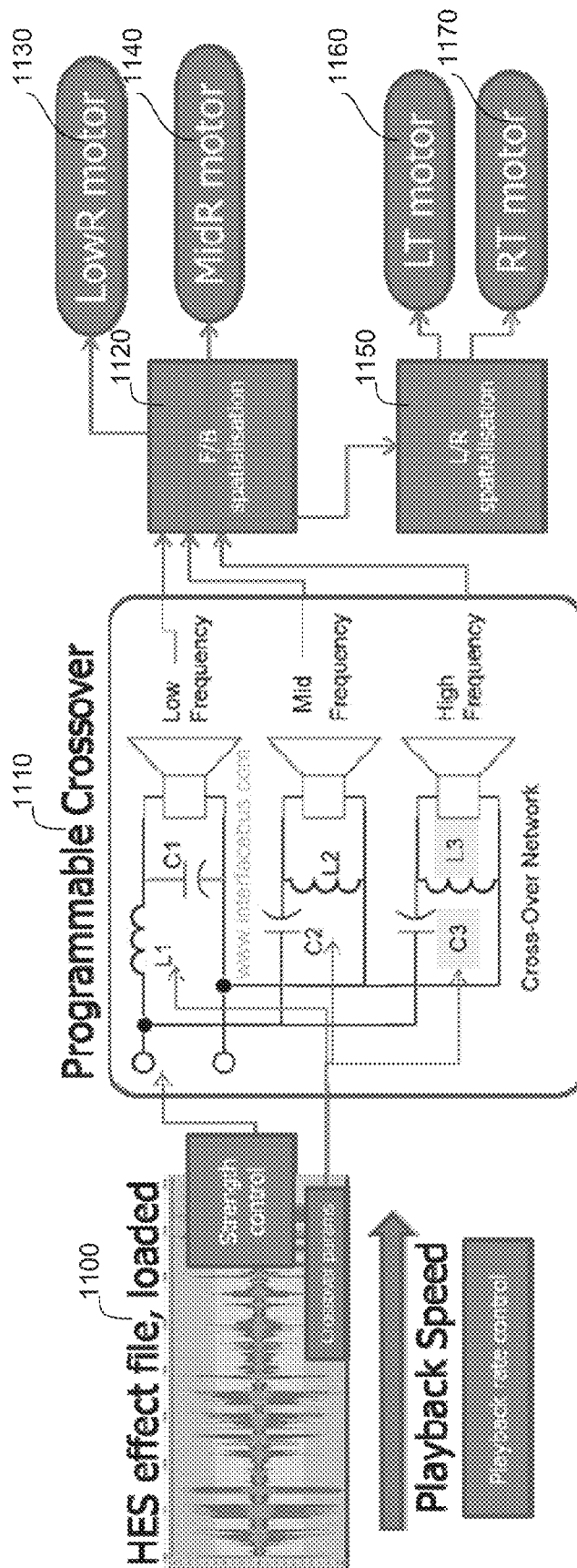


Fig. 11

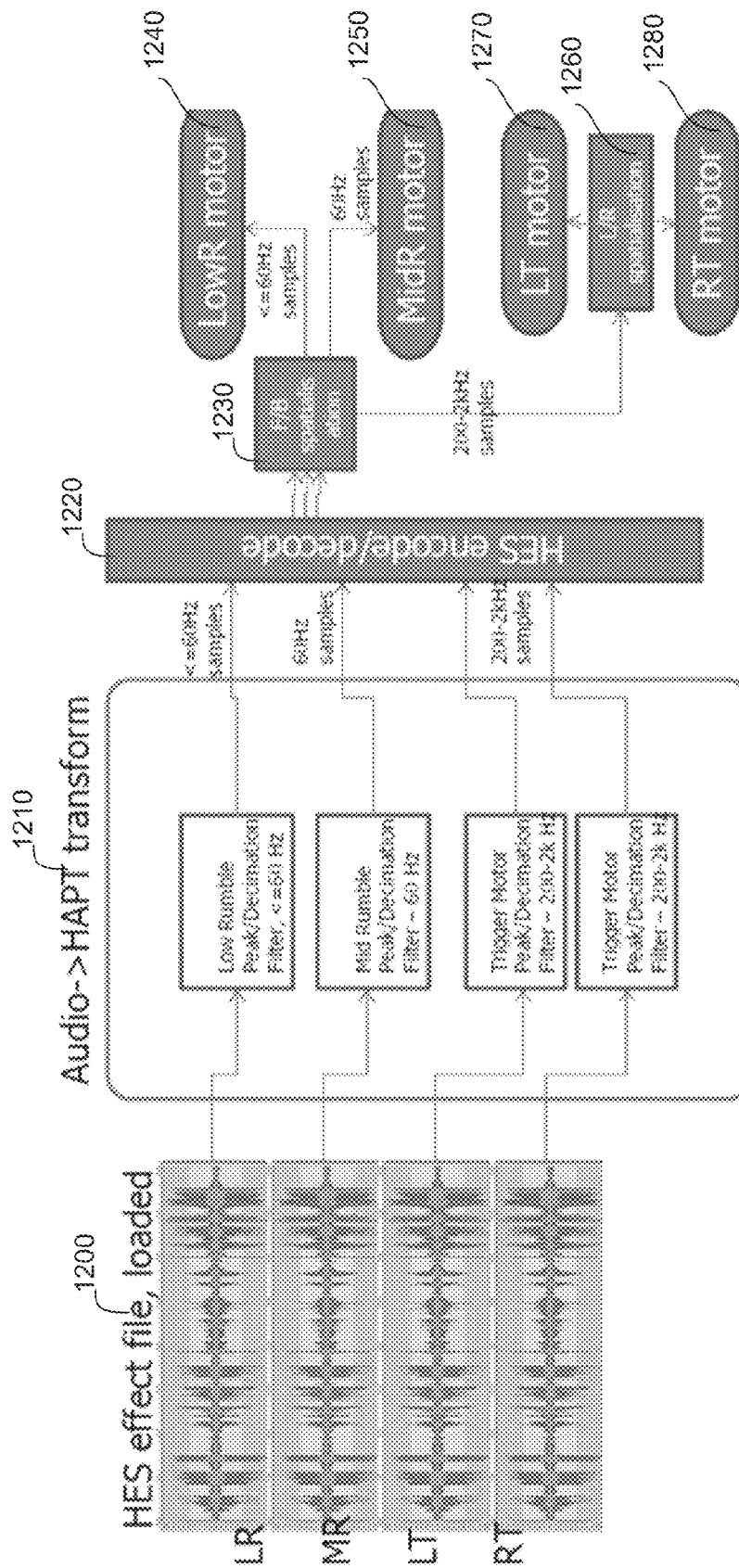


Fig. 12

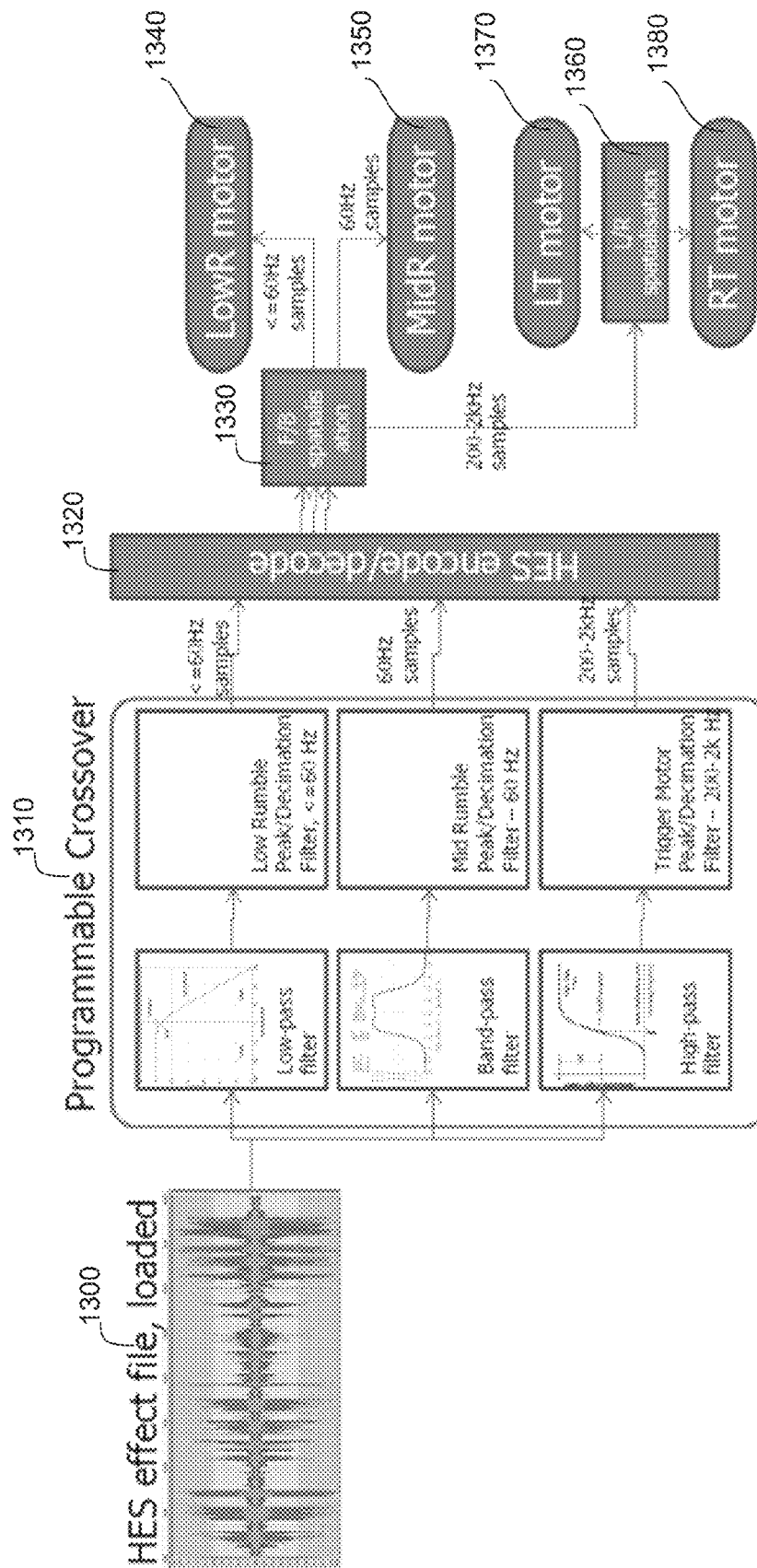


Fig. 13

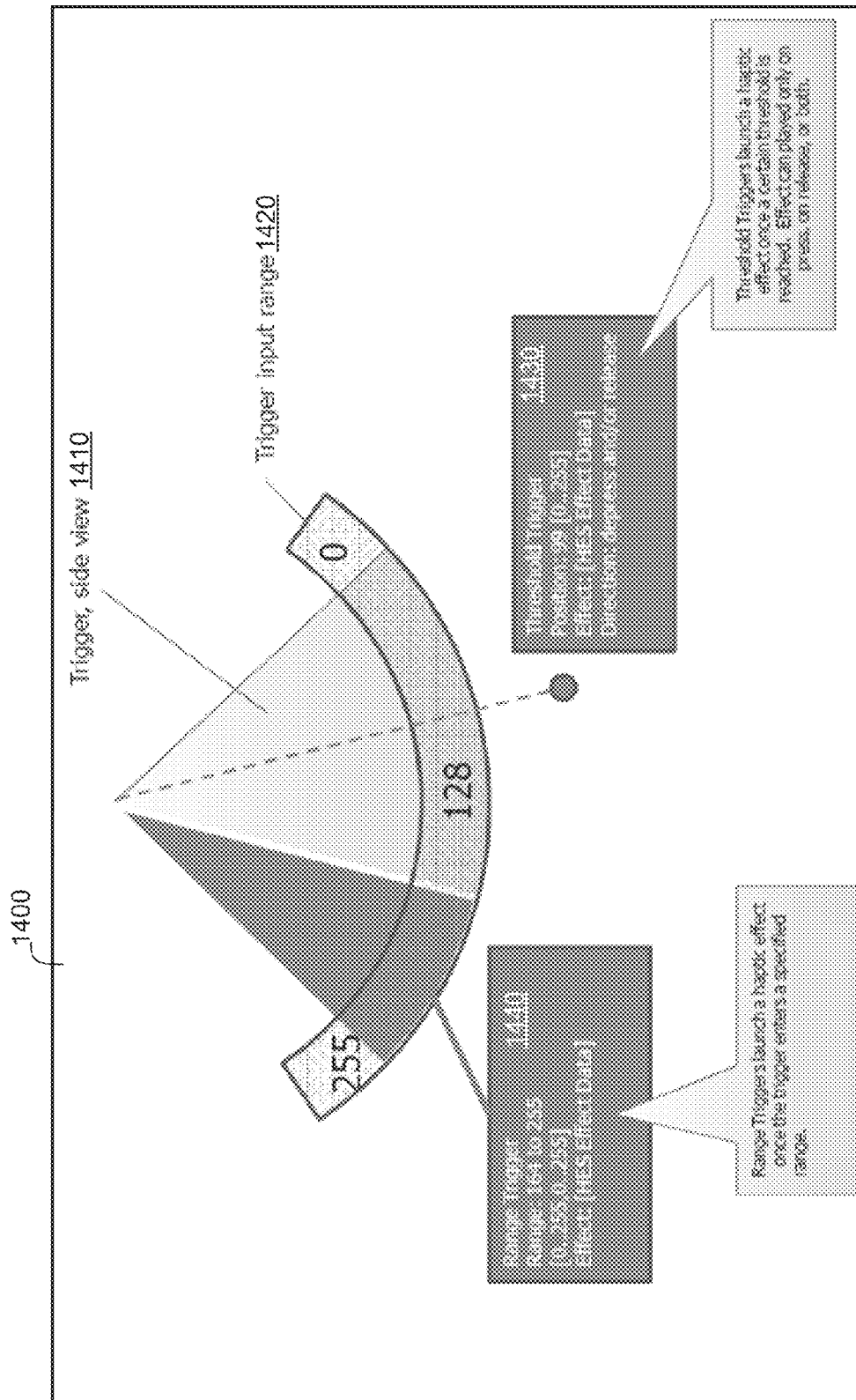


Fig. 14

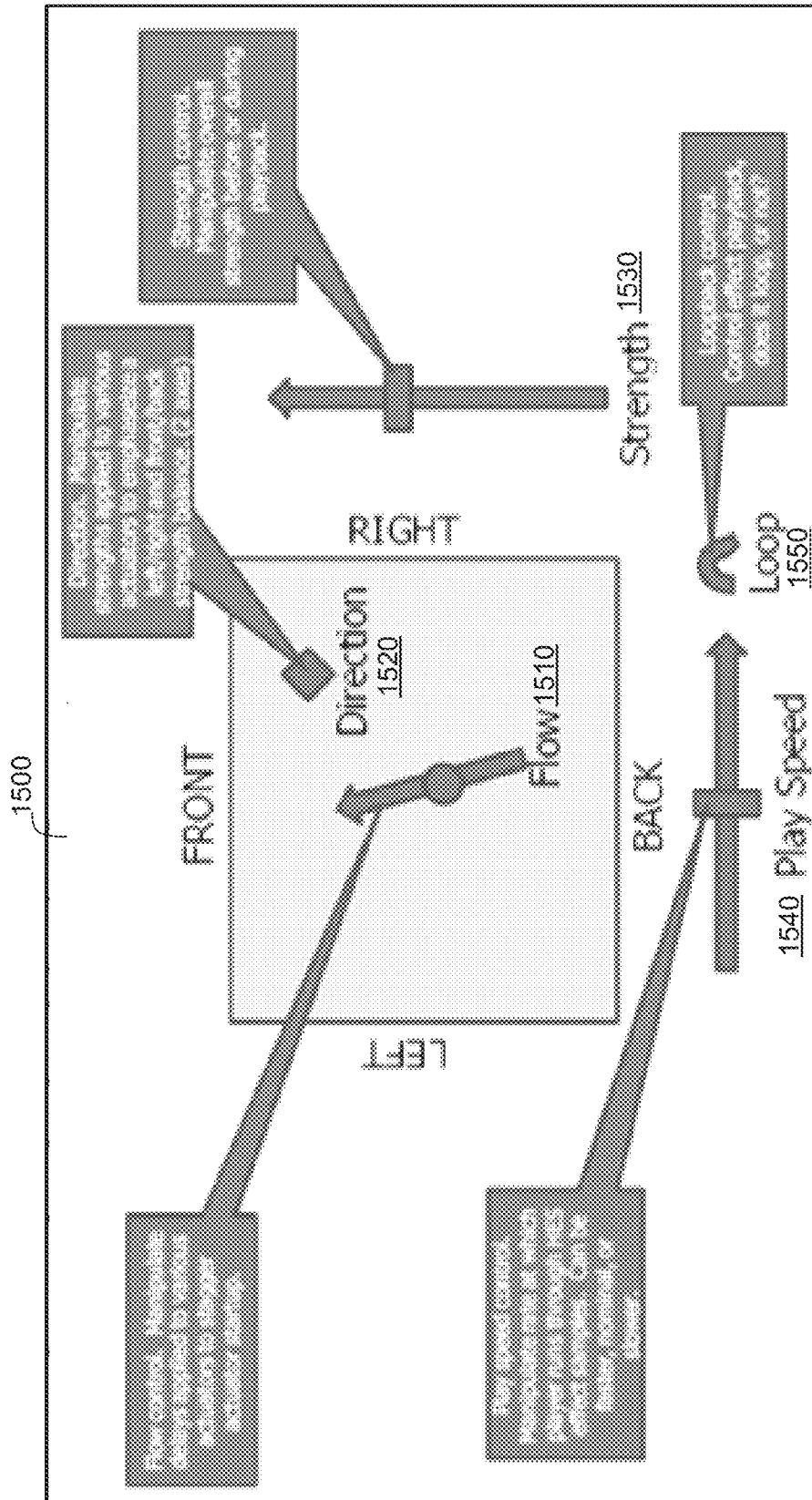


Fig. 15

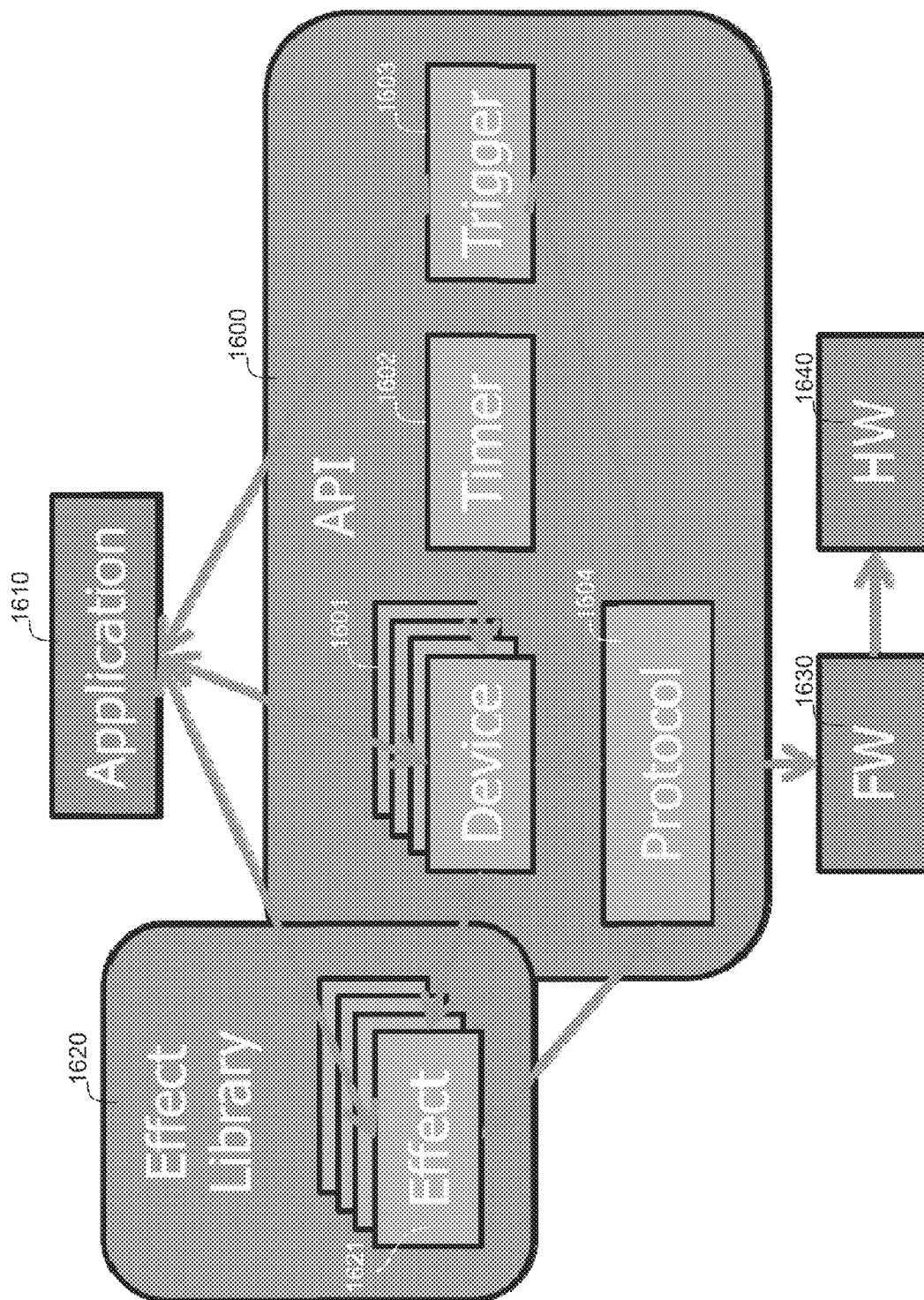


Fig. 16

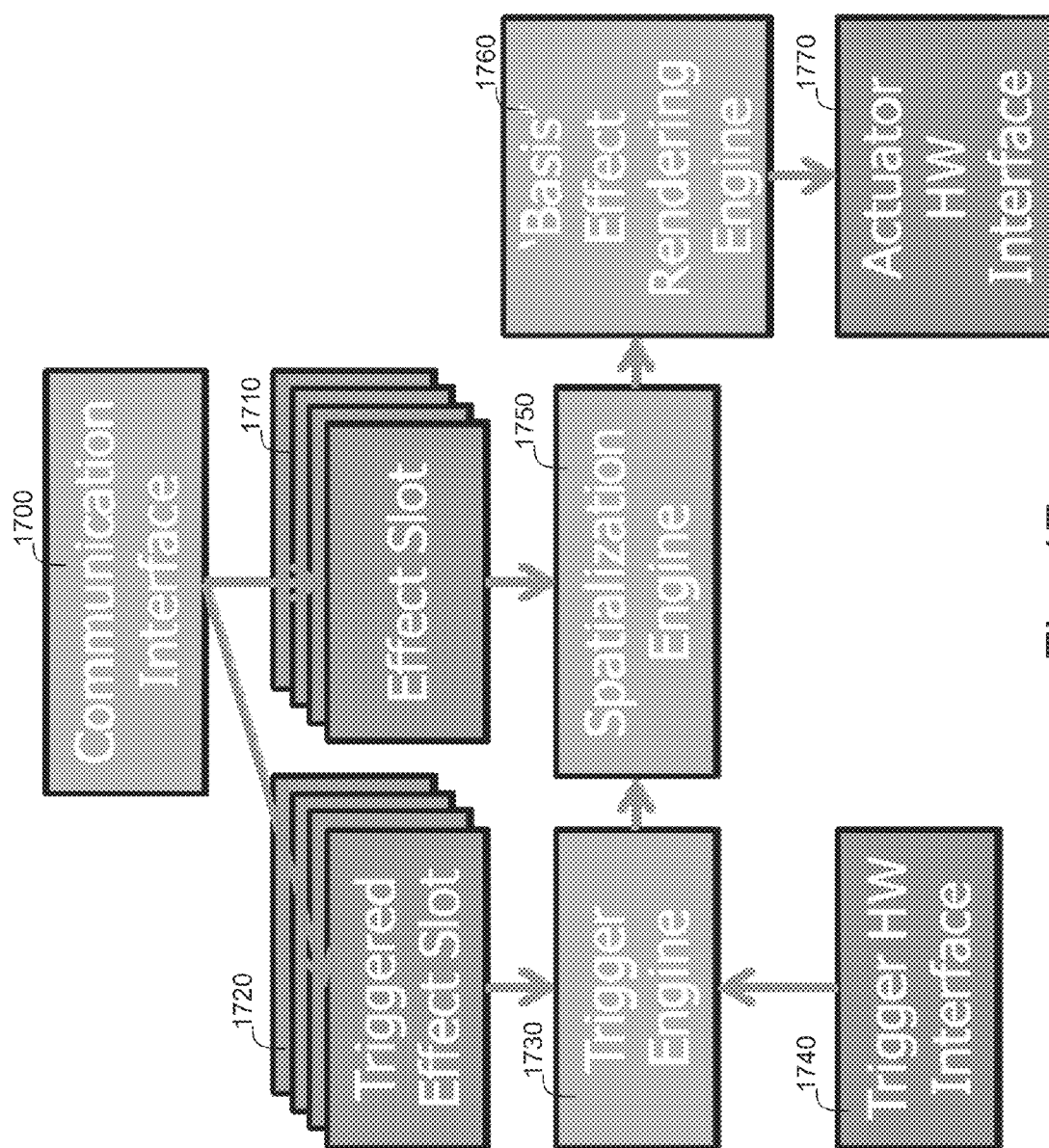


Fig. 17

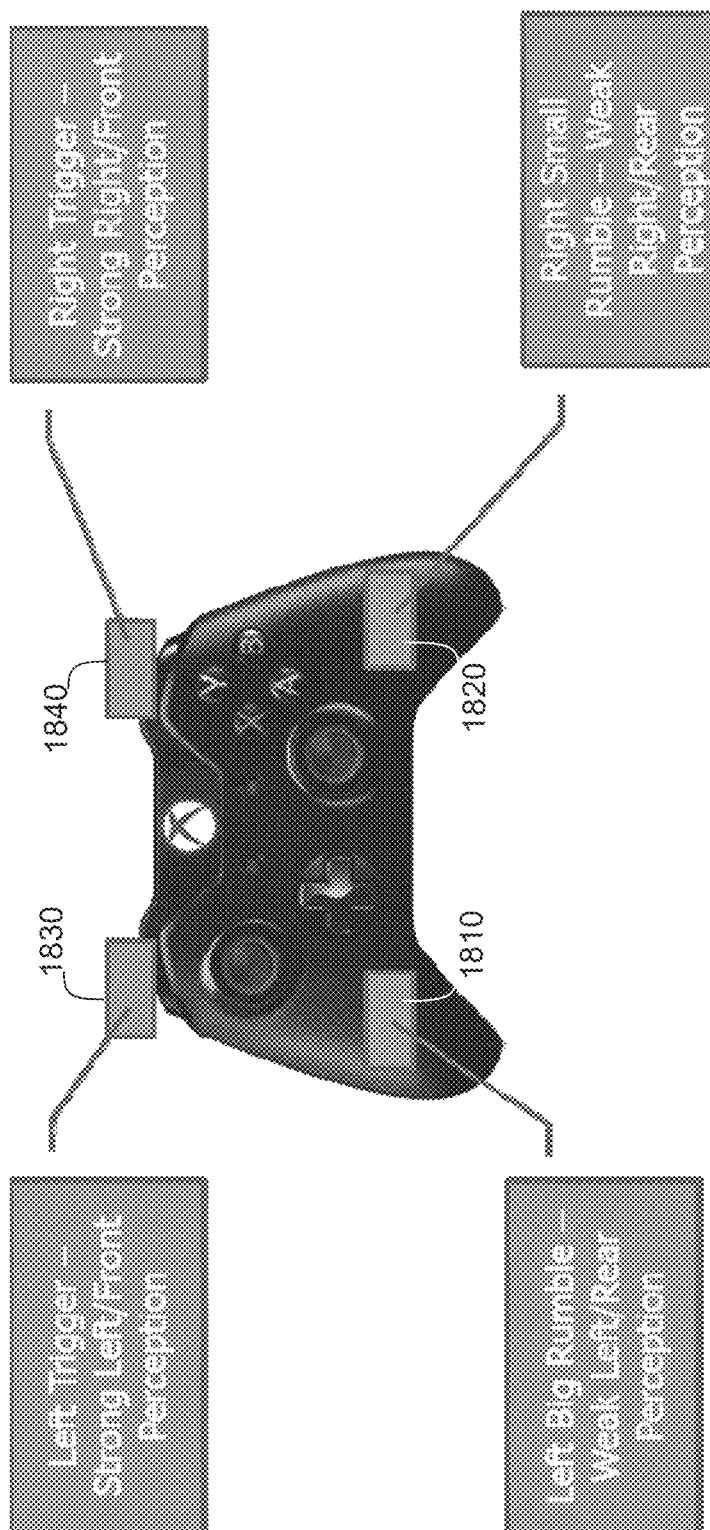


Fig. 18

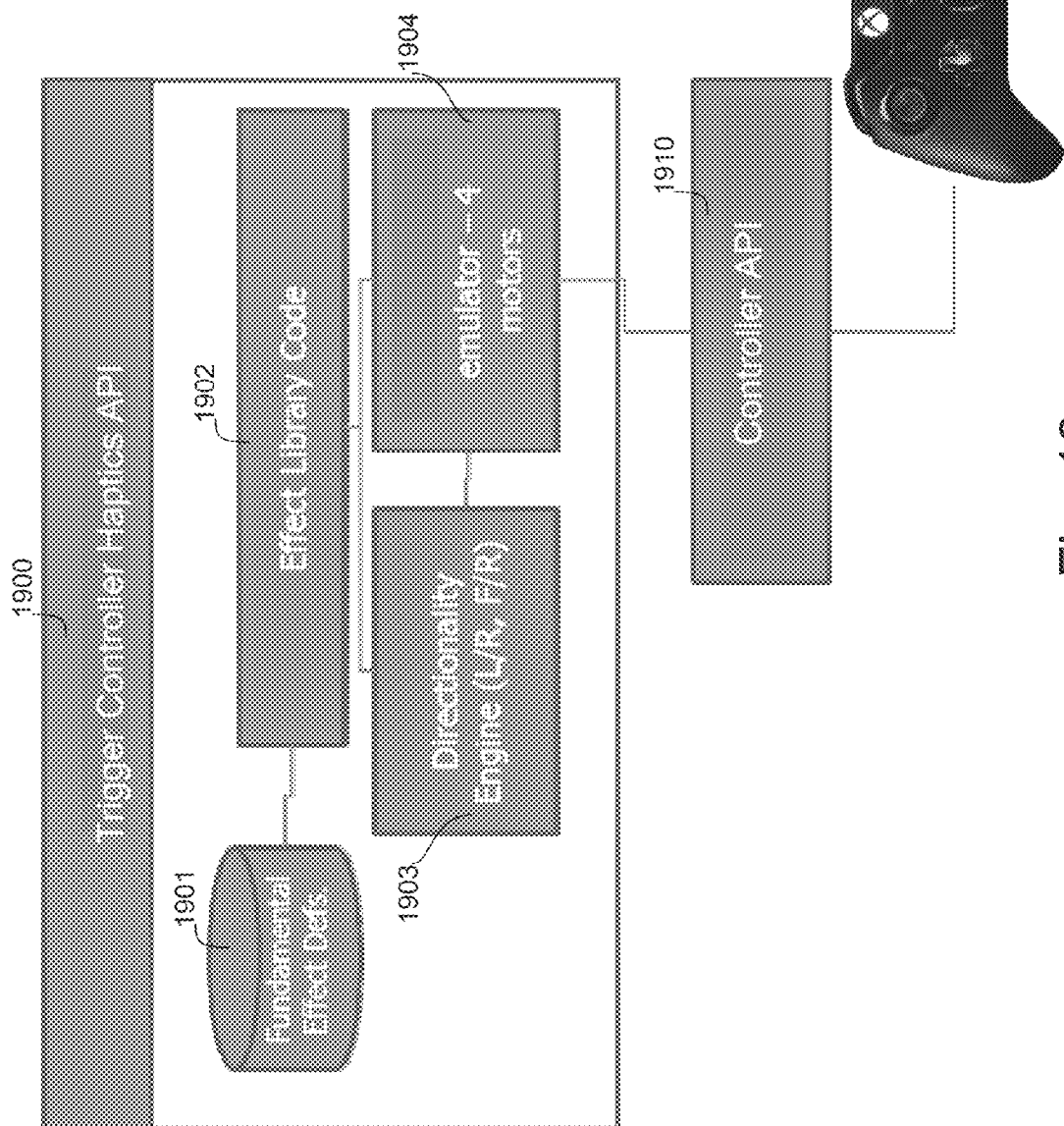


Fig. 19

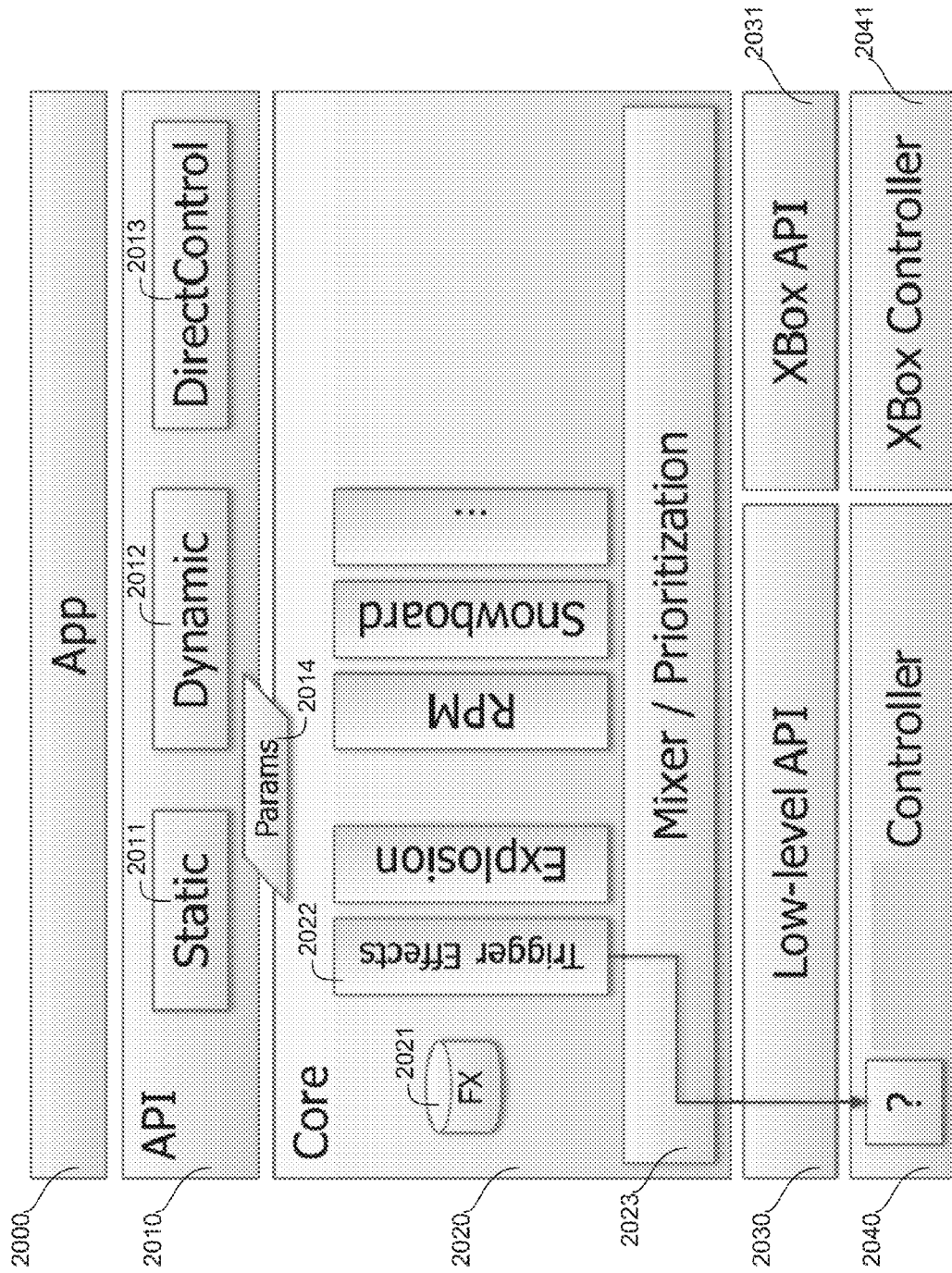


Fig. 20

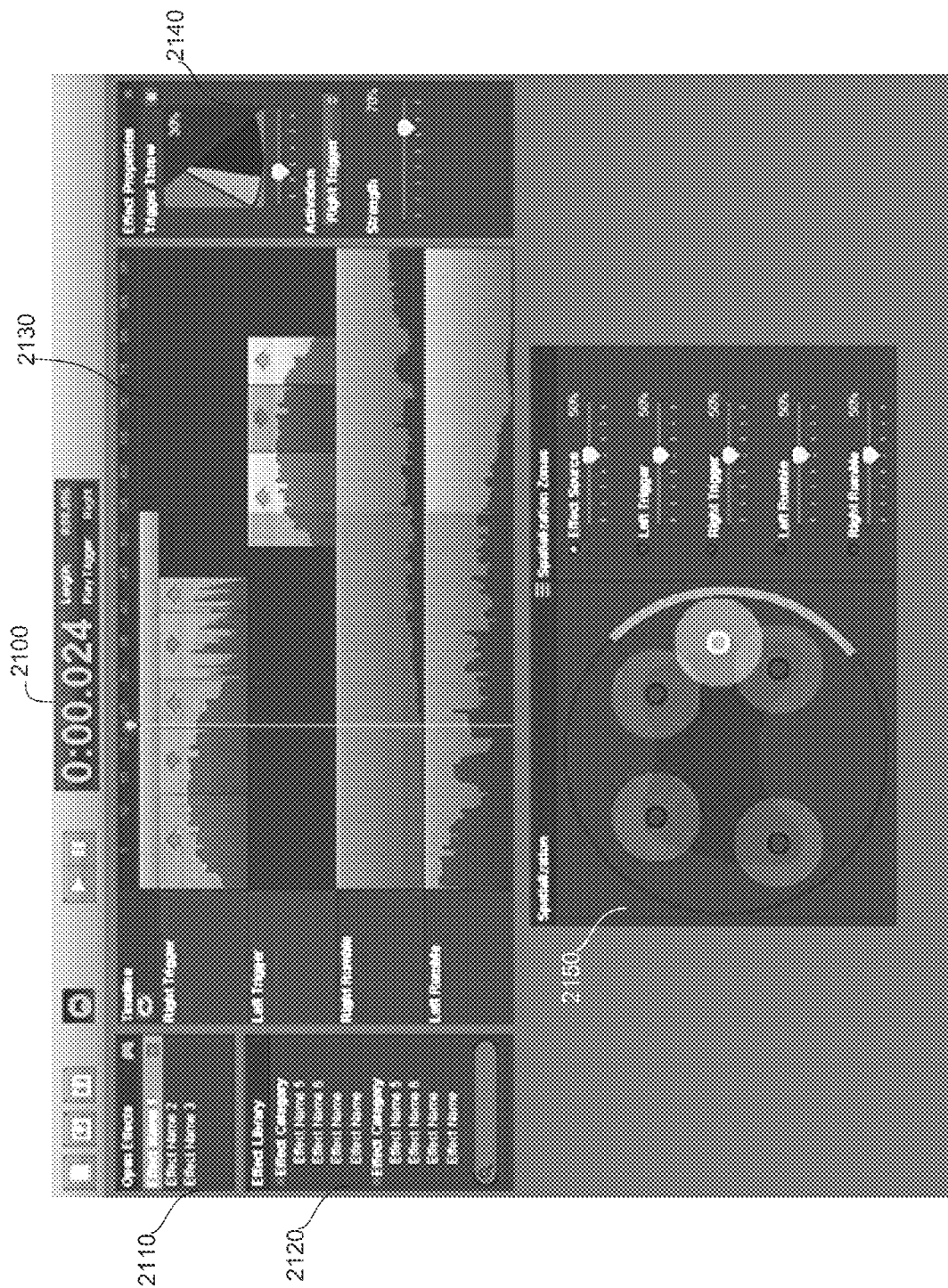


Fig. 21

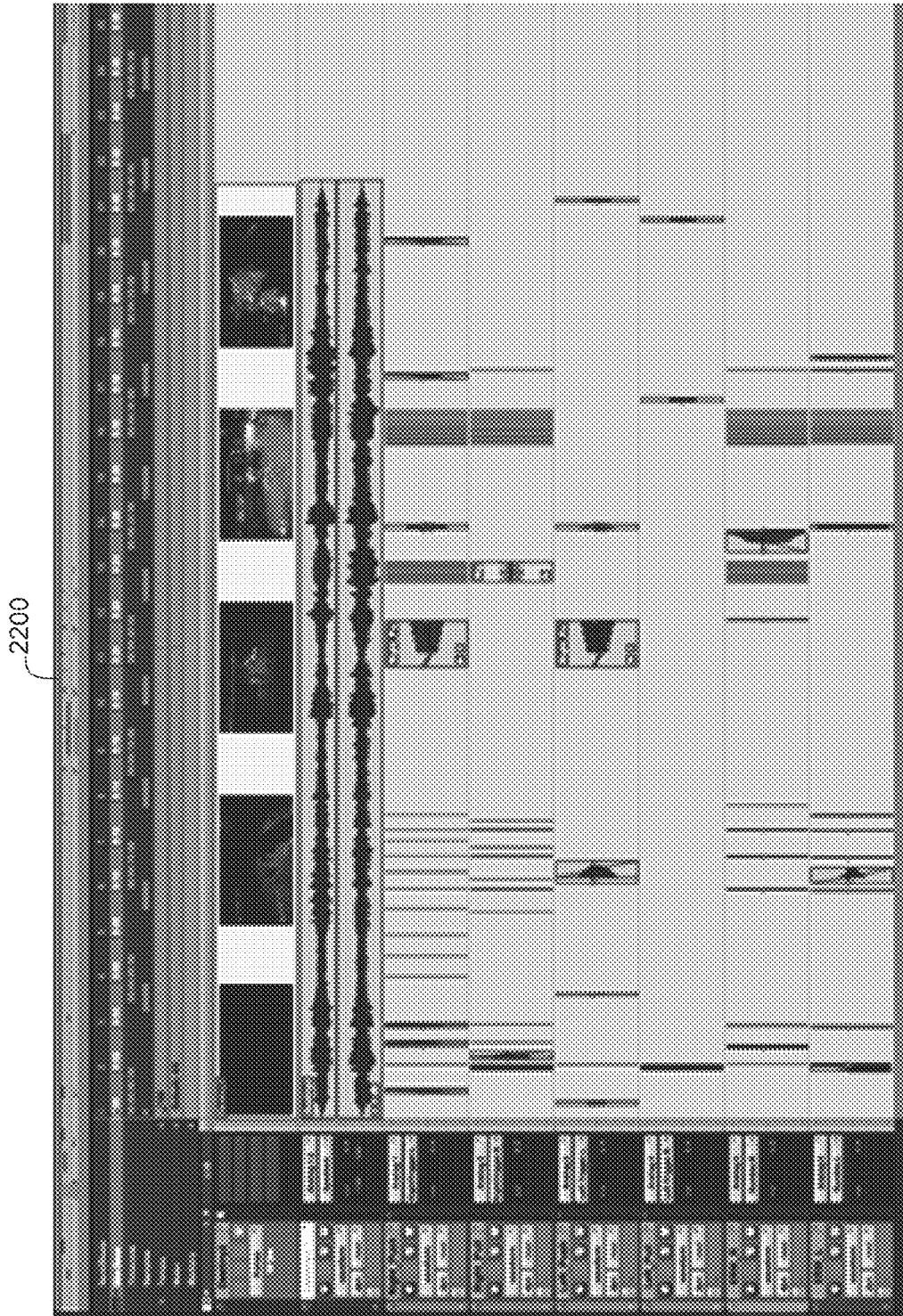


Fig. 22

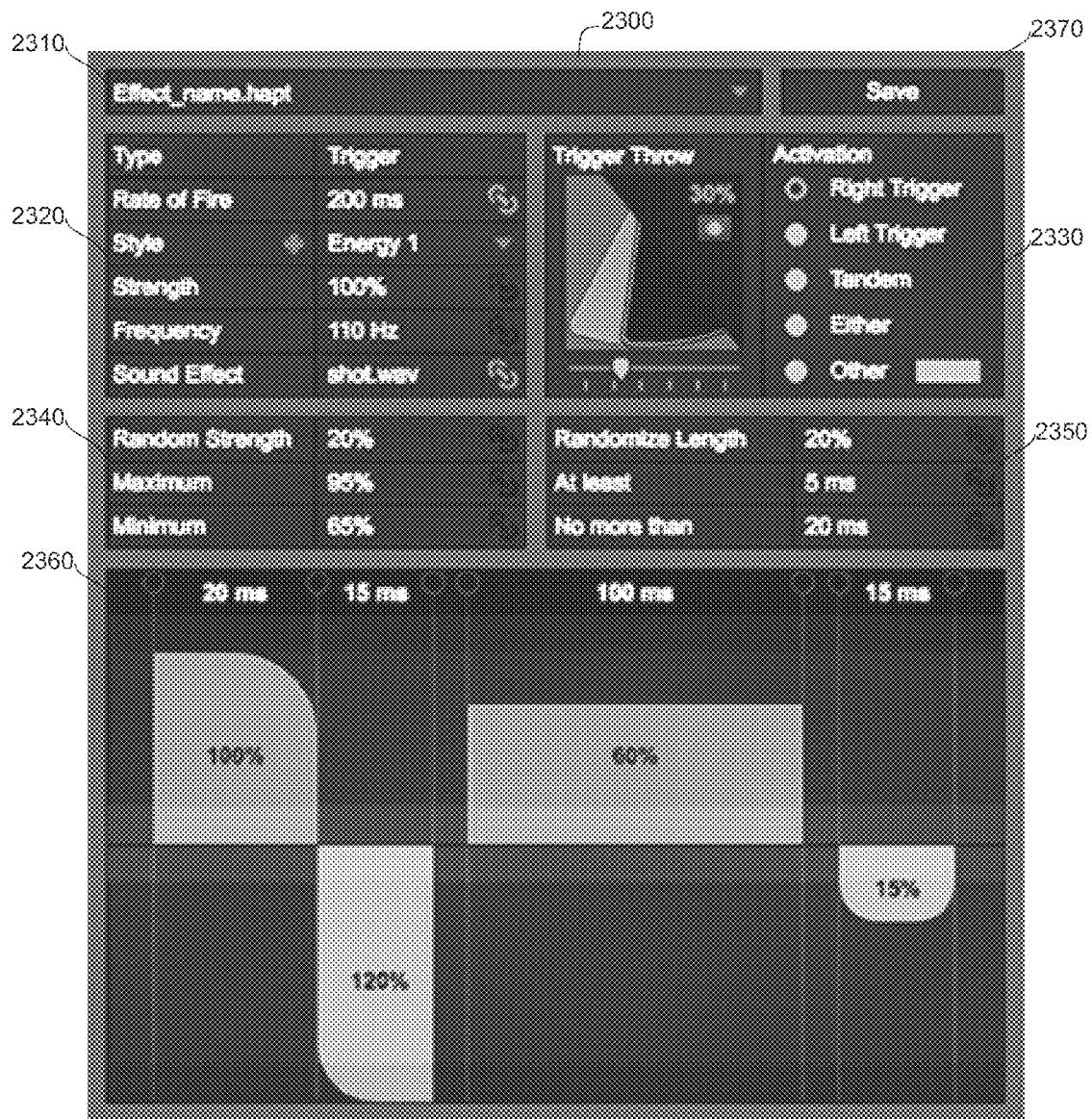


Fig. 23

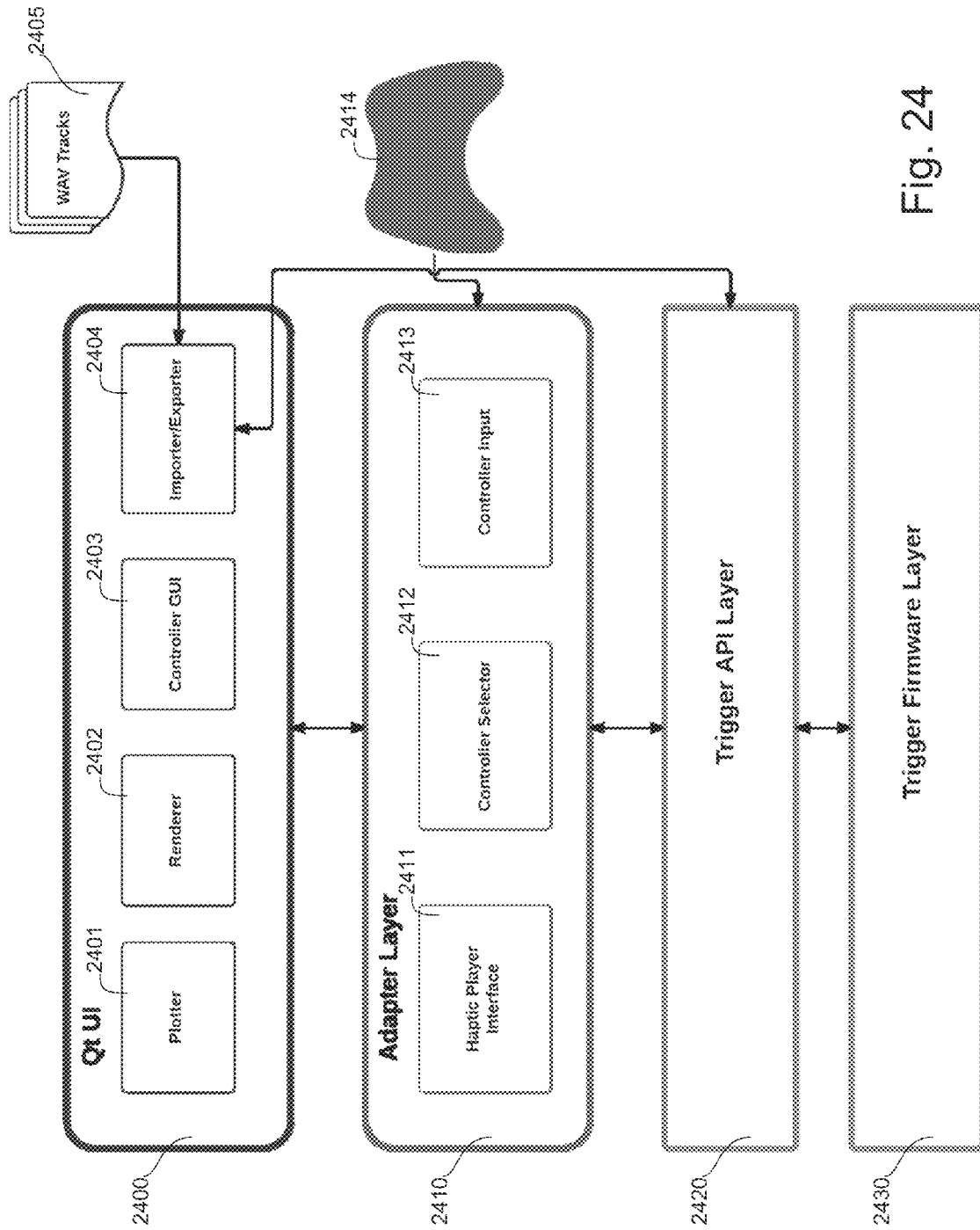


Fig. 24

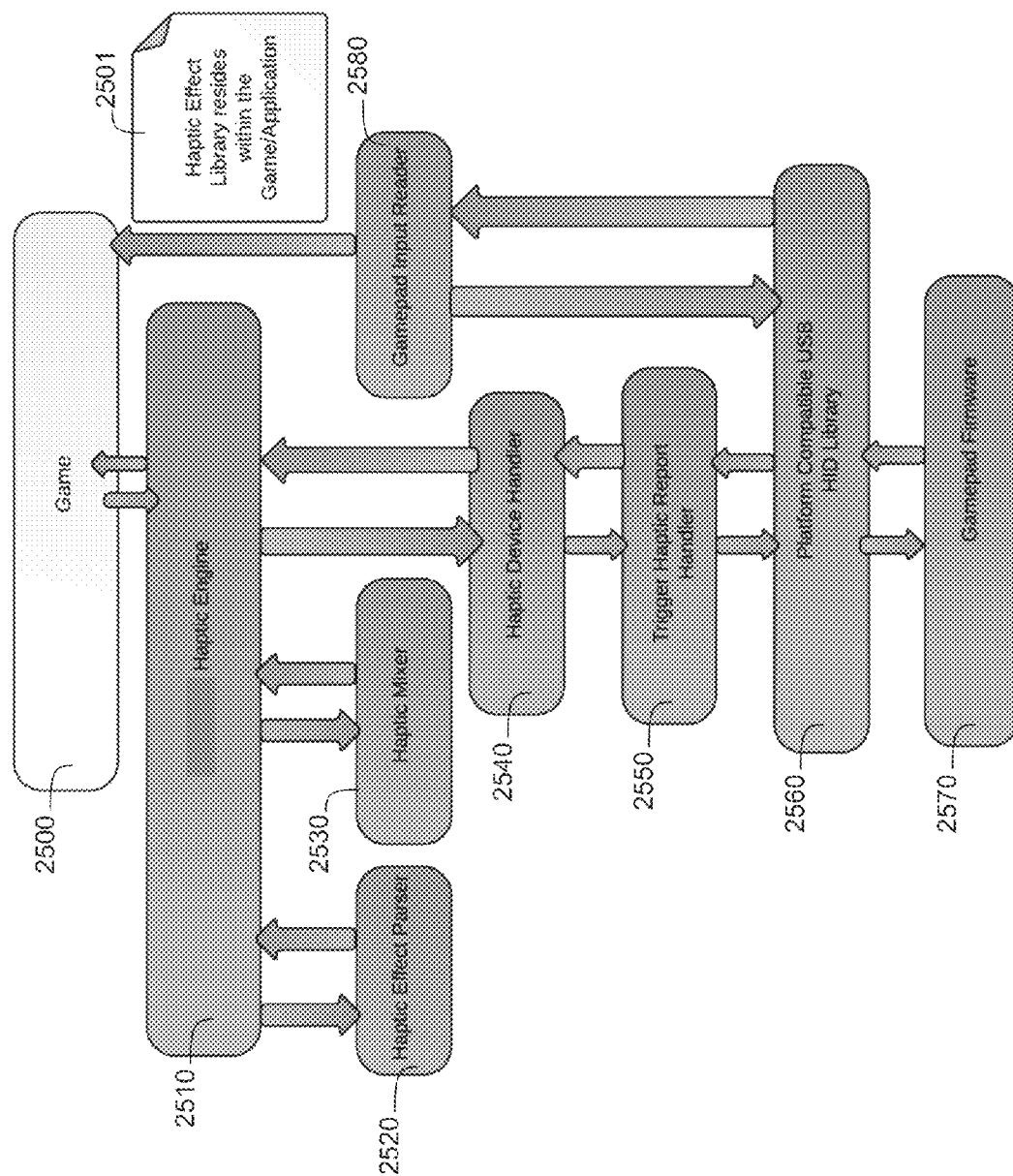


Fig. 25

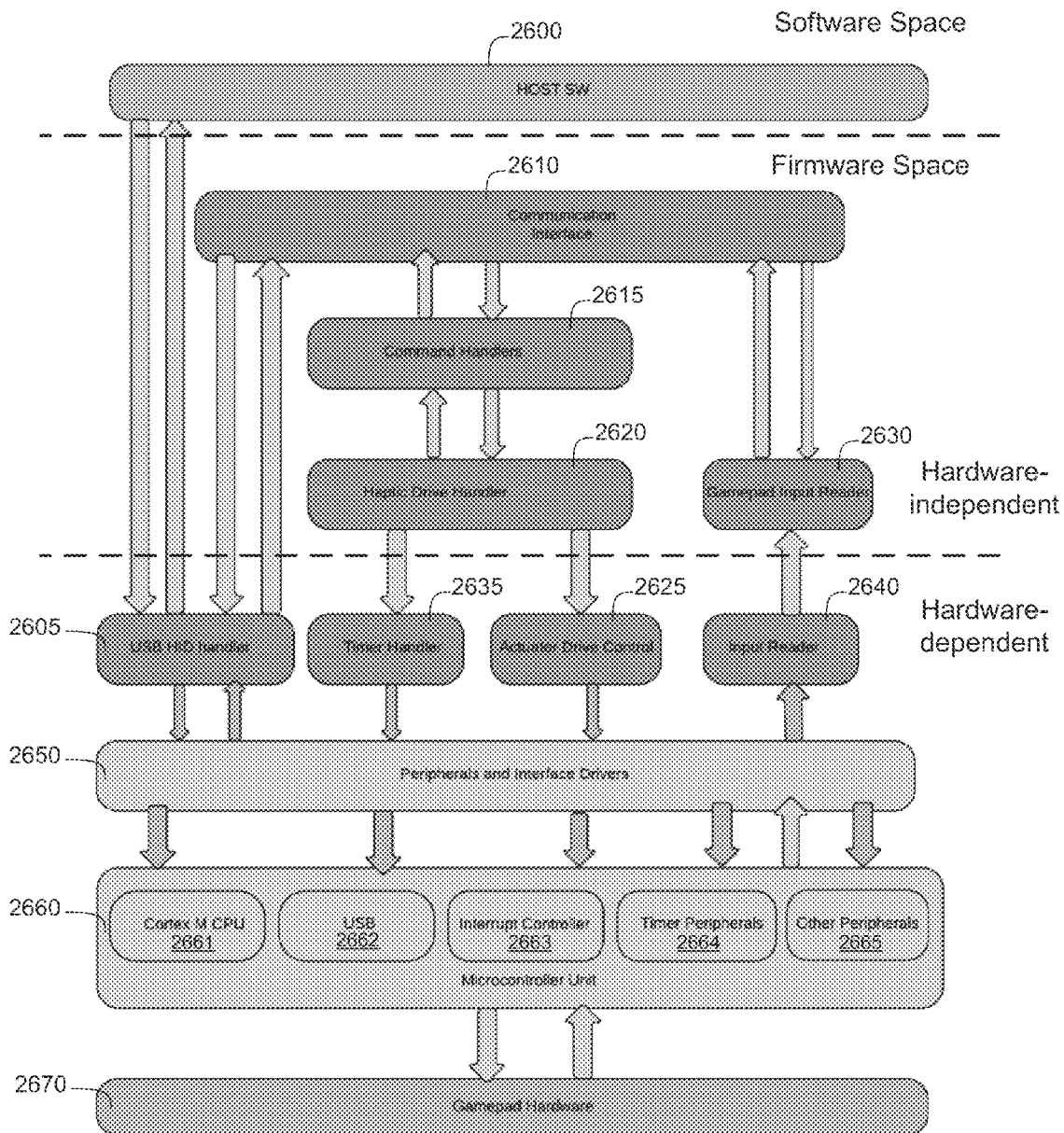


Fig. 26

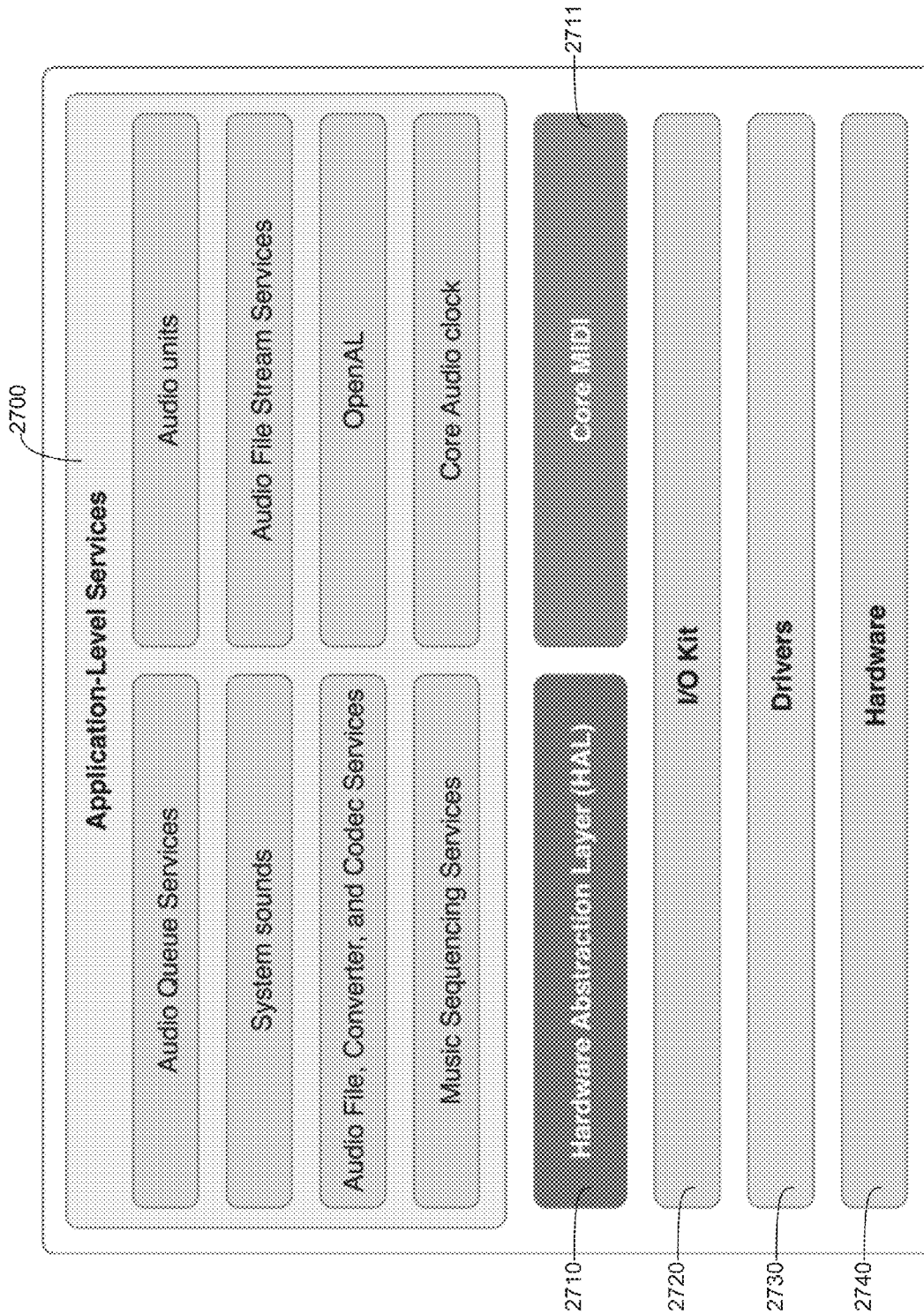


Fig. 27

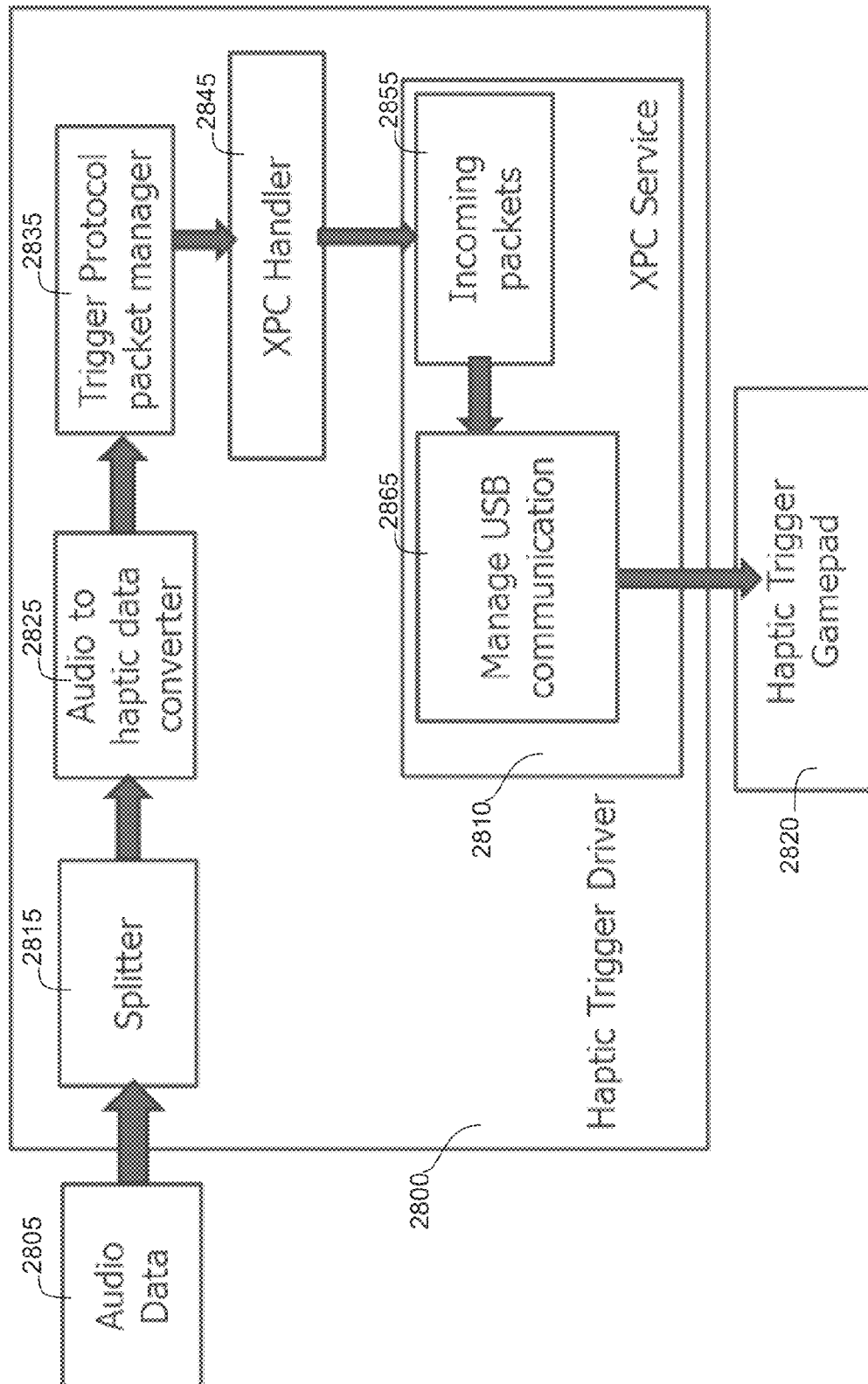


Fig. 28

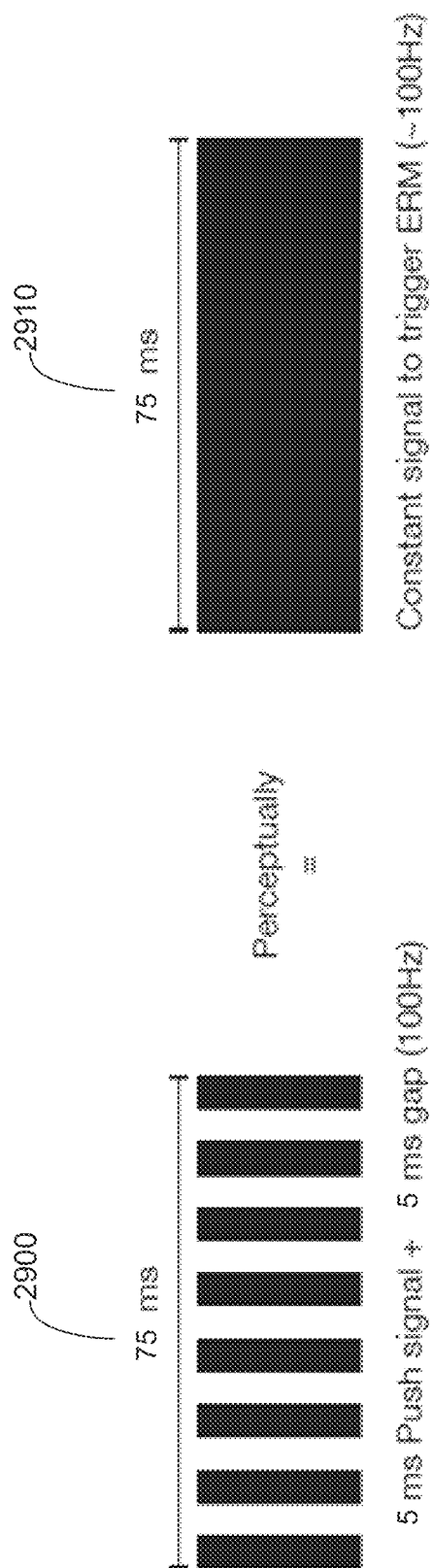


Fig. 29



Fig. 30

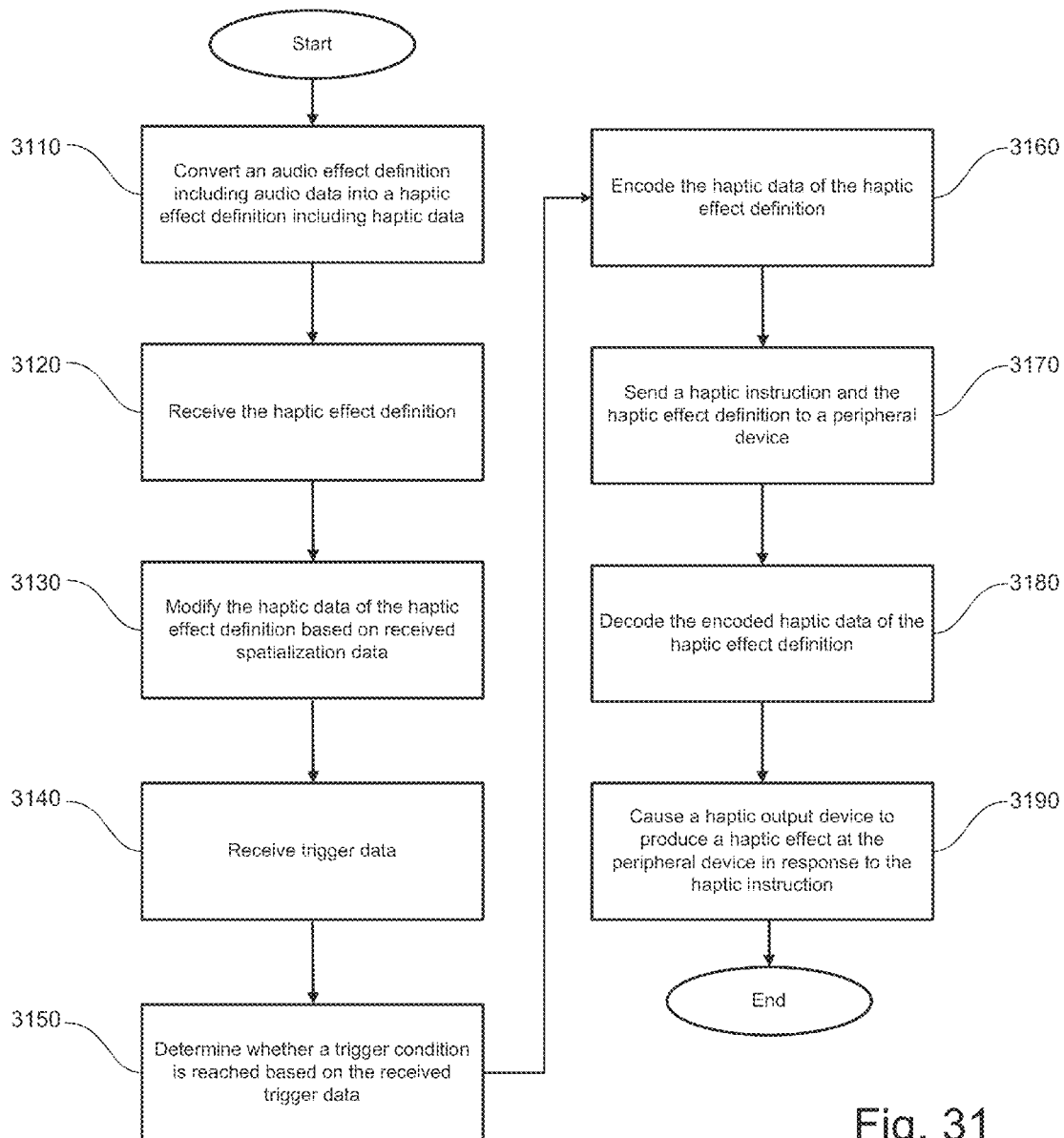


Fig. 31

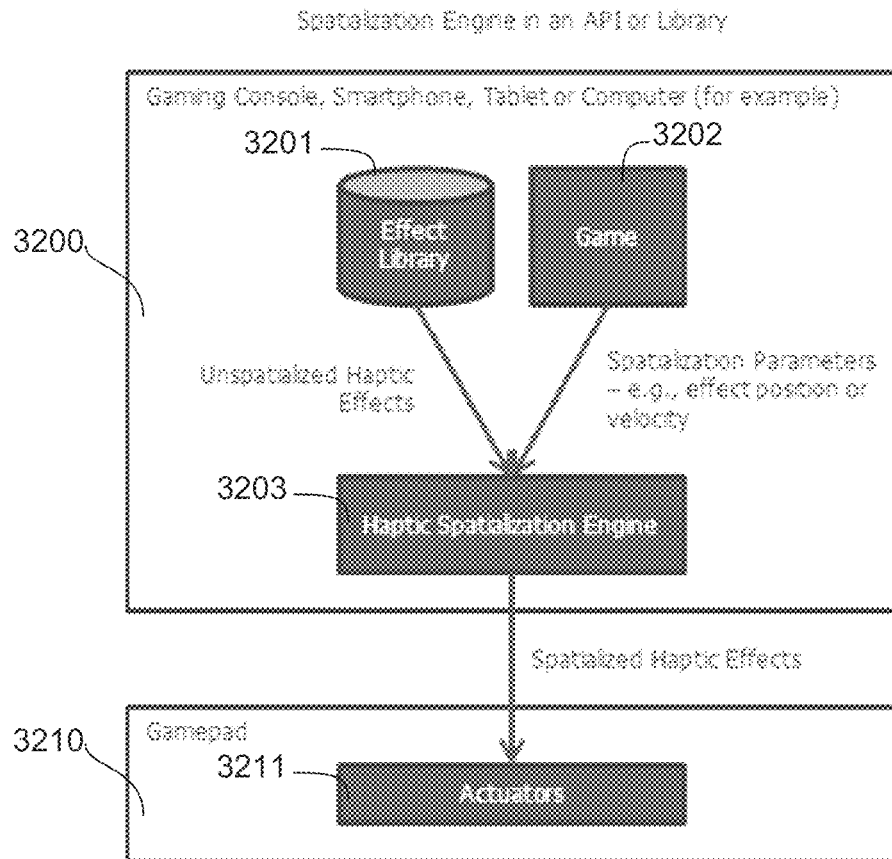


Fig. 32

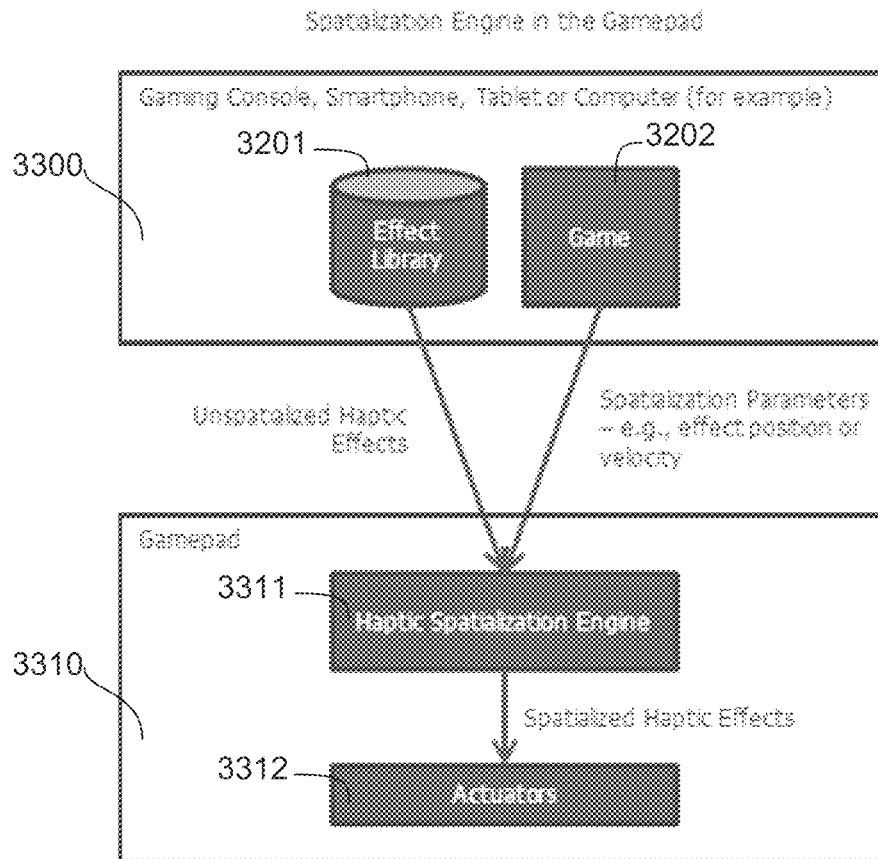


Fig. 33

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HAPTIC TRIGGER CONTROL SYSTEM**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application claims priority of U.S. Provisional Patent Application Ser. No. 61/904,342, filed on Nov. 14, 2013, the disclosure of which is hereby incorporated by reference.

FIELD

One embodiment is directed generally to a device, and more particularly, to a device that produces 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 (such as active and resistive force feedback) and/or tactile feedback (such as vibration, texture, and heat) is also provided to the user, more generally known collectively as “haptic feedback” or “haptic effects.” Haptic feedback can provide cues that enhance and simplify a user’s interaction with a video game controller, or other electronic device. Specifically, vibration effects, or vibrotactile haptic effects, may be useful in providing 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, such as medical devices, automotive controls, remote controls, and other similar devices where a user interacts with a user input element to cause an action, also benefit from haptic feedback or haptic effects. For example, and not by way of limitation, user input elements on medical devices may be operated by a user outside the body of a patient at a proximal portion of a medical device to cause an action within the patient’s body at a distal end of the medical device. Haptic feedback or haptic effects may be employed to alert the user to specific events, or provide realistic feedback to the user regarding an interaction of the medical device with the patient at the distal end of the medical device.

SUMMARY

One embodiment is a system that controls a haptic effect experienced at a peripheral device. The system receives a haptic effect definition including haptic data. The system further receives trigger data including at least one of: a position of a trigger of a peripheral device; or a range of the trigger of the peripheral device. The system further determines whether a trigger condition is reached based on the received trigger data. The system further sends a haptic instruction and the haptic effect definition to the peripheral device when the trigger condition is reached. The system further causes a haptic output device (or multiple haptic output devices) to produce haptic effects that are based on the haptic effect definition at the peripheral device in response to the haptic instruction.

BRIEF DESCRIPTION OF THE DRAWINGS

Further embodiments, details, advantages, and modifications will become apparent from the following detailed

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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 in accordance with one embodiment of the invention.

FIG. 2 illustrates a controller, according to an embodiment of the invention.

FIG. 3 illustrates another view of the controller of FIG. 2, according to an embodiment of the invention.

FIG. 4 illustrates a block diagram of a controller in conjunction with a host computer and display, according to an embodiment of the invention.

FIG. 5 illustrates a block diagram of a trigger haptic effect software stack for a system, according to an embodiment of the invention.

FIG. 6 illustrates an example user interface for designing a trigger haptic effect, according to an embodiment of the invention.

FIG. 7 illustrates a block diagram of components used to design a trigger haptic effect, according to an embodiment of the invention.

FIG. 8 illustrates a block diagram of components used to author a trigger haptic effect for direct playback, and a block diagram of components used to save the trigger haptic effect, according to an embodiment of the invention.

FIG. 9 illustrates a block diagram of components used to author a trigger haptic effect for crossover playback, and a block diagram of components used to save the trigger haptic effect, according to an embodiment of the invention.

FIG. 10 illustrates a block diagram of components used to directly play a trigger haptic effect, according to an embodiment of the invention.

FIG. 11 illustrates a block diagram of components used to play a trigger haptic effect using a programmable crossover, according to an embodiment of the invention.

FIG. 12 illustrates an example four-channel direct playback of a trigger haptic effect, according to an embodiment of the invention.

FIG. 13 illustrates an example crossover playback of a trigger haptic effect, according to an embodiment of the invention.

FIG. 14 illustrates an example user interface of a trigger engine, according to an embodiment of the invention.

FIG. 15 illustrates an example user interface of a spatialization engine, according to an embodiment of the invention.

FIG. 16 illustrates an architecture diagram of a trigger haptic effect application programming interface, according to an embodiment of the invention.

FIG. 17 illustrates an architecture diagram of firmware that produces trigger haptic effects, according to an embodiment of the invention.

FIG. 18 illustrates an example directionality model for a controller, according to an embodiment of the invention.

FIG. 19 illustrates a block diagram of a trigger haptic effect firmware stack, according to an embodiment of the invention.

FIG. 20 illustrates an architecture diagram of a system that provides trigger haptic effects experienced at a trigger of a controller, according to an embodiment of the invention.

FIG. 21 illustrates an example user interface for previewing and modifying a trigger haptic effect, according to an embodiment of the invention.

FIG. 22 illustrates an example user interface for converting an audio signal into a trigger haptic effect, according to an embodiment of the invention.

FIG. 23 illustrates an example user interface for creating a trigger haptic effect based on object parameters, according to an embodiment of the invention.

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FIG. 24 illustrates an architecture diagram of a system that previews trigger haptic effects, according to an embodiment of the invention.

FIG. 25 illustrates an architecture diagram of a system that produces trigger haptic effects, according to an embodiment of the invention.

FIG. 26 illustrates an architecture diagram of firmware that produces trigger haptic effects, according to an embodiment of the invention.

FIG. 27 illustrates an example audio architecture, according to an embodiment of the invention.

FIG. 28 illustrates an example audio driver that converts an audio effect into a trigger haptic effect, according to an embodiment of the invention.

FIG. 29 illustrates a generation of a trigger haptic effect in a first format that recreates a trigger haptic effect in a second format, according to an embodiment of the invention.

FIG. 30 illustrates another generation of a trigger haptic effect in a first format that recreates a trigger haptic effect in a second format, according to an embodiment of the invention.

FIG. 31 illustrates a flow diagram of the functionality of a haptic trigger control module, according to an embodiment of the invention.

FIG. 32 illustrates an example spatialization engine that resides in an API or library, according to an embodiment of the invention.

FIG. 33 illustrates an example spatialization engine that resides in a controller, according to an embodiment of the invention.

DETAILED DESCRIPTION

One embodiment is a system that provides haptic feedback that is experienced at a peripheral device, such as a game controller or gamepad. For example, the system can provide a trigger haptic effect that is experienced at a trigger of a controller, or some other peripheral device. The trigger haptic effect can complement rumble haptic effects that are also experienced at the controller, or other peripheral device. As another example, the system can provide a general haptic effect that is experienced at a user input element of the controller, gamepad, or other peripheral device. A wide variety of haptic feedback sensations can be created, such as detents, vibrations, textures, and stiffness. The haptic feedback sensations can complement a game application, or other software application, that can also be executed by the system. The haptic feedback sensations can be suited for a specific genre of game such as: first-person shooter; fantasy/roleplay; racing; or sports. In an alternate embodiment, a peripheral device, such as a game controller or gamepad, can have discrete isolated vibration regions on the handles of the peripheral device.

The system can first receive a haptic effect definition. The system can further receive trigger data, such as a position and/or range of a trigger, or positional information from the trigger, or some other user input element (e.g., joystick, etc.). Examples of such trigger data can include placing the trigger in a specific position, sweeping the trigger through a specific position, placing the trigger within a specific range, or sweeping the trigger through a specific range. The system can modify the haptic effect definition based on the received trigger data. The system can optionally further modify the haptic effect definition based on spatialization data, such as a direction and/or flow of a haptic effect that is based on the haptic effect definition. The system can then cause one or

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more motors or actuators of the controller, gamepad, or other peripheral device, to play, or otherwise output, haptic feedback based on the modified haptic effect definition, thus causing haptic feedback to be experienced. In other words, the system can cause the controller, gamepad, or other peripheral device, to playback a haptic effect based on the haptic effect definition. As understood by one of ordinary skill in the relevant art, “playback” is the act or instance of reproducing data (e.g., audio data, video data, or haptic data). Thus, in one example, the system can cause an overall trigger haptic effect to be experienced at a trigger of the controller.

In one embodiment, the system can include a number of haptic presets that can be selected, such as trigger haptic effect presets. The system can include a comprehensive library of haptic presets. Each selected haptic effect preset can be modified within a graphical user interface. The modified haptic effect preset can be compiled and executed within an execution of a game application, or other software application, where a controller, gamepad, or other peripheral device, can product a haptic effect, such as a trigger haptic effect.

In another embodiment, the system can include a manual content-driven toolset. The toolset allows a user to design haptic effect definitions alongside audio effect definitions. The system can then encode the haptic effect definitions into haptic files that can have an audio format, or that can be stored alongside audio files. A decoder that resides in a controller, gamepad, or other peripheral device, can subsequently decode the encoded haptic effect definitions. Further, the designed haptic effect definitions can be loaded into a trigger engine and/or a spatialization engine in order to launch haptic effects based on the designed haptic effect definitions. The trigger engine can allow haptic effect launches to be mapped to trigger movement or other trigger behavior, and the spatialization engine can move each haptic effect around to create the sensation of haptic effects originating from a specific direction. The trigger engine and/or the spatialization engine can be made available in an offline tool, where a user can graphically interact with the engines and feel the haptic playback within the controller, gamepad, or other peripheral device, in their hand, once the haptic effects are loaded into the engine.

In yet another embodiment, the system can include an automatic content-driven toolset. The toolset can automatically convert audio effect definitions into haptic effect definitions. The toolset can receive the audio effect definitions as audio files. The toolset can modify one or more parameters to control the conversion of the audio effect definition into a haptic effect definition. As an example, the one or more parameters can include: (a) an audio file parameter that identifies the audio file containing the audio effect definition to be converted; (b) a conversion control parameter that defines how the audio data of the audio effect definition gets divided into two or more distinct frequency bands, which are then applied to two or more distinct outputs (e.g., low rumble motor or actuator; middle rumble motor or actuator; and trigger motor or actuator); (c) a dynamic parameter that controls a magnitude mapping from an audio effect definition to a haptic effect definition, and can adjust a noise floor and dynamics range (either stretching or squashing the dynamics), as desired; and (d) a magnitude (or strength) parameter that controls an ultimate magnitude (or strength) of the haptic effect definition. In an alternate embodiment, rather than receiving an audio effect definition, the toolset can receive a haptic instruction that can be converted into a haptic effect definition. The haptic instruction can take the

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form of a gameplay parameter received by a gaming application, such as a rate of fire from a weapon within a game that can determine a duration of a haptic effect, a key frame in an animation within a game that can determine a start point and a stop point for the haptic effect, animation data for a directionality on an axis for the haptic effect, a damage amount for a weapon within the game that can determine a magnitude of the haptic effect, etc. Further, the converted haptic effect definition can be loaded into a trigger engine and/or a spatialization engine in order to launch haptic effects based on the designed haptic effect definition, as previously described. The trigger engine and/or the spatialization engine can be made available in an offline tool, as previously described.

In yet another embodiment, the system can include a haptic effect studio engine. A haptic effect studio can be provided to allow a user to define a haptic effect definition for a specific motor or actuator. The designed haptic effect definition can be loaded into a trigger engine and/or a spatialization engine in order to launch haptic effects based on the designed haptic effect definition, as previously described. The trigger engine and/or the spatialization engine can be made available in an offline tool, as previously described.

FIG. 1 illustrates a block diagram of a system 10 in accordance with one embodiment of the invention. In one embodiment, system 10 is part of a device (e.g., a personal computer or console, such as a video game console), and system 10 provides a haptic trigger control functionality for the device. In another embodiment, system 10 is separate from the device (e.g., personal computer or console), and remotely provides the aforementioned functionality for the device. Although shown as a single system, the functionality of system 10 can be implemented as a distributed system. System 10 includes a bus 12 or other communication mechanism for communicating information, and a processor 22 operably coupled to bus 12 for processing information. Processor 22 may be any type of general or specific purpose processor. System 10 further includes a memory 14 for storing information and instructions to be executed by processor 22. Memory 14 can be comprised of any combination of random access memory ("RAM"), read only memory ("ROM"), static storage such as a magnetic or optical disk, or any other type of computer-readable medium.

A computer-readable medium may be any available medium that can be accessed by processor 22 and may include both a volatile and nonvolatile medium, a removable and non-removable medium, a communication medium, and a storage medium. A communication medium may include computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism, and may include any other form of an information delivery medium known in the art. A storage medium may include RAM, flash memory, ROM, erasable programmable read-only memory ("EPROM"), electrically erasable programmable read-only memory ("EEPROM"), registers, hard disk, a removable disk, a compact disk read-only memory ("CD-ROM"), or any other form of a storage medium known in the art.

In one embodiment, memory 14 stores software modules that provide functionality when executed by processor 22. The modules include an operating system 15 that provides operating system functionality for system 10, as well as the rest of an overall device in one embodiment. The modules further include a haptic trigger control module 16 that controls a haptic effect experienced at a trigger, or some

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other user input element. In certain embodiments, haptic trigger control module 16 can comprise a plurality of modules, where each module provides specific individual functionality for controlling a haptic effect experienced at a trigger, or some other user input element. System 10 will typically include one or more additional application modules 18 to include additional functionality, such as peripheral firmware which can provide control functionality for a peripheral device, such as a controller 30.

System 10, in embodiments that transmit and/or receive data from remote sources, further includes a communication device 20, such as a network interface card, to provide mobile wireless network communication, such as infrared, radio, Wi-Fi, or cellular network communication. In other embodiments, communication device 20 provides a wired network connection, such as an Ethernet connection or a modem.

System 10 is operably connected to controller 30. Controller 30 is a peripheral device used to provide input to system 10. Controller 30 can be operably connected to system 10 using either a wireless connection or a wired connection. Controller 30 can further include a local processor which can communicate with system 10 using either a wireless connection or a wired connection. Alternatively, controller 30 may be configured to not include a local processor, and all input signals and/or output signals associated with controller 30 can be handled and processed directly by processor 22 of system 10.

Controller 30 can 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 10. Controller 30 can 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 10. As is described below in greater detail, controller 30 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 30.

Controller 30 can also include one or more actuators, or other types of haptic output devices. The local processor of controller 30, or, processor 22 in embodiments where controller 30 does not include a local processor, may transmit a haptic signal associated with a haptic effect to at least one actuator of controller 30. 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 30. Alternatively, the haptic effects can be experienced at an outer surface of controller 30. The actuator includes an actuator drive circuit. The actuator may be, for example, an electric motor, an electro-magnetic actuator, a voice coil, a shape memory alloy, an electroactive polymer, a solenoid, an eccentric rotating mass motor ("ERM"), 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. 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, kinesthetic haptic effects, or deformation haptic effects, in response to a drive signal. In alternate embodi-

ments, the one or more actuators within controller **30** can be replaced by some other type of haptic output device.

Controller **30** can further include one or more speakers. The local processor of controller **30**, or, processor **22** in embodiments where controller **30** does not include a local processor, may transmit an audio signal to at least one speaker of controller **30**, 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 **30** can further include one or more sensors. A sensor can 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 can 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 **30** can send the converted signal to the local processor of controller **30**, or, processor **22** in embodiments where controller **30** does not include a local processor. The sensor can be any device, such as, but not limited to, an accelerometer, an electrocardiogram, an electroencephalogram, an electromyograph, an electrooculogram, an electropalatograph, a galvanic skin response sensor, a capacitive sensor, a hall effect sensor, an infrared sensor, an ultrasonic sensor, a pressure sensor, a fiber optic sensor, a flexion sensor (or bend sensor), a force-sensitive resistor, a load cell, a LuSense CPS² 155, a miniature pressure transducer, a piezo sensor, a strain gage, a hygrometer, a linear position touch sensor, a linear potentiometer (or slider), a linear variable differential transformer, a compass, an inclinometer, a magnetic tag (or radio frequency identification tag), a rotary encoder, a rotary potentiometer, a gyroscope, an on-off switch, a temperature sensor (such as a thermometer, thermocouple, resistance temperature detector, thermistor, or temperature-transducing integrated circuit), microphone, photometer, altimeter, bio monitor, camera, or a light-dependent resistor.

FIG. 2 illustrates a controller **100**, according to an embodiment of the invention. In one embodiment, controller **100** is identical to controller **30** of FIG. 1. Further, FIG. 3 illustrates another view of controller **100**. Controller **100** may be generally used with a gaming system that may be connected to a computer, mobile phone, television, or other similar device. Components of controller **100** illustrated in FIGS. 2 and 3 (i.e., housing **102**, analog or digital stick **110**, button **114**, trigger **118**, and rumble actuators **122** and **124**) are further described below in greater detail in conjunction with FIG. 4.

FIG. 4 illustrates a block diagram of controller **100** used in a gaming system **101** that further includes a host computer **104** and a display **106**. As shown in the block diagram of FIG. 4, controller **100** includes a local processor **108** which communicates with host computer **104** via a connection **105**. Connection **105** may be a wired connection, a wireless connection, or other types of connections known to those skilled in the art. Controller **100** may be alternatively configured to not include local processor **108**, whereby all input/output signals from controller **100** are handled and processed directly by host computer **104**. Host computer **104** is operably coupled to display screen **106**. In an embodi-

ment, host computer **104** is a gaming device console and display screen **106** is a monitor which is operably coupled to the gaming device console, as known in the art. In another embodiment, as known to those skilled in the art, host computer **104** and display screen **106** may be combined into a single device.

A housing **102** of controller **100** is shaped to easily accommodate two hands gripping the device, either by a left-handed user or a right-handed user. Those skilled in the art would recognize that controller **100** is merely an example embodiment of a controller of similar shape and size to many "gamepads" currently available for video game console systems, such as a Microsoft® Xbox One™ controller or a PlayStation® DualShock™ controller, and that controllers with other configurations of user input elements, shapes, and sizes may be used, including but not limited to controllers such as a Wii™ remote or Wii™ U Controller, Sony® SixAxis™ controller or Sony® Wand controller, as well as controllers shaped as real life objects (such as tennis rackets, golf clubs, baseball bats, and the like) and other shapes, or controllers with a display or head-mounted display.

Controller **100** includes several user input elements, including an analog or digital stick **110**, a button **114**, and a trigger **118**. As used herein, user input element refers to an interface device such as a trigger, button, analog or digital stick, or the like, which is manipulated by the user to interact with host computer **104**. As can be seen in FIGS. 2 and 3, and as known to those skilled in the art, more than one of each user input element and additional user input elements may be included on controller **100**. Accordingly, the present description of a trigger **118**, for example, does not limit controller **100** to a single trigger. Further, the block diagram of FIG. 4 shows only one (1) of each of analog or digital stick **110**, button **114**, and trigger **118**. However, those skilled in the art would understand that multiple analog or digital sticks, buttons, and triggers, as well as other user input elements, may be used, as described above.

As can be seen in the block diagram of FIG. 4, controller **100** includes a targeted actuator or motor to directly drive each of the user input elements thereof as well as one or more general or rumble actuators **122**, **124** operably coupled to housing **102** in a location where a hand of the user is generally located. More particularly, analog or digital stick **110** includes a targeted actuator or motor **112** operably coupled thereto, button **114** includes a targeted actuator or motor **116** operably coupled thereto, and trigger **118** includes a targeted actuator or motor **120** operably coupled thereto. In addition to a plurality of targeted actuators, controller **100** includes a position sensor operably coupled to each of the user input elements thereof. More particularly, analog or digital stick **110** includes a position sensor **111** operably coupled thereto, button **114** includes a position sensor **115** operably coupled thereto, and trigger **118** includes a position sensor **119** operably coupled thereto. Local processor **108** is operably coupled to targeted actuators **112**, **116**, **120** as well as position sensors **111**, **115**, **119** of analog or digital stick **110**, button **114**, and trigger **118**, respectively. In response to signals received from position sensors **111**, **115**, **119**, local processor **108** instructs targeted actuators **112**, **116**, **120** to provide directed or targeted kinesthetic effects directly to analog or digital stick **110**, button **114**, and trigger **118**, respectively. Such targeted kinesthetic effects are discernible or distinguishable from general or rumble haptic effects produced by general actuators **122**, **124** 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. Further details of a controller configured to produce haptics are described in greater detail in application Ser. No. 14/258,644, filed Apr. 22, 2014, entitled “GAMING DEVICE HAVING A HAPTIC-ENABLED TRIGGER,” herein incorporated by reference in its entirety.

FIG. 5 illustrates a block diagram of a trigger haptic effect software stack for a system, according to an embodiment of the invention. The trigger haptic effect software stack is implemented on a system, such as system 10 of FIG. 1. In the illustrated embodiment, the system includes the following components: device 500, peripheral firmware 510, and controller 520. Device 500 can be any type of computer device, such as a personal computer, tablet, smartphone, or console (e.g., video game console). Peripheral firmware 510 is firmware for one or more peripheral devices (e.g., controllers) that can be operably connected to device 500. Controller 520 is an example of a peripheral that is operably connected to device 500. Controller 520 can be a video game controller. In one embodiment, controller 520 can be identical to controller 30 of FIG. 1, and controller 100 of FIGS. 2, 3, and 4.

Device 500 includes game input management code 501. Game input management code 501 includes a set of computer-readable instructions that manage input provided by controller 520 in the context of a game application, or other type of application, executed within device 500. Device 500 further includes peripheral input application programming interface (“API”) 502. Peripheral input API 502 includes a set of computer-readable functions or routines that allow game input management code 501 to interact with peripheral firmware 510 in order to receive and manage input provided by controller 520. Device 500 further includes rumble API 503. Rumble API includes a set of computer-readable functions or routines that allow game input management code 501 to interact with peripheral firmware 510 in order to transmit rumble instructions to one or more rumble motors, or rumble actuators, of controller 520 (e.g., rumble motors L and R, as illustrated in FIG. 5). A rumble instruction can cause a rumble motor, or rumble actuator, of controller 520 to produce a general or rumble haptic effect.

Device 500 further includes trigger haptic effect API 504 (identified in FIG. 5 as “API”). Trigger haptic effect API 504 includes a set of computer-readable functions or routines that are exposed to game input management code 501, and that allow game input management code 501 to interact with peripheral firmware 510 in order to transmit haptic instructions to controller 520, such as trigger instructions to one or more triggers of controllers 520 (e.g., triggers L and R, as illustrated in FIG. 5). A haptic instruction can cause one or more targeted motors, or targeted actuators, of controller 520 to produce a haptic effect at one or more user input elements of controllers 520. A trigger instruction is a specific type of haptic instruction that can cause one or more targeted motors, or targeted actuators, of controller 520 (e.g., motors L and R, as illustrated in FIG. 5) to produce a trigger haptic effect at one or more triggers of controllers 520 (e.g., triggers L and R, as illustrated in FIG. 5). A trigger haptic effect is a specific type of haptic effect that is experienced at a trigger of a controller, such as controller 520. Trigger haptic effect API 504 can store one or more trigger 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 520. 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 include an amplitude parameter, a frequency parameter, a waveform parameter, an envelope parameter, a magnitude (or strength) parameter, and a duration parameter. A trigger haptic effect definition is a specific type of haptic effect definition that can be sent to one or more motors, or actuators, of controller 520 (e.g., motors L and R, as illustrated in FIG. 5) to produce a trigger haptic effect at one or more triggers of controllers 520 (e.g., triggers L and R, as illustrated in FIG. 5).

According to the embodiment, trigger haptic effect API 504 can allow game input management code 501 to interact with direct playback/crossover 505, trigger engine 506, and spatialization engine 507, and can further manage direct playback/crossover 505, trigger engine 506, and spatialization engine 507 according to requests invoked by game input management code 501. Further, trigger haptic effect API 504 can store data required for communication with peripheral firmware 510, and required for generation of one or more trigger haptic effects. In an alternate embodiment, trigger haptic effect API 504 can reside within peripheral firmware 510 rather than device 500. Trigger haptic effect API 504 is further described below in greater detail in conjunction with FIG. 16.

Device 500 further includes direct playback/crossover 505. Direct playback/crossover 505 receives haptic data as input, produces haptic data as output, and transmits haptic data to one or more targeted motors, or targeted actuators, of controller 520 (e.g., motors L and R, as illustrated in FIG. 5). In certain embodiments, direct playback/crossover 505 can 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 505 can 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 505 can optionally use a programmable crossover to convert the haptic data. By converting the haptic data, device 500 can “deconstruct” the haptic effect and playback the haptic effect at multiple actuators faithfully. In one embodiment, the format of the haptic data can be a Haptic Elementary Stream (“HES”) format. A HES format is a file or data format for representing haptic data that can 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. Thus, the haptic data can be stored in a haptic file or haptic stream, where a format of the haptic file or haptic stream is an HES format. In other words, the HES format can be used by the haptic file or haptic stream to represent the haptic data in a haptic format. In an alternate embodiment, direct playback/crossover 505 can reside within peripheral firmware 510 rather than device 500. Direct playback/crossover 505 is further described below in greater detail in conjunction with FIGS. 7, 8, 9, 10, 11, 12, and 13.

Device 500 further includes trigger engine 506. Trigger engine 506 can receive haptic data, such as a trigger haptic effect definition, and can modify the haptic data based on data, such as trigger data (e.g., trigger data 513 as illustrated in FIG. 5) received from controller 520. Trigger data is data that includes one or more parameters that indicate a position and/or range of one or more triggers of controller 520 (e.g., triggers L and R as illustrated in FIG. 5). Trigger engine 506

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can further transmit haptic instructions to controller **520**. For example, trigger engine **506** can transmit trigger instructions to one or more triggers of controller **520** (e.g., triggers L and R, as illustrated in FIG. 5). As previously described, a trigger instruction can cause one or more targeted motors, or targeted actuators, of controller **520** (e.g., motors L and R, as illustrated in FIG. 5) to produce a trigger haptic effect at one or more triggers of controllers **520** (e.g., triggers L and R, as illustrated in FIG. 5). Thus, in one embodiment, by modifying the haptic data of the trigger haptic effect definition, trigger engine **506** can cause a specific trigger haptic effect to be experienced at a trigger based on a position and/or range of the trigger. In another embodiment, by modifying the haptic data of the trigger haptic effect definition, trigger engine **506** can scale a trigger haptic effect for one or more targeted motors, or targeted actuators, of controller **520** (e.g., motors L and R, as illustrated in FIG. 5) based on a position and/or range of the trigger. Trigger engine **506** can further store one or more haptic effect definitions, such as trigger haptic effect definitions. In an alternate embodiment, trigger engine **506** can reside within peripheral firmware **510** rather than device **500**. Trigger engine **506** is further described below in greater detail in conjunction with FIG. 14.

Device **500** further includes spatialization engine **507** (identified in FIG. 5 as “spatialisation engine”). Spatialization engine **507** can receive haptic data, such as a trigger haptic effect definition, and can modify the haptic data based on spatialization data. Spatialization data can include data that indicates a desired direction and/or flow of a haptic effect, such as a trigger haptic effect. In certain embodiments, spatialization engine **507** can receive spatialization data that includes a direction and/or flow from game input management code **501**. Further, spatialization data can also include one or more positions of one or more hands of a user located on controller **520**. In certain embodiments, spatialization engine **507** can receive spatialization data that includes one or more hand positions from controller **520**. Further, in certain embodiments, spatialization engine **507** can receive spatialization data that includes a position of a user’s character within a game application as communicated by game input management code **501**.

According to the embodiment, spatialization engine **507** can 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 **520** (e.g., rumble motors L and R, as illustrated in FIG. 5), and that the haptic effect is also scaled for one or more targeted motors, or targeted actuators, of controller **520** (e.g., motors L and R, as illustrated in FIG. 5). In other words, spatialization engine **507** can 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 **507** may scale one or more portions of the haptic effect. For example, spatialization engine **507** 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 **507** 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 certain embodiments, spatialization engine **507** can modify the haptic data in real-time. Further, in certain

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embodiments, spatialization engine **507** can have non-linear relationships between inputs and motor, or actuator, outputs in order to exaggerate an overall trigger haptic effect. In an alternate embodiment, spatialization engine **507** can reside within peripheral firmware **510** rather than device **500**. Spatialization engine **507** is further described below in greater detail in conjunction with FIGS. 15, 32, and 33.

Device **500** further includes encoder **508**. Encoder **508** encodes haptic data received from direct playback/crossover **505**, trigger engine **506**, and/or spatialization engine **507** into a format. In one embodiment, the format can be an HES format. Encoder **508** further transmits the encoded haptic data to peripheral firmware **510**.

Peripheral firmware **510** includes decoder and crossover **511**. Decoder and crossover **511** receives the encoded haptic data from encoder **508** and decodes the encoded haptic data. In certain embodiments, decoder and crossover **511** computes a programmable crossover in order to decode the encoded haptic data. In some of these embodiments, decoder and crossover **511** computes the programmable crossover in real-time. Peripheral firmware **510** further includes trigger control **512**. Trigger control **512** is a low-level control API for one or more targeted motors, or targeted actuators, of controller **520** (e.g., motors L and R, as illustrated in FIG. 5). Trigger control **512** can receive a trigger instruction from device **500**, can convert the trigger instruction into a low-level trigger instruction for a specified targeted motor, or targeted actuator, of controller **520**, and can transmit the low-level trigger instruction to the specified targeted motor, or targeted actuator, of controller **520**. The low-level trigger instruction can cause the specified targeted motor, or targeted actuator, to produce a trigger haptic effect at a specified trigger of controller **520**.

Peripheral firmware **510** further includes trigger data **513**. Trigger data **513**, as previously described, is data that includes one or more parameters, such as one or more parameters that indicate a position and/or range of one or more triggers of controller **520** (e.g., triggers L and R as illustrated in FIG. 5). Trigger data **513** can be received from controller **520** by peripheral firmware **510**. Peripheral firmware **510** can further store trigger data **513**, and can further transmit trigger data **513** to device **500**. Peripheral firmware **510** further includes other gamepad functions **514**, which are functions of controller **520** that can be managed by peripheral firmware **510**. Such functions can include wired/wireless communications, input reporting, protocol implementation, power management, etc. Peripheral firmware **510** further includes rumble control **515**. Rumble control **515** is a low-level control API for one or more rumble motors, or rumble actuators, of controller **520** (e.g., rumble motors L and R, as illustrated in FIG. 5). Rumble control **515** can receive a rumble instruction from device **500**, can convert the rumble instruction into a low-level rumble instruction for a specified rumble motor, or rumble actuator, of controller **520**, and can transmit the low-level trigger instruction to the specified rumble motor, or rumble actuator, of controller **520**.

Controller **520** includes triggers L and R. Controller **520** further includes gear boxes L and R and motors L and R. Motor L and gearbox L are operably coupled to trigger L within controller **520**. Likewise, motor R and gearbox R are operably coupled to trigger R within controller **520**. When motor L receives a trigger instruction, motor L and gearbox L 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 collectively cause a trigger haptic effect to be experienced at trigger R. Accord-

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ing to the embodiment, peripheral firmware **510** sends trigger instructions to motors L and R of controller **520** using drive electronics **530**. Controller **520** further includes potentiometers L and R. Potentiometer L can detect a position and/or range of trigger L, and can further send the detected position and/or range of trigger L to peripheral firmware **510** as trigger data. Likewise, potentiometer R can detect a position and/or range of trigger R, and can further send the detected position and/or range of trigger R to peripheral firmware **510** as trigger data. In one embodiment, potentiometers L and R can each be replaced with another type of position sensor, such as a hall effect sensor. Controller **520** further includes 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 body of controller **520**. Likewise, when rumble motor R receives a rumble instruction, rumble motor R cause a haptic effect to be experienced along a right body of controller **520**. According to the embodiment, peripheral firmware **510** sends rumble instructions to rumble motors L and R of controller **520** using rumble drive electronics **530**.

In an alternate embodiment, one or more targeted motors, or targeted actuators, can be operably coupled to one or more user input elements (such as 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) of controller **520**. According to the alternate embodiment, peripheral firmware **510** can send instructions to the one or more targeted motors or targeted actuators, causing the one or more targeted motors or targeted actuators to produce haptic effects that are experienced at the one or more user input elements of controller **520**.

FIG. 6 illustrates an example user interface **600** for designing a trigger haptic effect, according to an embodiment of the invention. A system (such as system **10** of FIG. 1) can provide user interface **600** to a user as a dedicated tool for designing a trigger haptic effect. In this embodiment, a user can design a trigger haptic effect based on a pre-existing trigger haptic effect definition, with the option of modifying the pre-existing trigger haptic effect definition. According to the embodiment, user interface **600** includes effect presets **610**. Effect presets **610** can display one of more haptic effect presets, such as trigger haptic effect presets. A haptic effect preset is a pre-defined haptic effect definition of an arbitrary shape and/or form that produces a pre-defined haptic effect. A haptic effect preset can be stored within a haptic file or haptic stream. In one embodiment, a format of the haptic file or haptic stream can be an HES format. A trigger haptic effect preset is a specific type of haptic effect preset that produces a pre-defined trigger haptic effect. User interface **600** further includes edit area **620**. According to the embodiment, a user can select a haptic effect preset displayed within effect presets **610**, and edit area **620** can display a graphical representation of the haptic effect definition that is represented by the selected haptic effect preset. Further, a user can modify one or more parameters of the selected haptic effect definition by interacting with one or more display elements (such as buttons) within edit area **620**. By modifying one or more parameters of a haptic effect definition, one can modify one or more corresponding attributes of a corresponding haptic effect. Example parameters of a haptic effect definition that can be modified include an amplitude parameter, a frequency parameter, a waveform parameter, an envelope parameter, a magnitude (or strength) parameter, and a duration parameter.

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User interface **600** further includes effect definitions **630**. According to the embodiment, the user can save a modified haptic effect definition as a new haptic effect definition, where the new haptic effect definition is displayed within effect definitions **630**. The new haptic effect definition can be stored within a haptic file or haptic stream. In one embodiment, a format of the haptic file or haptic stream can be an HES format. The new haptic effect definition can further be exported to an external haptic file or external haptic stream. User interface **600** further includes a play button **640**. Interacting with play button **640** can cause the system to output a haptic effect at a controller that can be operably controlled to user interface **600**. If the haptic effect is a trigger haptic effect, the system can output the trigger haptic effect at a trigger of the controller. The haptic effect can be a selected pre-defined haptic effect definition or a selected new haptic effect definition.

User interface **600** further includes trigger engine area **650**. Trigger engine area **650** is an editable visual area that can visualize a trigger haptic effect that is generated by a trigger engine (such as trigger engine **506** of FIG. 5). As previously described, a trigger engine can receive a trigger haptic effect definition and can modify the trigger haptic effect definition based on a position and/or range of a trigger of a controller. Thus, trigger engine area **650** can display a visualization of the trigger, including an actual position of the trigger. Further, trigger engine area **650** can display a position and/or range of the trigger that is defined for a trigger haptic effect definition, where the position and/or range can cause the trigger engine to modify the trigger haptic effect definition. A user can edit the position and/or range of the trigger that is defined for the trigger haptic effect definition. User interface **600** further includes spatialization engine area **660**. Spatialization engine area **660** is an editable visual area that can visualize a trigger haptic effect that is originally generated by the trigger engine and further modified by a spatialization engine (such as spatialization engine **507** of FIG. 5). As previously described, the spatialization engine can modify the trigger haptic effect definition so that a trigger haptic effect is scaled for one or more targeted motors, targeted actuators, rumble motors, or rumble actuators, of a controller. Thus, spatialization engine area **660** can display a visualization of the controller. The spatialization engine area **660** can further display a visualization of the trigger haptic effect experienced at each targeted motor, targeted actuator, rumble motor, or rumble actuator of the controller. A user can edit a scaling of the trigger haptic effect that is experienced at each targeted motor, targeted actuator, rumble motor, or rumble actuator of the controller.

FIG. 7 illustrates a block diagram of components used to design a trigger haptic effect, according to an embodiment of the invention. In this embodiment, a system (such as system **10** of FIG. 1) can provide authoring component **700** as a dedicated tool for either: (1) authoring a trigger haptic effect (i.e., by authoring a haptic effect definition); or (2) authoring a trigger haptic effect as an audio effect (i.e., by authoring an audio effect definition). In one embodiment, authoring component **700** can be a "Pro Tools®" product by Avid Technology, Inc. The system can further use either single-port crossover audio stream input/output ("ASIO") driver **710** or four-port ASIO driver **720** to stream the haptic effect definition or audio effect definition. Single-port crossover driver **710** can stream the haptic effect definition or audio effect definition as a single channel of haptic data or audio data. In contrast, four-port ASIO driver **720** can stream the haptic effect definition or audio effect definition as four channels of haptic data or audio data. In an alternate embodiment,

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four-port ASIO driver **720** can be replaced by another driver that streams the haptic effect definition or audio effect definition as any plural number of channels of haptic data or audio data, such as six or eight channels of haptic data or audio data. In an embodiment where a user authors an audio effect definition, either single-port crossover ASIO driver **710** or four-port ASIO driver **720** can also convert the audio effect definition into a haptic effect definition. The system can further use HES encoder **730** to encode the audio effect definition or haptic effect definition into an external format, such as an HES format. If the system streams the audio effect definition or haptic effect definition as a single channel of haptic data or audio data using single-port crossover driver **710**, HES encoder **730** can apply a crossover input warp algorithm to separate the haptic data or audio data into three different bands that can be mapped to three different outputs (such as: (1) a low-frequency rumble motor, or rumble actuator; (2) a medium-frequency rumble motor, or rumble actuator; or (3) a high-frequency targeted motor, or targeted actuator).

The crossover input warp algorithm can reside either in the device itself, or reside on the opposite side of a communications link, executing on a processor different from that of the device. The crossover input warp algorithm may also separate the input data (haptic or audio) into two bands, where lower frequencies are separated and then optionally further transformed before being applied to one or more actuator outputs, and higher frequencies are separated and then optionally transformed before being applied to a number of actuators distinct from those used for the lower-frequency separated data. This type of data separation could occur on an arbitrary number of frequency bands and actuator outputs. In alternate embodiments, the input data (audio or haptic) can be separated into multiple overlapping frequency regions, which are then each optionally transformed and applied to a number of output actuators. Another set of embodiments could create a number of signal strength bands, where the input data (audio or haptic) is separated according to output power or strength (such as through peak detection, RMS calculations, etc.), and these separated data streams are each applied to one or more distinct sets of actuators. In alternate embodiments, the input data (audio or haptic) can be separated according to output power or strength (such as through peak detection, RMS calculations, etc.) into distinct but overlapping data streams, instead of completely distinct streams, where the strength filtering algorithms capture overlapping regions of strength, optionally apply the transformations and apply each of the outputs to a number of output actuators.

The system can further send the encoded audio effect definition or the encoded haptic effect definition to a human interface device (“HID”) interpreter **740** that resides on controller **750**. HID interpreter **740** receives and interprets the encoded audio effect definition or the encoded haptic effect definition in order to provide a trigger haptic effect at a trigger of controller **750**. In one embodiment, a system can further modify the encoded audio effect definition or the encoded haptic effect definition using a trigger engine (such as trigger engine **506** of FIG. **5**) and/or a spatialization engine (such as spatialization engine **507** of FIG. **5**) before the system sends the encoded audio effect definition or the encoded haptic effect definition to HID interpreter **740** of controller **750**.

FIG. **8** illustrates a block diagram of components used to author a trigger haptic effect for direct playback, and a block diagram of components used to save the trigger haptic effect, according to an embodiment of the invention. In this

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embodiment, a system (such as system **10** of FIG. **1**) can provide audio authoring component **800** as a dedicated tool for authoring a trigger haptic effect as an audio effect (i.e., by authoring an audio effect definition). In one embodiment, audio authoring component **800** can be a “Pro Tools®” product by Avid Technology, Inc.

Once a user of the system has authored a trigger haptic effect using audio authoring component **800**, the user can preview the trigger haptic effect. The preview functionality can allow for further customization of the trigger haptic effect. Upon previewing the trigger haptic effect, the system can send the authored audio effect definition to four-channel output driver **801**, where four-channel output driver **801** can stream the audio effect definition as four channels of audio data. In one embodiment, four-channel output driver **801** can be a four-channel ASIO output driver. In an alternate embodiment, four-channel output driver **801** can be replaced by another driver that streams the audio effect definition as any plural number of channels of audio data, such as six or eight channels of audio data.

Further, the system can send the audio stream to audio-to-haptic converter **802**, where audio-to-haptic converter **802** can convert the audio effect definition of the audio stream into a haptic effect definition using a haptic conversion algorithm. In one embodiment, each separate channel of the audio effect definition that corresponds to a motor, or actuator, can be converted into a channel of a haptic effect definition. Example haptic conversion algorithms are described in the following patents or patent applications (all of which are hereby incorporated by reference in their entirety): U.S. Pat. Nos. 7,979,146; 8,000,825; 8,378,964; U.S. Pat. App. Pub. No. 2011/0202155; U.S. Pat. App. Pub. No. 2011/0215913; U.S. Pat. App. Pub. No. 2012/0206246; U.S. Pat. App. Pub. No. 2012/0206247; U.S. Pat. App. Pub. No. 2013/0265286; U.S. Pat. App. Pub. No. 2013/0131851; U.S. Pat. App. Pub. No. 2013/0207917; U.S. Pat. App. Pub. No. 2013/0335209; U.S. Pat. App. Pub. No. 2014/0064516; U.S. patent application Ser. Nos. 13/661,140; 13/785,166; 13/788,487; 14/078,438; 14/078,442; 14/078,445; 14/051,933; 14/020,461; 14/020,502; 14/277,870; and 14/467,184.

The system can further send the converted haptic effect definition to HES multi-channel encoder **803**, where multi-channel encoder **803** can encode the converted haptic effect definition into an external format, such as an HES format. The system can further send the encoded and converted haptic effect definition to trigger controller interface (“I/F”) **804** that resides on controller **805**. Trigger controller I/F **804** can receive and interpret the encoded and converted haptic effect definition in order to preview the authored trigger haptic effect at a trigger of controller **805**.

In this embodiment, the system can provide audio authoring component **810**, where audio authoring component **810** is identical to audio authoring component **800**. Once a user of the system has authored a trigger haptic effect using audio authoring component **810**, the user can save the trigger haptic effect. Upon saving the trigger haptic effect, the system can export the audio effect definition as separate audio files **811**. In one embodiment where the audio effect definition includes four channels, audio files **811** can include four audio files. In an alternate embodiment, where the audio effect definition includes another number of channels, audio files **811** can include that number of separate audio files. In certain embodiments, audio files **811** can be a Waveform Audio File (“WAV”) format. The system can further send audio files **811** to a HES encoder graphical user interface (“GUI”) **812**, where HES encoder GUI **812** can encode audio files **811** into a single audio file. In one embodiment,

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the audio file can be an HES format. Further, the system can send the audio file to audio-to-haptic converter **812**, where audio-to-haptic converter **813** can convert the audio effect definition of the audio file into a haptic effect definition using a haptic conversion algorithm. In one embodiment, each separate channel of the audio effect definition that corresponds to a motor, or actuator, can be converted into a channel of a haptic effect definition. The system can further send the converted haptic effect definition to HES multi-channel encoder **814**, where multi-channel encoder **814** can encode the converted haptic effect definition into an external format, such as an HES format. The system can further store the encoded and converted haptic effect definition within a haptic file **815**. In one embodiment, haptic file **815** can be an HES file.

FIG. 9 illustrates a block diagram of components used to author a trigger haptic effect for crossover playback, and a block diagram of components used to save the trigger haptic effect, according to an embodiment of the invention. In this embodiment, a system (such as system **10** of FIG. 1) can provide audio authoring component **900** as a dedicated tool for authoring a trigger haptic effect as an audio effect (i.e., by authoring an audio effect definition).

Once a user of the system has authored a trigger haptic effect using audio authoring component **900**, the user can preview the trigger haptic effect. Upon previewing the trigger haptic effect, the system can send the authored audio effect definition to single-channel output driver **901**, where single-channel output driver **901** can stream the audio effect definition as a single channel of audio data. In one embodiment, single-channel output driver **901** can be a single-channel ASIO output driver. Further, the system can send the audio stream to audio-to-haptic converter **902**, where audio-to-haptic converter **902** can convert the audio effect definition of the audio stream into a haptic effect definition using a haptic conversion algorithm. In one embodiment, each separate channel of the audio effect definition that corresponds to a motor, or actuator, can be converted into a channel of a haptic effect definition. Even further, the system can send the converted haptic effect definition to crossover GUI **905**, where crossover GUI **905** can apply a crossover input warp algorithm to separate the converted haptic effect definition into three different channels that can be mapped to three different outputs (such as: (1) a low-frequency rumble motor, or rumble actuator; (2) a medium-frequency rumble motor, or rumble actuator; or (3) a high-frequency targeted motor, or targeted actuator).

The system can further send the converted haptic effect definition to HES multi-channel encoder **903**, where multi-channel encoder **903** can encode the converted haptic effect definition into an external format, such as an HES format. The system can further send the encoded and converted haptic effect definition to trigger controller I/F **904** that resides on controller **906**. Trigger controller I/F **904** can receive and interpret the encoded and converted haptic effect definition in order to preview the authored trigger haptic effect at a trigger of controller **906**.

In this embodiment, the system can provide audio authoring component **910**, where audio authoring component **910** is identical to audio authoring component **900**. Once a user of the system has authored a trigger haptic effect using audio authoring component **910**, the user can save the trigger haptic effect. Upon saving the trigger haptic effect, the system can export the audio effect definition as a single audio file **911**. In certain embodiments, audio file **911** can be a WAV format. The system can further export crossover settings **912**. The system can further send audio file **911** to

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a HES encoder GUI **913**, where HES encoder GUI **913** can encode audio file **911** and crossover settings **912** into a single audio file. In one embodiment, the audio file can be an HES format. The system can further send the audio file to HES single-channel and crossover encoder **914**, where single-channel and crossover encoder can encode the audio file into an external format, such as an HES format. The system can further store the encoded audio file within a haptic file **915**. In one embodiment, haptic file **915** can be an HES file.

FIG. 10 illustrates a block diagram of components used to directly play a trigger haptic effect, according to an embodiment of the invention. According to an embodiment, a system (such as system **10** of FIG. 1) can load a haptic file **1000** that includes a haptic effect definition. In one embodiment, haptic file **1000** can be an HES file. According to the embodiment, the haptic effect definition included within haptic file **1000** includes four channels, where each channel includes a portion of the haptic data included within the haptic effect definition. In an alternate embodiment, the haptic effect definition included within haptic file **1000** can include any plural number of channels. Each channel of the haptic effect definition can be associated with a targeted motor, targeted actuator, rumble motor, or rumble actuator. In the illustrated embodiment, the first channel (i.e., "channel LR") is associated with a low rumble motor, the second channel (i.e., "channel MR") is associated with a medium rumble motor, the third channel (i.e., "channel LT") is associated with a motor that is operably coupled to a left trigger, and the fourth channel (i.e., "channel RT") is associated with a targeted motor that is operably coupled to a right trigger. In one embodiment, the haptic effect definition included within haptic file **1000** can define a playback speed and a playback rate control.

According to the embodiment, the system can send the four channels of the haptic effect definition included within haptic file **1000** to strength control **1010**, where strength control **1010** can modify a strength, or magnitude, of the haptic data included within each channel of the haptic effect definition. The system can then send the four channels of the haptic effect definition to front/back ("F/B") spatialization **1020**, where F/B spatialization **1020** can modify the haptic data included within each channel of the haptic effect definition based on spatialization data. The spatialization data can include a direction and/or flow of a haptic effect. In one embodiment, the direction and/or flow of the haptic effect can be a frontwards or backwards direction. Further, spatialization data can include one or more hand positions. According to the embodiment, F/B spatialization **1020** can modify the haptic data included within each channel so that a haptic effect is scaled for each motor, or actuator. The system can then send channel LR to low rumble motor **1030** (identified in FIG. 10 as "LowR motor"), and can further send channel MR to medium rumble motor **1040** (identified in FIG. 10 as "MidR motor"). The haptic data contained within channel LR can cause low rumble motor **1030** to produce a general or rumble haptic effect, and the haptic data contained within channel MR can cause medium rumble motor **1040** to produce a general or rumble haptic effect.

The system can further send channels LT and RT to left/right ("L/R") spatialization **1050**, where L/R spatialization **1050** can modify the haptic data included within channels LT and RT based on spatialization data. The spatialization data can include a direction and/or flow of a haptic effect. In one embodiment, the direction and/or flow of the haptic effect can be a left or right direction. Further, spatialization data can include one or more hand positions. According to the embodiment, L/R spatialization **1050** can

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modify the haptic data included within each channel so that a haptic effect is scaled for each motor, or actuator. The system can then send channel LT to left trigger targeted motor **1060** (identified in FIG. **10** as “LT motor”), and can further send channel RT to right trigger targeted motor **1070** (identified in FIG. **10** as “RT motor”). The haptic data contained within channel LT can cause left trigger targeted motor **1060** to produce a trigger haptic effect at a left trigger, and the haptic data contained within channel RT can cause right trigger targeted motor **1070** to produce a trigger haptic effect at a right trigger.

FIG. **11** illustrates a block diagram of components used to play a trigger haptic effect using a programmable crossover, according to an embodiment of the invention. According to an embodiment, a system (such as system **10** of FIG. **1**) can load a haptic file **1100** that includes a haptic effect definition. In one embodiment, haptic file **1100** can be an HES file. According to the embodiment, the haptic effect definition included within haptic file **1100** includes a single channel, where the channel includes the haptic data included within the haptic effect definition. Also according to the embodiment, the haptic effect definition included within haptic file **1100** includes one or more crossover parameters, where the one or more crossover parameters can be parameters for a crossover input warp algorithm. In one embodiment, the haptic effect definition included within haptic file **1100** can define a playback speed and a playback rate control.

According to the embodiment, the system can send the channel of the haptic effect definition included within haptic file **1100**, and the one or more crossover parameters also included within haptic file **1100**, to programmable crossover **1110**. Programmable crossover **1110** can apply a crossover input warp algorithm using the one or more crossover parameters to separate the channel into three different channels: a low-frequency channel; a medium-frequency channel; and a high-frequency channel. The low-frequency channel includes a portion of the haptic data included within the haptic effect definition that includes one or more low frequencies. The medium-frequency channel includes a portion of the haptic data included within the haptic effect definition that includes one or more medium frequencies. The high-frequency channel includes a portion of the haptic data included within the haptic effect definition that includes one or more high frequencies.

The system can then send the three channels of the haptic effect definition to F/B spatialization **1120**, where F/B spatialization **1120** can modify the haptic data included within each channel of the haptic effect definition based on spatialization data. The spatialization data can include a direction and/or flow of a haptic effect. In one embodiment, the direction and/or flow of the haptic effect can be a frontwards or backwards direction. Further, spatialization data can include one or more hand positions. According to the embodiment, F/B spatialization **1120** can modify the haptic data included within each channel so that a haptic effect is scaled for each motor, or actuator. The system can then send the low frequency channel to low rumble motor **1130** (identified in FIG. **11** as “LowR motor”), and can further send the middle frequency channel to medium rumble motor **1140** (identified in FIG. **11** as “MidR motor”). The haptic data contained within the low-frequency channel can cause low rumble motor **1130** to produce a general or rumble haptic effect, and the haptic data contained within the medium-frequency channel can cause medium rumble motor **1140** to produce a general or rumble haptic effect.

The system can further send the high-frequency channel to L/R spatialization **1150**, where L/R spatialization **1150**

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can modify the haptic data included within the high frequency channel based on spatialization data. In one embodiment, the direction and/or flow of the haptic effect can be a left or right direction. Further, spatialization data can include one or more hand positions. According to the embodiment, L/R spatialization **1150** can modify the haptic data included within the channel so that a haptic effect is scaled for each motor, or actuator. The system can then send the high-frequency channel to left trigger targeted motor **1160** (identified in FIG. **11** as “LT motor”), and can also send the high-frequency channel to right trigger targeted motor **1170** (identified in FIG. **11** as “RT motor”). The haptic data contained within the high-frequency channel can cause left trigger targeted motor **1160** to produce a trigger haptic effect at a left trigger, and the haptic data contained within the high-frequency channel can cause right trigger targeted motor **1170** to produce a trigger haptic effect at a right trigger.

FIG. **12** illustrates an example four-channel direct playback of a trigger haptic effect, according to an embodiment of the invention. According to an embodiment, a system (such as system **10** of FIG. **1**) can load an audio file **1200** that includes an audio effect definition. In one embodiment, audio file **1200** can be an HES file. According to the embodiment, the audio effect definition included within audio file **1200** includes four channels, where each channel includes a portion of the audio data included within the audio effect definition. In an alternate embodiment, the audio effect definition included within audio file **1200** can include any plural number of channels. Each channel of the haptic effect definition can be associated with a targeted motor, targeted actuator, rumble motor, or rumble actuator. In the illustrated embodiment, the first channel (i.e., “channel LR”) is associated with a low rumble motor, the second channel (i.e., “channel MR”) is associated with a medium rumble motor, the third channel (i.e., “channel LT”) is associated with a targeted motor that is operably coupled to a left trigger, and the fourth channel (i.e., “channel RT”) is associated with a targeted motor that is operably coupled to a right trigger.

According to the embodiment, the system can send the four channels of the audio effect definition included within audio file **1200** to audio-to-haptic converter **1210**, where audio-to-haptic converter **1210** can convert the audio effect definition into a haptic effect definition using a haptic conversion algorithm. In one embodiment, each separate channel of the audio effect definition can be converted into a channel of a haptic effect definition. In the illustrated embodiment: channel LR can be converted using a peak/decimation filter with a range of less than 60 hertz (“Hz”); channel MR can be converted using a peak/decimation filter with a value of 60 Hz; and channels LT and RT can each be converted using a peak/decimation filter with a range of 200 Hz-2 kHz.

The system can further send the four channels of the converted haptic effect definition to encoder/decoder **1220**, where encoder/decoder **1220** can encode each channel of the converted haptic effect definition into an external format, such as an HES format. The system can then send the four encoded channels of the converted haptic effect definition to F/B spatialization **1230**, where F/B spatialization **1230** can modify the converted haptic data included within each encoded channel of the converted haptic effect definition based on spatialization data. The spatialization data can include a direction and/or flow of a haptic effect. In one embodiment, the direction and/or flow of the haptic effect can be a frontwards or backwards direction. Further, spa-

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tialization data can include one or more hand positions. According to the embodiment, F/B spatialization **1230** can modify the converted haptic data included within each encoded channel so that a haptic effect is scaled for each motor, or actuator. The system can then send encoded channel LR to low rumble motor **1240** (identified in FIG. **12** as “LowR motor”), and can further send encoded channel MR to medium rumble motor **1250** (identified in FIG. **12** as “MidR motor”). The converted haptic data contained within channel LR can cause low rumble motor **1240** to produce a general or rumble haptic effect, and the converted haptic data contained within channel MR can cause medium rumble motor **1250** to produce a general or rumble haptic effect.

The system can further send encoded channels LT and RT to L/R spatialization **1260**, where L/R spatialization **1260** can modify the converted haptic data included within encoded channels LT and RT based on spatialization data. The spatialization data can include a direction and/or flow of a haptic effect. In one embodiment, the direction and/or flow of the haptic effect can be a left or right direction. Further, spatialization data can include one or more hand positions. According to the embodiment, L/R spatialization **1260** can modify the haptic data included within each channel so that a haptic effect is scaled for each motor, or actuator. The system can then send channel LT to left trigger targeted motor **1270** (identified in FIG. **12** as “LT motor”), and can further send channel RT to right trigger targeted motor **1280** (identified in FIG. **12** as “RT motor”). The haptic data contained within channel LT can cause left trigger targeted motor **1270** to produce a trigger haptic effect at a left trigger, and the haptic data contained within channel RT can cause right trigger targeted motor **1280** to produce a trigger haptic effect at a right trigger.

FIG. **13** illustrates an example crossover playback of a trigger haptic effect, according to an embodiment of the invention. According to an embodiment, a system (such as system **10** of FIG. **1**) can load an audio file **1300** that includes an audio effect definition. In one embodiment, audio file **1300** can be an HES file. According to the embodiment, the audio effect definition included within audio file **1300** includes a single channel, where the channel includes the audio data included within the audio effect definition. In an embodiment, the audio effect definition included within audio file **1300** can include one or more crossover parameters, where the one or more crossover parameters can be parameters for a crossover input warp algorithm.

According to the embodiment, the system can send the channel of the audio effect definition included within audio file **1300**, and, in one embodiment, the one or more crossover parameters also included within audio file **1300**, to programmable crossover **1310**. Programmable crossover **1310** can apply a crossover input warp algorithm (in one embodiment, using the one or more crossover parameters) to separate the channel into three different channels: a low-frequency channel; a medium-frequency channel; and a high-frequency channel. Programmable crossover **1310** can further convert the audio effect definition into a haptic effect definition using a haptic conversion algorithm. In one embodiment, each separate channel of the audio effect definition can be converted into a channel of a haptic effect definition. In the illustrated embodiment: the low-frequency channel can be converted using a peak/decimation filter with a range of less than 60 hertz (“Hz”); the medium-frequency channel can be converted using a peak/decimation filter with

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a value of 60 Hz; and the high-frequency channel can each be converted using a peak/decimation filter with a range of 200 Hz-2 kHz.

The system can further send the three channels of the converted haptic effect definition to encoder/decoder **1320**, where encoder/decoder **1320** can encode each channel of the converted haptic effect definition into an external format, such as an HES format. The system can then send the three channels of the haptic effect definition to F/B spatialization **1330**, where F/B spatialization **1330** can modify the haptic data included within each channel of the haptic effect definition based on spatialization data. The spatialization data can include a direction and/or flow of a haptic effect. In one embodiment, the direction and/or flow of the haptic effect can be a frontwards or backwards direction. Further, spatialization data can include one or more hand positions. According to the embodiment, F/B spatialization **1330** can modify the haptic data included within each channel so that a haptic effect is scaled for each motor, or actuator. The system can then send the low-frequency channel to low rumble motor **1340** (identified in FIG. **13** as “LowR motor”), and can further send the middle-frequency channel to medium rumble motor **1350** (identified in FIG. **13** as “MidR motor”). The haptic data contained within the low-frequency channel can cause low rumble motor **1340** to produce a general or rumble haptic effect, and the haptic data contained within the medium-frequency channel can cause medium rumble motor **1350** to produce a general or rumble haptic effect.

The system can further send the high-frequency channel to L/R spatialization **1360**, where L/R spatialization **1360** can modify the haptic data included within the high-frequency channel based on spatialization data. In one embodiment, the direction and/or flow of the haptic effect can be a left or right direction. Further, spatialization data can include one or more hand positions. According to the embodiment, L/R spatialization **1360** can modify the haptic data included within the channel so that a haptic effect is scaled for each motor, or actuator. The system can then send the high frequency channel to left trigger targeted motor **1370** (identified in FIG. **13** as “LT motor”), and can also send the high frequency channel to right trigger targeted motor **1380** (identified in FIG. **13** as “RT motor”). The haptic data contained within the high frequency channel can cause left trigger targeted motor **1370** to produce a trigger haptic effect at a left trigger, and the haptic data contained within the high frequency channel can cause right trigger targeted motor **1380** to produce a trigger haptic effect at a right trigger.

FIG. **14** illustrates an example user interface **1400** of a trigger engine, according to an embodiment of the invention. User interface **1400** is an editable visual area that can visualize one or more trigger haptic effects that are generated by a trigger engine (such as trigger engine **506** of FIG. **5**). User interface **1400** can further allow a user to programmatically manage the one or more trigger haptic effects. As previously described, a trigger engine can receive a trigger haptic effect definition and can modify the trigger haptic effect definition based on a position and/or range of a trigger of a controller. According to the embodiment, user interface **1400** displays trigger view **1410**, where trigger view **1410** is a visualization of the trigger. Trigger view **1410** can display a trigger input range **1420**, where trigger input range **1420** is a visualization of a valid input range of the trigger. In the illustrated embodiment, trigger input range **1420** can be represented by a spectrum of integer values ranging from 0 to 255. The trigger resides at an initial position of 0 within trigger input range **1420**. By pressing or squeezing the

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trigger, a user can adjust a position of the trigger to any valid position within trigger input range **1420**. When the user releases the trigger, the position of the trigger adjusts back to position **0** within trigger input range **1420**.

Using user interface **1400**, a user can create one or more trigger definitions, where a trigger definition defines a condition that causes a trigger haptic effect to be generated or modified. In some embodiments, a condition can be a position of a trigger, where the position is within trigger input range **1420**. In other embodiments, a condition can be a range of the trigger, where the range is within trigger input range **1420**. User interface **1400** includes threshold trigger definition **1430**, which is an example of a trigger definition. Threshold trigger definition **1430** causes a trigger haptic effect that is based on a specified trigger haptic effect definition to be generated when the trigger reaches a specified position, where the specified position is **99** in the illustrated embodiment. Threshold trigger definition **1430** can define that the trigger haptic effect be generated only on a press of the trigger, only on a release of the trigger, or both a press and a release of the trigger. In an alternate embodiment, threshold trigger definition **1430** can be replaced with a position trigger definition that causes a trigger haptic effect that is based on a specified trigger haptic effect definition to only be generated when the trigger resides at a specified position, as opposed to simply reaching the specified position. User interface **1400** further includes range trigger definition **1440**, which is another example of a trigger definition. Range trigger definition **1440** causes a trigger haptic effect that is based on a specified trigger haptic effect definition to be generated when the trigger reaches a specified range, where the specified range is **164 to 255** in the illustrated embodiment.

FIG. **15** illustrates an example user interface **1500** of a spatialization engine, according to an embodiment of the invention. User interface **1500** is an editable visual area that can visualize a trigger haptic effect that is originally generated by a trigger engine (such as trigger engine **506** of FIG. **5**) and further modified by a spatialization engine (such as spatialization engine **507** of FIG. **5**). User interface **1500** can further allow a user to programmatically manage one or more modifications of the trigger haptic effect by the spatialization engine. Such modifications can further be recorded for dynamic playback in the future. As previously described, a spatialization engine can modify a haptic effect definition that is originally generated by a trigger engine so that a trigger haptic effect is scaled for one or more targeted motors, targeted actuators, rumble motors, or rumble actuators, of a controller. More specifically, a spatialization engine can modify a haptic effect definition as applied to each targeted motor, targeted actuator, rumble motor, or rumble actuator to convey a sense of direction of the trigger haptic effect as experienced by a user of the controller. Each modification to the haptic effect definition can be based on an intended direction and/or flow of a trigger haptic effect as defined by the specialization engine. Further, each modification can also be based on an input received by the controller, where the input indicates a position of a user's hand on the controller. Thus, the spatialization engine can receive a haptic effect definition that is originally generated by a trigger engine, and can modify the haptic effect definition based on the "spatialization" aspect of the trigger haptic effect (e.g., a position and/or flow of the trigger haptic effect). In an alternate embodiment, a spatialization engine can modify an original haptic effect definition, as opposed to a haptic effect definition that is originally generated by a trigger engine, so that a haptic effect is scaled for one or

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more targeted motors, targeted actuators, rumble motors, or rumble actuators, of a controller.

User interface **1500** includes flow **1510**. Flow **1510** allows a user to programmatically manage a flow of a trigger haptic effect. A flow is a temporal start-of-playback offset modification to delay playback on individual targeted motors, targeted actuators, rumble motors, or rumble actuators of a controller. Alternatively, a flow can be a duration modification to modify a duration of a haptic effect experienced at targeted motors, targeted actuators, rumble motors, or rumble actuators of a controller. For example, a flow can be defined so that haptic playback first begins on a left targeted motor or targeted actuator, then subsequently begins on a middle rumble motor or rumble actuator, and then further begins on a right targeted motor or targeted actuator. In this example, a flow of the overall trigger haptic effect is left-to-right, as a user of a controller first experiences the haptic playback of the overall trigger haptic effect at the left of the controller, then at the middle of the controller, and then at the right of the controller. A flow can be from left to right or vice-versa, front to back or vice-versa, or a combination of the two. Thus, a flow can define a haptic playback vector. Flow **1510** can be visualized within user interface **1500** as an arrow that can be placed horizontally, vertically, or diagonally within user interface **1500**. Thus, by interacting with flow **1510**, a user can modify one or more delays applied to various motors or actuators of the controller to stagger haptic playback.

User interface **1500** further includes direction **1520**. Direction **1520** allows a user to programmatically modify a direction of a trigger haptic effect. A direction is a magnitude (or strength) modification to emphasize a front-back and/or left-right bias (or balance) among various motors or actuators of a controller. Alternatively, a direction can be a frequency modification. For example, a direction can be defined so that haptic playback of the trigger haptic effect is the strongest at the right of the controller. Direction **1520** can be visualized within user interface **1500** as a point within a two-dimensional grid or space defined by two axes. Thus, by interacting with direction **1520**, a user can modify magnitudes (or strengths) applied to various motors or actuators to emphasize a left-right and/or front-back bias (or balance).

User interface **1500** further includes strength **1530**. Strength **1530** allows a user to programmatically modify a magnitude (or strength) of an overall trigger haptic effect either before or during playback. Strength **1530** can be visualized within user interface **1500** as a slider. Thus, by interacting with strength **1530**, a user can modify an overall magnitude (or strength) of a trigger haptic effect. User interface **1500** further includes play speed **1540**. Play speed **1540** allows a user to programmatically modify a play speed, or rate, at which a system (such as system **10** of FIG. **1**) processes a trigger haptic effect definition of a trigger haptic effect in order to playback the trigger haptic effect. Play speed **1540** can be visualized within user interface **1500** as a slider. Thus, by interacting with play speed **1540**, a user can modify a play speed, or rate, of a trigger haptic effect. User interface **1500** further includes loop **1550**. Loop **1550** allows a user to programmatically modify whether a playback of a trigger haptic effect loops or not. Loop **1550** can be visualized within user interface **1500** as a button. Thus, by interacting with loop **1550**, a user can control a looping of a trigger haptic effect. Further details of a spatialization engine are further described below in greater detail in conjunction with FIGS. **32** and **33**.

FIG. **16** illustrates an architecture diagram of a trigger haptic effect API **1600**, according to an embodiment of the

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invention. Trigger haptic effect API **1600** includes a set of computer-readable functions or routines that allow a developer to play haptic effects, such as trigger haptic effects, at a user input element of a controller, such as a trigger. The trigger haptic effect API can include an extensive haptic effect library containing pre-defined haptic effect definition for many different game genres, such as driving/racing, weapons/warfare, and sports (e.g., soccer, football, baseball, golf, or hockey). In one embodiment, the trigger haptic effect API can include a set of C++ classes, and is not required to use advanced features, such as exceptions and run-time type information, which may be turned off in client applications. In alternate embodiments, the trigger haptic effect API can use other language bindings, such as C, Java, or C#. Further, the trigger haptic effect API can provide plug-ins for certain game engines, such as Unity 3D™ and Marmalade™.

According to the embodiment, trigger haptic effect API **1600** can be accessed by application **1610**, which is a software application, such as a game application, that can be executed on a system (such as system **10** of FIG. **1**). Further, trigger haptic effect API **1600** can access an effect library **1620**, where effect library **1620** can include one or more haptic effect definitions, such as haptic effect definition **1621** (identified in FIG. **16** as “effect **1621**”). As previously described, an example of a haptic effect definition is a trigger haptic effect definition. Further, trigger haptic effect API **1600** includes one or more device definitions, such as device definition **1601** (identified in FIG. **16** as “device **1601**”). A device definition includes device data that defines a hardware device, such as a controller, gamepad, or other peripheral device, where a haptic effect is to be played. Trigger haptic effect API **1600** further includes one or more timer definitions, such as timer definition **1602** (identified in FIG. **16** as “timer **1602**”). A timer definition includes timer data that defines a time period where all haptic effect definitions registered to a specific hardware device are updated. Trigger haptic effect API **1600** further includes trigger definition **1603** (identified in FIG. **16** as “trigger **1603**”). A trigger definition includes trigger data that defines a trigger of a specific hardware device. Trigger haptic effect API **1600** further includes protocol definition **1604** (identified in FIG. **16** as “protocol **1604**”). A protocol definition describes a protocol of a communication interface used by trigger haptic effect API **1600** to communicate with a specific hardware device. Using protocol definition **1604**, trigger haptic effect API **1600** can communicate with device firmware **1630** (identified in FIG. **16** as “FW **1630**”), where device firmware **1630** is firmware for the specific hardware device. Using device firmware **1630**, trigger haptic effect API **1600** can further communicate with hardware device **1640** (identified in FIG. **16** as “HW **1640**”), where hardware device **1640** is the specific hardware device.

In one embodiment, application **1610** can access device definition **1601** to acquire a target hardware device (i.e., HW **1640**) where a haptic effect is to be played. By accessing device definition **1601**, application **1610** can further access timer definition **1602**, trigger definition **1603**, and protocol definition **1604**. Application **1610** can further access haptic effect definition **1621** from effect library **1620** to instantiate a haptic effect. Application **1610** can further cause the haptic effect to be played at the target hardware device (i.e., HW **1640**) by sending an instruction to the target hardware device (i.e., HW **1640**) via trigger haptic effect API **1600** and FW **1630**.

FIG. **17** illustrates an architecture diagram of firmware that produces trigger haptic effects, according to an embodi-

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ment of the invention. The architecture includes communication interface **1700**. Communication interface **1700** provides for communication between a trigger haptic effect API (such as trigger haptic effect API **1600** of FIG. **16**) and firmware for a peripheral device, such as a controller or gamepad. The architecture further includes effect slot **1710**. An effect slot defines a type of haptic effect, and can include the following parameters: magnitude (or strength); frequency (or period); envelope (e.g., attack level, attack time, fade level, and fade time); actuator (e.g., specific actuators or virtual actuators, such as “rumble” or “directional”); direction (e.g., one or two angles, or a two-dimensional vector); distance (e.g., can be used to module an entire haptic effect); start/end haptic effect definition (e.g., a starting haptic effect definition and an ending haptic effect definition that can be interpolated to create an interpolated haptic effect). A specific type of effect slot **1710** is a triggered effect slot **1720**. A triggered effect slot defines a type of trigger haptic effect, and, in addition to the aforementioned parameters of an effect slot, can include the following additional parameters: trigger button (e.g., none, left, or right); trigger start/stop, points, and directions (e.g., start/stop the trigger haptic effect when a trigger button reaches a certain position while moving in a certain direction); and trigger end point (e.g., interpolate between a start trigger haptic effect definition and an end trigger haptic definition while playing the trigger haptic effect).

The architecture further includes trigger engine **1730**. As previously described, trigger engine **1730** can receive a trigger haptic effect definition and can modify the trigger haptic effect definition based on trigger data, such as a position and/or range of a trigger of a controller. The architecture further includes trigger hardware interface **1740** (identified in FIG. **17** as “trigger HW interface **1740**”). Trigger hardware interface **1740** is a communication interface that allows trigger engine **1730** to receive trigger data from a peripheral device, such as a controller or gamepad. The architecture further includes spatialization engine **1750**. As previously described, spatialization engine **1750** can modify a haptic effect definition, such as a trigger haptic effect definition, so that a haptic effect, such as a trigger haptic effect, is scaled for one or more targeted motors, targeted actuators, rumble motors, or rumble actuators, of a controller. The architecture further includes basis effect rendering engine **1760**. Basis effect rendering engine **1760** renders a haptic effect, such as a trigger haptic effect, for a motor or actuator based on a haptic effect definition, such as a trigger haptic effect definition. The architecture further includes actuator hardware interface **1770** (identified in FIG. **17** as “actuator HW interface **1770**”). Actuator hardware interface **1770** is a communication interface that allows basis effect rendering engine **1760** to send haptic data included within the rendered haptic effect to a motor or actuator to cause the motor or actuator to play the haptic effect.

FIG. **18** illustrates an example directionality model for a controller, according to an embodiment of the invention. According to the embodiment, the controller includes rumble motors **1810** and **1820**, and targeted motors **1830** and **1840**, where targeted motors **1830** and **1840** are each operably coupled to a trigger of the controller. Rumble motors **1810** and **1820** can have complementary vibration ranges. Further, targeted motors **1830** and **1840** can generate higher-frequency vibrations that are more spatially-isolated. It can be understood that using rumble motors **1810** and **1820** for a left/right spatialized haptic effect provides an asymmetric vibration experience (i.e., different frequency content that is

not well spatially separated for most users). Thus, a haptic effect definition can include left-front, right-front, and directionless channels. Further, a front/back directionality can be reinforced by transitioning a vibration from rumble motors **1810** and **1820** to targeted motors **1830** and **1840**. Thus, rumble motors **1810** and **1820** can be used for directionless low-frequency haptic effects. Rumble motors **1810** and **1820** can optionally also be used for back/front directionality. Further, targeted motors **1830** and **1840** can be used for left/right directionality.

FIG. **19** illustrates a block diagram of a trigger haptic effect firmware stack, according to an embodiment of the invention. The trigger haptic effect firmware stack can be for firmware for a peripheral device, such as peripheral firmware **510** of FIG. **5**. The trigger haptic effect firmware stack can include trigger controller haptics API **1900**. Trigger controller haptics API **1900** includes a set of computer-readable functions or routines that allow the firmware to play haptic effects, such as trigger haptic effects, at a user input element of a controller, such as a trigger. Trigger controller haptics API **1900** can include fundamental effect definitions **1901**. Effect definitions **1901** include one or more haptic effect definitions, such as trigger haptic effect definitions. Trigger controller haptics API **1900** can further include effect library code **1902**. Effect library code **1902** includes a set of computer-readable instructions that can instantiate a haptic effect based on a haptic effect definition stored within effect definitions **1901**. Effect library code **1902** can provide one or more effect-specific parameters as part of the instantiation of a haptic effect based on a haptic effect definition. Trigger controller haptic API **1900** can further include directionality engine **1903**. Directionality engine **1903** can modify a haptic effect definition, such as a trigger haptic effect definition, so that a haptic effect, such as a trigger haptic effect, is scaled for one or more targeted motors, targeted actuators, rumble motors, or rumble actuators, of a controller. Trigger controller haptic API **1900** further includes emulator **1904**. Emulator **1904** renders a haptic effect, such as a trigger haptic effect, for one or more motors or actuators (e.g., four motors) of a controller based on a haptic effect definition, such as a trigger haptic effect definition. Trigger controller haptic API **1900** further sends the rendered haptic effect to controller **1920** (or some other peripheral device) using controller API **1910**.

FIG. **20** illustrates an architecture diagram of a system (such as system **10** of FIG. **1**) that provides trigger haptic effects experienced at a trigger of a controller, according to an embodiment of the invention. The system includes application **2000** (identified in FIG. **20** as “app **2000**”). Application **2000** is a software application, such as a game application, that can be executed on the system. The system further includes trigger haptic effect API **2010** (identified in FIG. **20** as “API **2010**”). In one embodiment, trigger haptic effect API **2010** is identical to trigger controller haptic API **1900** of FIG. **19**. According to the embodiment, trigger haptic effect API **2010** can be a single API for all controllers, gamepads, or other peripheral devices. Thus, trigger haptic effect API **2010** can abstract differences between controllers, gamepads, and other peripheral devices. Further, trigger haptic effect API **2010** can include a built-in effects library that includes one or more built-in haptic effect definitions. A built-in haptic effect definition is a data structure that encapsulates one or more attributes of a corresponding haptic effect.

One type of a built-in haptic effect definition is static haptic effect definition **2011** (identified in FIG. **20** as “static **2011**”). Static haptic effect definition **2011** is a set of one or

more periodic or magnitude sweep effect definitions that produce a static haptic effect that does not change over time. Examples include a car crash, a rocket launcher, and a user interface confirmation. Static haptic effect definition **2011** can be called directly by application **2000** based on events within a game. A static haptic effect produced by static haptic effect definition **2011** can be used as a trigger haptic effect.

Another type of a built-in haptic effect definition is dynamic haptic effect definition **2012** (identified in FIG. **20** as “dynamic **2012**”). Dynamic haptic effect definition **2012** is an algorithm that receives one or more parameters **2014** as input and produces a continuously changing haptic effect (i.e., a dynamic haptic effect). Examples include an engine’s revolutions per minute (“RPM”), a snowboard, and an explosion. A static haptic effect definition can be turned into a dynamic haptic effect definition by including a vector (i.e., distance and direction), and an input position/state of one or more buttons or axes). A dynamic haptic effect can be based on game variables that can be passed from application **2000**. A dynamic haptic effect can also be based on controller input, such as trigger input.

Another type of a built-in haptic effect definition is direct control haptic effect definition **2013** (identified in FIG. **20** as “direct control **2013**”). In a direct control scenario, direct control haptic effect definition **2013** can be defined in a way that allows direct rendering to the output device, with very little processing applied to direct control haptic effect definition **2013** as it travels through core effect library **2020**. In this scenario, direct control haptic effect definition **2013** can include a number of distinct data channels that corresponds to, and maps exactly to, a number of output actuators on an output device. Alternately, direct control haptic effect definition **2013** can contain a number of distinct data channels that exceeds the number of available output actuators on the output device, and core effect library **2020** can select a number of channels, where each channel is selected such that it best maps to a particular actuator in the output device, and core effect library **2020** can then transmit the selected channels’ data to the mapped actuators.

The system further includes core effect library **2020** (identified in FIG. **20** as “core **2020**”). Core effect library **2020** includes one or more haptic effect definitions **2021** (identified in FIG. **20** as “FX **2021**”). Haptic effect definitions **2021** can include trigger haptic effect definitions **2022** (identified in FIG. **20** as “trigger effects **2022**”). Examples of haptic effect definitions can include explosion haptic effect definitions, RPM haptic effect definitions, snowboard haptic effect definitions, and other haptic effect definitions. Core effect library further includes mixer **2023** (identified in FIG. **20** as “mixer/prioritization **2023**”). Mixer **2023** can mix or prioritize one or more haptic effect definitions.

The system further includes low-level API **2030**. Low-level API **2030** can receive an instruction to play a haptic effect based on a haptic effect definition, and can convert the instruction to a low-level instruction that can be interpreted by a controller **2040**. An example of low-level API **2030** is Xbox® API **2031** by Microsoft Corporation, and an example of controller **2040** is Xbox® controller **2041** by Microsoft Corporation.

FIG. **21** illustrates an example user interface **2100** for previewing and modifying a trigger haptic effect, according to an embodiment of the invention. A system (such as system **10** of FIG. **1**) can provide user interface **2100** to a user as a trigger haptic effect preview and modification tool. According to the embodiment, user interface **2100** includes open effects **2110**. Open effects **2110** can display one of more

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haptic effect presets, such as trigger haptic effect presets, that are available to be selected. User interface **2100** further includes effect library **2120**. Effect library **2120** can display one or more haptic effect presets, such as trigger haptic effect presets, that are included within a haptic effects library. Effect library **2120** can display the one or more haptic effect presets by category.

User interface **2100** further includes timeline **2130**. According to the embodiment, a user can select a haptic effect preset displayed within open effects **2110**, and timeline **2130** can display a graphical representation of the haptic effect definition that is represented by the selected haptic effect preset. In the illustrated embodiment, the haptic effect definition includes four channels, with each channel including haptic data that is mapped for a specific output (e.g., (1) targeted motor or actuator for a right trigger; (2) targeted motor or actuator for a left trigger; (3) right rumble motor or actuator; and (4) left rumble motor or actuator), and each channel being displayed along the timeline. However, in other embodiments, the haptic effect definition can include any number of channels. Further, a user can modify one or more channels of the selected haptic effect definition by interacting with one or more display elements within timeline **2130**. By modifying one or more channels of a haptic effect definition, one can modify one or more attributes of a corresponding haptic effect.

User interface **2100** further includes effect properties **2140**. Effect properties **2140** is an editable visual area that can visualize a trigger haptic effect that is generated by a trigger engine (such as trigger engine **506** of FIG. **5**). As previously described, a trigger engine can receive a trigger haptic effect definition and can modify the trigger haptic effect definition based on a position and/or range of a trigger of a controller. Thus, effect properties **2140** can display a visualization of the trigger, including an actual position of the trigger. Further, effect properties **2140** can display a position and/or range of the trigger that is defined for a trigger haptic effect definition, where the position and/or range can cause the trigger engine to modify the trigger haptic effect definition. A user can edit the position and/or range of the trigger that is defined for the trigger haptic effect definition. Further, effect properties **2140** can display a list of triggers for a controller, so the user can edit the trigger that is defined for the trigger haptic effect definition. Even further, effect properties **2140** can display a magnitude (or strength) of the trigger haptic effect definition, and a user can modify the magnitude (or strength).

User interface **2100** further includes spatialization **2150**. Spatialization **2150** is an editable visual area that can visualize a trigger haptic effect that is originally generated by the trigger engine and further modified by a spatialization engine (such as spatialization engine **507** of FIG. **5**). As previously described, the spatialization engine can modify the trigger haptic effect definition so that a trigger haptic effect is scaled for one or more targeted motors, targeted actuators, rumble motors, or rumble actuators, of a controller. Thus, spatialization **2150** can display a visualization of the controller. Spatialization **2150** can further display a visualization of the trigger haptic effect experienced at each targeted motor, targeted actuator, rumble motor, or rumble actuator of the controller. A user can edit a scaling of the trigger haptic effect that is experienced at each targeted motor, targeted actuator, rumble motor, or rumble actuator of the controller, as well as edit a scaling of a source of the trigger haptic effect.

FIG. **22** illustrates an example user interface **2200** for converting an audio signal into a trigger haptic effect,

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according to an embodiment of the invention. According to an embodiment, haptic effect design can become part of an audio design process that is incorporated into user interface **2200**. More specifically, audio effect definitions 3-8 displayed within user interface **2200** can be converted into haptic effect definitions, where the haptic effect definitions can be exported.

FIG. **23** illustrates an example user interface **2300** for creating a trigger haptic effect based on object parameters, according to an embodiment of the invention. According to the embodiment, user interface **2300** includes haptic effect definition name **2310** which displays a name of a haptic effect definition. User interface **2300** further includes object parameters **2320** which displays one or more object parameters of the haptic effect definition. Example object parameters illustrated in the embodiment include: type; rate of fire; style; strength (or magnitude); frequency; and sound effect. User interface **2300** further includes trigger modification **2330** which allows a user to modify trigger aspects of the haptic effect definition, such as trigger throw and trigger activation. User interface **2300** further includes strength (or magnitude) modification **2340** which allows a user to modify strength (or magnitude) aspects of the haptic effect definition, such as: random strength (or magnitude); maximum strength (or magnitude); or minimum strength (or magnitude). User interface **2300** further includes duration modification **2350** which allows a user to modify duration aspects of the haptic effect definition, such as: randomizing length; minimum duration; or maximum duration. User interface **2300** further includes haptic effect visualization **2360** which allows a user to visualize a haptic effect based on the haptic effect definition. User interface **2300** further includes save **2370** which allows a user to save the modified haptic effect definition.

FIG. **24** illustrates an architecture diagram of a system (such as system **10** of FIG. **1**) that previews trigger haptic effects, according to an embodiment of the invention. The system includes user interface **2400**. In one embodiment, user interface **2400** is a Qt user interface, where Qt is a cross-platform application and user interface framework. The system further includes adapter layer **2410**. The system further includes trigger API layer **2420**. The system further includes trigger firmware layer **2430**.

User interface **2400** includes plotter **2401**. Plotter **2401** takes a haptic effect definition specified by a user as input, and sends the haptic data includes within the haptic effect definition through adapter layer **2410** to trigger API layer **2420**. Trigger API layer **2420** sends back individual channel data that plotter **2401** displays within user interface **2400**. Render **2402** takes input from controller GUI **2403** and starts a haptic player render loop. The input is routed through adapter layer **2410**, which has callbacks setup with trigger API layer **2420** to and relay controller input **2413** (such as button and trigger input) sent from controller **2414**. Adapter layer **2410** can also communicate with plotter **2401** while the render loop is running to update user interface **2400**. Controller GUI **2403** can also select controller **2414** using controller selector **2412**, and can show what is connected. Controller GUI **2403** can also set up a trigger activation point. Further, importer/exporter **2404** can take input audio files and convert them to a haptic file. In one embodiment, an audio file is a WAV file. Further, adapter layer **2410** can be embedded within user interface **2400**, or can be a separate library. When adapter layer **2410** is a separate library, adapter layer **2410** can be a separate C++ library.

FIG. **25** illustrates an architecture diagram of a system (such as system **10** of FIG. **1**) that produces trigger haptic

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effects, according to an embodiment of the invention. The system includes game application **2500** (identified in FIG. **25** as “game **2500**”). Game application **2500** includes a set of computer-readable instructions that manage input provided by a controller, gamepad, or other peripheral device, in the context of a software game, or other type of software application. In one embodiment, game application **2500** includes haptic effect library **2501**, where haptic effect library **2501** includes one or more haptic effect definitions.

The system further includes haptic engine **2510**. Haptic engine **2510** is a high-level API that can utilize a low level API to perform the playing of a haptic effect, and to add haptic effects to game application **2500**. Haptic engine **2510** can load, start, stop, and render a haptic effect. Haptic engine **2510** can interface with haptic effect parser **2520** to parse/get information about a haptic effect. Haptic engine **2510** can further interface with haptic mixer **2530** to start or stop an effect and modify a mixer buffer. Haptic engine **2510** can further interface with haptic device handler **2550** to get a device handle of, and render haptic effects on, a controller, gamepad, or other peripheral device.

The system further includes haptic effect parser **2520**. Haptic effect parser **2520** includes an API that can load a haptic effect in memory, verify its format, and obtain information about the haptic effect, such as size, duration, and haptic data. The system further includes haptic mixer **2530**. Haptic mixer **2530** supports playback of multiple haptic effects at the same time. The system further includes haptic device handler **2540**. Haptic device handler **2540** can initiate and manage communication with a controller, gamepad, or other peripheral device. Haptic device handler **2540** can interface with a Universal Serial Bus (“USB”) communication layer and obtain a device handle of the controller, gamepad, or other peripheral device. Haptic device handler **2540** can further initialize several state machine structures critical for haptic effect playback.

The system further includes trigger haptic report handler **2550**. Trigger haptic report handler **2550** can package haptic data into USB HID packets according to a trigger communication protocol. The system further includes platform compliant USB HID library **2560**. Platform compliant USB HID library **2560** includes one or more computer-readable routines to interface with USB HID and Bluetooth HID class of controllers, gamepads, or other peripheral devices. The system further includes peripheral firmware **2570** (identified in FIG. **25** as “gamepad firmware **2570**”). Peripheral firmware **2570** is firmware for a controller, gamepad, or other peripheral device. The system further includes peripheral input reader **2580** (identified in FIG. **25** as “gamepad input reader **2580**”). Peripheral input reader **2580** receives peripheral input that is sent by the controller, gamepad, or other peripheral device. Peripheral input reader **2580** further interprets the peripheral input and sends the peripheral input to game application **2500**.

FIG. **26** illustrates an architecture diagram of firmware that produces trigger haptic effects, according to an embodiment of the invention. The firmware architecture can make the firmware modular, can separate hardware-independent component from hardware-dependent components, and can make porting easier from one microcomputer unit to another. The hardware-independent layer can communicate with the hardware-dependent layer by functional pointers. The hardware-dependent layer can be ported to another microcontroller unit based on the implementation template. All hardware-dependent routines can interface with a board configuration file that can give an inside look of the hardware which has different port/button definitions.

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FIG. **26** includes host software **2600** (identified in FIG. **26** as “HOST SW **2600**”). Host software **2600** includes a set of computer-readable instructions that manage input provided by a controller, gamepad, or other peripheral device, in the context of a software game, or other type of software application. Host software **2600** can be within a software space. FIG. **26** further includes USB HID handler **2605**. USB HID handler **2605** can be a main entry point for all communication between a controller, gamepad, or other peripheral device, and host software **2600**. USB HID handler **2605** can include one or more computer-readable functions or routines to encode/decode data, such as haptic data, according to a trigger communication protocol. USB HID handler **2605** can also store all USB descriptors and routines to handle USB communication. USB HID handler **2605** can be within a firmware space.

FIG. **26** further includes communication interface **2610**. Communication interface **2610** can parse an incoming packet and call command handler **2615** to take appropriate actions. FIG. **26** further includes command handler **2615**. Command handler **2615** can include one or more computer-readable functions or routines to handle commands supported by a trigger protocol that supports haptic playback on actuators. FIG. **26** further includes haptic drive handler **2620**. Haptic drive handler **2620** can update a state of a haptic playback engine, updates drive values of actuators and controls the actuators. Haptic drive handler **2620** can interface with hardware-dependent timer handler **2635** and actuator control **2625** by function pointer mechanism. Communication interface **2610**, command handler **2615** and haptic drive handler **2620** can all be within a firmware space.

FIG. **26** further includes actuator control **2625** (identified in FIG. **26** as “actuator drive control **2625**”). Actuator control **2625** can control the actuators and set the drive values. Actuator control **2625** can include one or more computer-readable functions or routines to interface with a pulse-width modulation generation unit, and to interface with actuator driver chips. FIG. **26** further includes controller input reader **2630** (identified in FIG. **26** as “gamepad input reader **2630**”). Controller input reader **2630** can interface with platform-dependent input reader **2640** to obtain a state of different inputs of the controller, gamepad, or other peripheral device, package the inputs, and send the inputs to communication interface **2610** to be further sent to host software **2600**. FIG. **26** further includes timer handler **2635**. Timer handler **2635** is a hardware-dependent layer that can control a timer responsible for generating periodic interrupts to call a routine that updates a drive value for the actuators. FIG. **26** further includes input reader **2640**. Input reader **2640** is a hardware-dependent layer that can obtain a state of all potentiometers and digital inputs of a controller, gamepad, or other peripheral device. FIG. **26** further includes peripheral and interface driver **2650**. Peripheral and interface driver **2650** can include one or more computer-readable functions or routines to control communication interfaces and hardware peripheral devices. Actuator control **2625**, controller input reader **2630**, timer handler **2635**, input reader **2640**, and peripheral and interface driver **2650** can all be within a firmware space.

FIG. **26** further includes microcontroller unit **2660**, which can include components, such as computer processing unit **2661**, USB **2662**, interrupt controller **2663**, timer peripherals **2664**, and other peripherals **2665**. The functionality of these components is known to one of ordinary skill in the relevant art. FIG. **26** further includes controller hardware **2670** (identified in FIG. **26** as “gamepad hardware **2670**”). The functionality of controller hardware **2670** is also known to

one of ordinary skill in the relevant art. Microcontroller unit **2660**, and controller hardware **2670** can all be within a firmware space. Further, communication interface **2610**, command handler **2615**, haptic drive handler **2625**, and controller input reader **2630** can all be hardware-independent components, whereas USB HID handler **2605**, actuator control **2625**, timer handler **2635**, input reader **2640**, peripheral and interface driver **2650**, microcontroller unit **2660**, and controller hardware **2670** can all be hardware-dependent components.

In one embodiment, a controller, gamepad, or other peripheral device, can have a customized protocol for conveying haptic data and for driving individual motors or actuators. Accordingly, an audio driver can be provided that receives an audio file that includes a haptic effect authored as an audio effect definition from an audio authoring component, and that sends the audio data included within the audio file to the controller, gamepad, or other peripheral device. In one embodiment, the audio authoring component can be a "Pro Tools®" product by Avid Technology, Inc. The audio driver can get loaded during a boot up process. The audio driver can expose a necessary number of audio channels in order to make haptic effect definitions possible for using all the motors or actuators in the controller, gamepad, or other peripheral device. The audio driver can further work in user space, and can be accessible to all user space audio editing/playback applications. The audio driver can further read the audio data that an audio authoring component sends to the controller, gamepad, or other peripheral device. The audio driver can further perform necessary processing on the audio data being presented and can convert the audio data into haptic data, such as actuator drive values. The audio driver can further communicate the haptic data to the controller, gamepad, or other peripheral device over a communication interface.

According to the embodiment, a controller, gamepad, or other peripheral device, can include four actuators. Two actuators can be used as trigger actuators influencing haptic feedback on triggers. The trigger actuators can be bi-directional. Two kinds of direction events can happen with the trigger actuators: PUSH and PULL. The PUSH and PULL directions can be relative to a user's finger on the trigger. Two other actuators can be used as rumble actuators influencing general haptic feedback or rumble feedback within the controller, gamepad, or other peripheral device. The rumble actuators can be uni-directional. More specifically, the rumble actuators can spin in either a clockwise direction or a counter-clockwise direction, but not both directions. The direction of the motion can be dependent on the controller and/or the drive electronics of the controller.

In this embodiment, the following channel layout can be chosen for the audio driver:

Channel Number	Channel Purpose
0	Push channel for left trigger
1	Pull channel for left trigger
2	Push channel for right trigger
3	Pull channel for right trigger
4	Left rumble
5	Right rumble

In one embodiment, an audio format chosen for a 16-bit PCM can be 44.1 KHz. The audio driver can receive the audio data from an audio authoring component, convert the audio data into haptic data (e.g., drive values), and communicate the haptic data to the controller accordingly.

FIG. 27 illustrates an example audio architecture, according to an embodiment of the invention. The audio architecture includes application-level services **2700**. Application-level services **2700** can include such services as: audio queue services; audio units; system sounds; audio file stream services; audio file, converter, and codec services; OpenAL; music sequencing services; or a core audio clock. Application-level services **2700** communicate with hardware abstraction layer ("HAL") **2710**. An example of HAL **2710** is core Musical Instrument Digital Interface ("MIDI") **2711**. In turn, HAL **2710** communicates with input/output ("I/O") kit **2720**, drivers **2730**, and hardware **2740**. I/O kit **2720**, drivers **2730**, and hardware **2740** exist in kernel space. In order to receive audio data that application-level services intend to send to hardware **2740**, an audio driver can require a plug-in to HAL **2710**, where the plug-in can receive the audio data and access hardware **2740**. The plug-in of the audio driver can receive audio data from application-level services **2700** in real-time, or in near real-time, and can convert the audio data to haptic data (e.g., drive values) performing decimation on a 5-millisecond ("ms") portion of audio data. An example audio driver is described further in greater detail in conjunction with FIG. 28.

FIG. 28 illustrates an example audio driver **2800** (identified in FIG. 28 as "haptic trigger driver **2800**") that converts an audio effect into a trigger haptic effect, according to an embodiment of the invention. Audio driver **2800** receives audio data **2805** from one or more applications. Audio data can be an interleaved multi-channel audio stream, such as a four-channel audio stream or a six-channel audio stream. Subsequently, splitter **2815** separates the audio data of the various channels into respective channel buffers. Further, audio-to-haptic data converter **2825** converts the audio data of each channel buffer into haptic data. More specifically, in one embodiment, audio-to-haptic data converter **2825** executes a peak-detection algorithm on the channel buffers on a portion of audio data (e.g., 5 ms of audio data) and populates values in a decimated value array of each channel. Audio-to-haptic data converter **2825** then calculates drive values of the individual actuators based on the following formulas:

Drive value for triggers:(PushChannelDecimated-
Value-PullChannelDecimatedValue)→Scale it
to [0,255]

Drive value for rumbles:(DecimatedValue)→Scale it
to [128,255]

Subsequently, trigger protocol packet manager **2835** obtains drive values for all the actuators (e.g., all four actuators) and packages the drive values as data packets, such as USB HID packets, according to a trigger communication protocol. Further, XPC handler **2845** receives the data packets from trigger protocol packet manager **2835** and sends the data packets to XPC service **2810**, which is a background service. At **2855**, XPC service **2810** receives the data packets and, at **2865**, sends the data packets to **2865** to a controller **2820** (identified in FIG. 28 as "haptic trigger gamepad **2820**"), over a USB interface.

FIG. 29 illustrates a generation of a trigger haptic effect in a first format that recreates a trigger haptic effect in a second format, according to an embodiment of the invention. According to the embodiment, different controllers, gamepads, or other peripheral devices can have different types of motors or actuators, which can produce different types of trigger haptic effects at a trigger. For example, a motor or actuator may produce kinesthetic feedback at a trigger for a first controller, whereas a motor or actuator may

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produce vibrotactile feedback at a trigger for a second controller. Thus, it can be necessary to convert a trigger haptic effect from a first format to a second format. This can be accomplished by converting an underlying trigger haptic effect definition from a first format to a second format. By converting the trigger haptic effect definition, the trigger haptic effect can be gracefully degraded so that it is equivalent to a haptic effect definition that produces an equivalent trigger haptic effect at a different controller.

FIG. 29 includes trigger haptic effect 2900 that is based on a trigger haptic effect definition. The trigger haptic effect definition for trigger haptic effect 2900 approximately defines a haptic signal at a frequency of 100 Hz (i.e., 5 ms push haptic signal and 5 ms gaps) for a duration of 75 ms. As illustrated in FIG. 29, trigger haptic effect 2900 recreates trigger haptic effect 2910 which is based on a separate trigger haptic effect definition. The trigger haptic effect definition for trigger haptic effect 2910 defines a constant haptic signal at a frequency of approximately 100 Hz for a duration of 75 ms. Thus, according to the embodiment, trigger haptic effect 2900 and trigger haptic effect 2910 are “perceptually equal,” where a user experiences an identical, or substantially identical, haptic feedback from both trigger haptic effect 2900 and trigger haptic effect 2910, and where “substantially identical haptic feedback” is haptic feedback produced by a recreated haptic effect that fulfills an identical or similar designed intent, or is otherwise identically or similarly experienced, as haptic feedback produced by an original haptic effect, even when the haptic feedback produced by the recreated haptic effect differs from the haptic feedback produced by the original haptic effect.

FIG. 30 illustrates another generation of a trigger haptic effect in a first format that recreates a trigger haptic effect in a second format, according to an embodiment of the invention. FIG. 30 includes trigger haptic effect 3000 that is based on a trigger haptic effect. As illustrated in FIG. 30, trigger haptic effect 3010 recreates haptic effect 3000, where trigger haptic effect 3010 is based on a separate haptic effect definition. The trigger haptic effect definition for trigger haptic effect 3000 defines an attack (i.e., rise) time and a decay time. The trigger haptic effect definition for trigger haptic effect 3010 defines lower magnitudes for a length of the attack time of trigger haptic effect 3000, and for a length of the decay time of trigger haptic effect 3000.

FIG. 31 illustrates a flow diagram of the functionality of a haptic trigger control module (such as haptic trigger control module 16 of FIG. 1), according to an embodiment of the invention. In one embodiment, the functionality of FIG. 31 is 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. In certain embodiments, some of the functionality can be omitted.

The flow begins and proceeds to 3110. At 3110, an audio effect definition including audio data is converted into a haptic effect definition including haptic data. In one embodiment, the haptic effect definition can define a haptic effect that can be experienced at a user input element of a peripheral device, or that can be experienced at the peripheral device. Further, in one embodiment, a user input element can be a trigger, and a peripheral device can be a controller or gamepad. The flow then proceeds to 3120. At 3120, the haptic effect definition is received. In one embodiment, the

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haptic effect definition can be a trigger haptic effect definition. Further, in an embodiment, the haptic effect definition can recreate a haptic effect of a different format. The flow then proceeds to 3130.

At 3130, the haptic data of the haptic effect definition is modified based on received spatialization data. The spatialization data can include at least one of: a direction of the haptic effect; or a flow of the haptic effect. In certain embodiments, the modifying the haptic data of the haptic effect definition can include scaling at least one of: a magnitude of the haptic data; a frequency of the haptic data; or a duration of the haptic data. The flow then proceeds to 3140. At 3140, trigger data is received. The trigger data can include at least one of: a position of the trigger of the peripheral device; or a range of the trigger of the peripheral device. The flow then proceeds to 3150.

At 3150, it is determined whether a trigger condition is reached based on the received trigger data. The flow then proceeds to 3160. At 3160, the haptic data of the haptic effect definition is encoded. In certain embodiments, the haptic data of the haptic effect definition can be encoded within an audio file or audio stream. The flow then proceeds to 3170.

At 3170, a haptic instruction and the haptic effect definition are sent to the peripheral device. In certain embodiments, the haptic instruction and the haptic effect definition can be sent to the peripheral device when the trigger condition is reached. In these embodiments, the haptic instruction can be a trigger instruction. In certain embodiments, the sending the haptic effect definition to the peripheral device can include directly sending the haptic data of the haptic effect definition to the peripheral device. In other embodiments, the sending the haptic effect definition to the peripheral device can include: (1) converting the haptic data of the haptic effect definition from a first format to a second format; and (2) sending the converted haptic data of the haptic effect definition to the peripheral device. The flow then proceeds to 3180.

At 3180, the encoded haptic data of the haptic effect definition is decoded. In certain embodiments, the encoded haptic data can be decoded by computing a programmable crossover. The flow then proceeds to 3190. At 3190, the haptic instruction causes a haptic output device to produce a haptic effect based on the haptic effect definition at the peripheral device. In certain embodiments, the haptic instruction can cause the haptic output device to produce the haptic effect based on the haptic effect definition at the user input element of the peripheral device. In certain embodiments, the haptic instruction can be a trigger instruction, the haptic effect definition can be a trigger haptic effect definition, the haptic output device can be a targeted haptic output device, and the targeted haptic output device can produce the haptic effect at a trigger of the peripheral device. In certain embodiments, the targeted haptic output device can be a targeted actuator. In some of those embodiments, the targeted actuator can be a targeted motor. Further, in certain embodiments, the haptic instruction can cause multiple haptic output devices to produce multiple haptic effects based on the haptic effect definition at the peripheral device. The flow then ends.

In an embodiment, as previously described, a spatialization engine can receive haptic data, such as a trigger haptic effect definition, and can modify the haptic data based on spatialization data, where spatialization data can include one or more parameters. Thus, the spatialization engine can localize or spatialize haptic effects. More specifically, the spatialization engine can produce a haptic effect that con-

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veys a distance of the haptic effect by scaling or attenuating the haptic effect on an actuator or motor based on the distance of the haptic effect. The spatialization engine can further produce a haptic effect that conveys movement on a controller, gamepad, or other peripheral device by delaying or scaling the haptic effect on different actuators or motors. The spatialization engine can be a component of an API or library, or can be implemented in firmware for a controller, gamepad, or other peripheral device.

FIG. 32 illustrates an example spatialization engine that resides in an API or library, according to an embodiment of the invention. The spatialization engine is implemented on a system, such as system 10 of FIG. 1. In the illustrated embodiment, the system includes the following components: device 3200 (identified in FIG. 32 as “gaming console, smartphone, tablet or computer (for example) 3200”), and controller 3210 (identified in FIG. 32 as “gamepad 3210”). Device 3200 can be any type of computer device, such as a personal computer, tablet, smartphone, or console (e.g., video game console). Controller 3210 is an example of a peripheral device that is operably connected to device 3200. Controller 3210 can be a video game controller. In one embodiment, controller 3210 can be identical to controller 30 of FIG. 1, controller 100 of FIGS. 2, 3, and 4, and controller 520 of FIG. 5.

Device 3200 includes effect library 3201, where effect library 3201 can include one or more haptic effect definitions. In the embodiment, these haptic effect definitions can be identified as unspatialized haptic effect definitions, as they are haptic effect definitions that have not been modified by a spatialization engine. Device 3200 further includes game 3202, where game 3202 is a software application, such as a game application, that can be executed on the system. According to the embodiment, game 3202 can generate one or more spatialization parameters, where the one or more spatialization parameters can define a position, velocity, direction, and/or flow of a haptic effect defined by a haptic effect definition that is stored within effect library 3201.

Device 3200 further includes spatialization engine 3203 (identified in FIG. 32 as “haptic spatialization engine 3203”), where effect library 3201 can send one or more unspatialized haptic effect definitions to spatialization engine 3203, and where game 3202 can send one or more spatialization parameters to spatialization engine 3203. Spatialization engine 3203 can receive the one or more unspatialized haptic effect definitions, and can modify the one or more unspatialized haptic effect definitions based on the one or more spatialization parameters. According to the embodiment, spatialization engine 3203 can modify the one or more unspatialized haptic effect definitions, so that one or more haptic effects are scaled or attenuated for one or more actuators 3211 of controller 3210, where the one or more modified haptic effect definitions can be identified as spatialized haptic effect definitions. In other words, spatialization engine 3203 can modify the haptic effect definition that is sent to each actuator of actuators 3211, and thus, modify the haptic effect that is experienced at each actuator of actuators 3211, in order to convey a sense of position, velocity, direction, and/or flow of the haptic effect. Spatialization engine 3203 can subsequently send the one or more spatialized haptic effect definitions to controller 3210. Controller 3210 can subsequently send each spatialized haptic effect definition to each actuator of actuators 3211, where each actuator can produce a spatialized haptic effect.

FIG. 33 illustrates an example spatialization engine that resides in a controller, according to an embodiment of the invention. The spatialization engine is implemented on a

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system, such as system 10 of FIG. 1. In the illustrated embodiment, the system includes the following components: device 3300 (identified in FIG. 33 as “gaming console, smartphone, tablet or computer (for example) 3300”), and controller 3310 (identified in FIG. 33 as “gamepad 3310”). Device 3300 can be any type of computer device, such as a personal computer, tablet, smartphone, or console (e.g., video game console). Controller 3310 is an example of a peripheral device that is operably connected to device 3300. Controller 3310 can be a video game controller. In one embodiment, controller 3310 can be identical to controller 30 of FIG. 1, controller 100 of FIGS. 2, 3, and 4, and controller 520 of FIG. 5.

Device 3300 includes effect library 3301, where effect library 3301 can include one or more haptic effect definitions, identified as unspatialized haptic effect definitions. Device 3300 further includes game 3302, where game 3302 is a software application, such as a game application, that can be executed on the system. According to the embodiment, game 3302 can generate one or more spatialization parameters, where the one or more spatialization parameters can define a position, velocity, direction, and/or flow of a haptic effect defined by a haptic effect definition that is stored within effect library 3301.

Controller 3310 includes spatialization engine 3311 (identified in FIG. 33 as “haptic spatialization engine 3311”), where effect library 3301 can send one or more unspatialized haptic effect definitions to spatialization engine 3311, and where game 3302 can send one or more spatialization parameters to spatialization engine 3311. Spatialization engine 3311 can receive the one or more unspatialized haptic effect definitions, and can modify the one or more unspatialized haptic effect definitions based on the one or more spatialization parameters, where the one or more modified haptic effect definitions are identified as spatialized haptic effect definitions. Spatialization engine 3311 can subsequently send each spatialized haptic effect definition to each actuator of actuators 3312, where each actuator can produce a spatialized haptic effect.

Thus, in one embodiment, a system can provide a haptic control architecture that can generate a haptic effect that is experienced at a peripheral device, such as a controller or gamepad. The haptic effect can be a trigger haptic effect that is experienced at a trigger of the peripheral device. The trigger haptic effect can be customized by the haptic control architecture based on trigger data that is received by the system, where the trigger data can include a position and/or range of the trigger. The trigger haptic effect can be further spatialized by the haptic control architecture so that the trigger haptic effect is scaled at each motor or actuator of the peripheral device, so that the trigger haptic effect includes a sense of directionality and/or flow. By incorporating haptic feedback experienced at a peripheral device, and in particular, haptic feedback experienced at a trigger of the peripheral device, into a gaming application that is executed by the system, a more realistic and immersive gaming experience can be provided.

The features, structures, or characteristics of the invention described throughout this specification may be combined in any suitable manner in one or more embodiments. For example, the usage of “one embodiment,” “some embodiments,” “certain embodiment,” “certain embodiments,” or other similar language, throughout this specification refers to the fact that a particular feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment of the present invention. Thus, appearances of the phrases “one embodiment,” “some

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embodiments,” “a certain embodiment,” “certain embodiments,” or other similar language, throughout this specification do not necessarily all refer to the same group of embodiments, and the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

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 non-transitory computer-readable medium having instructions stored thereon that, when executed by a processor, cause the processor to control a haptic effect rendered at a peripheral device, the controlling comprising:

receiving a haptic effect definition data structure that defines a plurality of parameters associated with each of a plurality of haptic data channels, each channel including a portion of haptic data from the haptic effect definition data structure for a different targeted haptic output device of a plurality of haptic output devices;

receiving trigger data including at least one of: a position of a trigger of the peripheral device; or a range of the trigger of the peripheral device;

determining whether a trigger condition is reached based on the received trigger data;

sending, through an application programming interface, a haptic instruction and the haptic effect definition data structure to the peripheral device after the trigger condition is reached; and

causing the haptic output devices to produce one or more haptic effects that are based on the haptic effect definition data structure at a user input element and a surface of the peripheral device in response to the haptic instruction;

wherein the portion of the haptic data contained within each channel causes a corresponding haptic output device to produce one or more haptic effects at a corresponding user input element or surface of the peripheral device.

2. The non-transitory computer-readable medium of claim 1, the controlling the haptic effect further comprising modifying the haptic data of the haptic effect definition data structure based on first spatialization data, and modifying the haptic data of the haptic effect definition data structure of a subset of channels based on second spatialization data.

3. The non-transitory computer-readable medium of claim 2, wherein the modifying the haptic data of the haptic effect definition data structure comprises scaling at least one of: a magnitude of the haptic data; a frequency of the haptic data; or a duration of the haptic data.

4. The non-transitory computer-readable medium of claim 1, wherein each channel is coupled to a different haptic output device so that multiple channels are not coupled to a single haptic output device.

5. The non-transitory computer-readable medium of claim 1, wherein the sending the haptic effect definition data structure to the peripheral device further comprises:

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converting the haptic data of the haptic effect definition data structure from a first format to a second format; and

sending the converted haptic data of the haptic effect definition data structure to the peripheral device.

6. The non-transitory computer-readable medium of claim 1, the controlling the haptic effect further comprising encoding the haptic data of the haptic effect definition data structure within a file or stream that has an audio format.

7. The non-transitory computer-readable medium of claim 6, the controlling the haptic effect further comprising decoding the encoded haptic data within the file or stream.

8. The non-transitory computer-readable medium of claim 7, the decoding the encoded haptic data further comprising computing a programmable crossover.

9. The non-transitory computer-readable medium of claim 1, wherein the haptic effect definition data structure recreates a haptic effect of a different format.

10. The non-transitory computer-readable medium of claim 1, wherein the peripheral device comprises a controller or gamepad.

11. The non-transitory computer-readable medium of claim 1,

wherein the haptic effect definition data structure comprises a trigger haptic effect definition,

wherein the haptic instruction comprises a trigger instruction;

wherein at least one user input element comprises the trigger; and

wherein the one or more haptic output devices comprise one or more targeted haptic output devices.

12. The non-transitory computer-readable medium of claim 1, the controlling the haptic effect further comprising converting an audio effect definition comprising audio data into the haptic effect definition data structure.

13. The non-transitory computer-readable medium of claim 1, wherein the haptic output device comprises an actuator.

14. The non-transitory computer-readable medium of claim 13, wherein the actuator comprises a motor.

15. A computer-implemented method for controlling a haptic effect rendered at a user input element of a peripheral device, the computer-implemented method comprising:

receiving a haptic effect definition data structure that defines a plurality of parameters associated with each of a plurality of haptic data channels, each channel including a portion of haptic data from the haptic effect definition data structure for a different targeted haptic output device of a plurality of haptic output devices;

receiving trigger data including at least one of: a position of a trigger of the peripheral device; or a range of the trigger of the peripheral device;

determining whether a trigger condition is reached based on the received trigger data;

sending, through an application programming interface, a haptic instruction and the haptic effect definition data structure to the peripheral device after the trigger condition is reached; and

causing a plurality of haptic output devices to produce one or more haptic effects that are based on the haptic effect definition data structure at a user input element and a surface of the peripheral device in response to the haptic instruction;

wherein the portion of the haptic data contained within each channel causes a corresponding haptic output

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device to produce one or more haptic effects at a corresponding user input element and surface of the peripheral device.

16. The computer-implemented method of claim 15, wherein modifying the haptic data of the haptic effect definition data structure based on received spatialized direction comprises modification to at least one of: a direction of the haptic effect; or a flow of the haptic effect.

17. The computer-implemented method of claim 16, wherein the modifying the haptic data of the haptic effect definition data structure comprises scaling at least one of: a magnitude of the haptic data; a frequency of the haptic data; or a duration of the haptic data.

18. The computer-implemented method of claim 15, wherein the sending the haptic effect definition data structure to the peripheral device further comprises directly sending the haptic data of the haptic effect definition data structure to the peripheral device.

19. The computer-implemented method of claim 15, wherein the sending the haptic effect definition data structure to the peripheral device further comprises:

- converting the haptic data of the haptic effect definition data structure from a first format to a second format; and
- sending the converted haptic data of the haptic effect definition data structure to the peripheral device.

20. A system for controlling a haptic effect rendered at a user input element of a peripheral device, the system comprising:

- a memory configured to store a haptic trigger control module; and
- a processor configured to execute the haptic trigger control module stored on the memory;

wherein the processor, when executing the haptic trigger control module, is configured to receive a haptic effect definition data structure that defines a plurality of parameters associated with each of a plurality of haptic data channels, each channel including a portion of haptic data from the haptic effect definition data structure for a different targeted haptic output device of a plurality of haptic output devices;

wherein the processor, when executing the haptic trigger control module, is further configured to receive trigger data including at least one of: a position of a trigger of the peripheral device; or a range of the trigger of the peripheral device;

wherein the processor, when executing the haptic trigger control module, is further configured to determine whether a trigger condition is reached based on the received trigger data;

wherein the processor, when executing the haptic trigger control module, is further configured to send, through an application programming interface, a haptic instruction and the haptic effect definition data structure to the peripheral device after the trigger condition is reached; and

wherein the processor, when executing the haptic trigger control module, is further configured to cause a plurality of haptic output devices to produce one or more haptic effects that are based on the haptic effect definition data structure at a user input element and a surface of the peripheral device in response to the haptic instruction;

wherein the portion of the haptic data contained within each channel causes a corresponding haptic output

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device to produce one or more haptic effects at a corresponding user input element or surface of the peripheral device.

21. The system of claim 20, wherein the processor, when executing the haptic trigger control module, is further configured to modify the haptic data of the haptic effect definition data structure based on received spatialized direction comprising at least one of: a direction of the haptic effect; or a flow of the haptic effect.

22. The system of claim 21, wherein the processor, when executing the haptic trigger control module, is further configured to scale at least one of: a magnitude of the haptic data; a frequency of the haptic data; or a duration of the haptic data.

23. The system of claim 20, wherein the processor, when executing the haptic trigger control module, is further configured to directly send the haptic data of the haptic effect definition data structure to the peripheral device.

24. The system of claim 20, wherein the processor, when executing the haptic trigger control module, is further configured to convert the haptic data of the haptic effect definition data structure from a first format to a second format; and wherein the processor, when executing the haptic trigger control module, is further configured to send the converted haptic data of the haptic effect definition data structure to the peripheral device.

25. A non-transitory computer-readable medium having instructions stored thereon that, when executed by a processor, cause the processor to control a haptic effect rendered at a peripheral device, the controlling comprising:

- receiving a haptic effect definition data structure that defines a plurality of parameters associated with each of a plurality of haptic data channels, each channel including a portion of haptic data from the haptic effect definition data structure for a different targeted haptic output device of a plurality of haptic output devices;
- modifying the haptic data of the haptic effect definition based on received spatialization data including at least one of: a direction of the haptic effect; or a flow of the haptic effect; sending, through an application programming interface, a haptic instruction and the haptic effect definition data structure to the peripheral device; and causing a plurality of haptic output devices to produce one or more haptic effects based on the haptic effect definition data structure at a user input element and a surface of the peripheral device in response to the haptic instruction;

wherein the portion of the haptic data contained within each channel causes a corresponding haptic output device to produce one or more haptic effects at a corresponding user input element or surface of the peripheral device.

26. The non-transitory computer-readable medium of claim 25, wherein the modifying the haptic data of the haptic effect definition data structure comprises scaling at least one of: a magnitude of the haptic data; a frequency of the haptic data; or a duration of the haptic data.

27. The non-transitory computer-readable medium of claim 25, the controlling the haptic effect further comprising converting an audio effect definition comprising audio data into the haptic effect definition data structure.

28. The non-transitory computer-readable medium of claim 25, wherein the causing the one or more haptic output devices to produce the one or more haptic effects further comprises causing the one or more haptic output devices to

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produce the one or more haptic effects at a user input element of the peripheral device.

29. The non-transitory computer-readable medium of claim 28, wherein the user input element comprises one of: a digital button; an analog button; a bumper; a directional pad; an analog or digital stick; a driving wheel; or a trigger.

30. A non-transitory computer-readable medium having instructions stored thereon that, when executed by a processor, cause the processor to control a haptic effect experienced at a peripheral device, the controlling comprising:

receiving a haptic effect definition data structure that defines a plurality of parameters associated with each of a plurality of haptic data channels and a trigger haptic effect definition data structure that defines a plurality of parameters associated with each of a plurality of trigger haptic data channels, each channel including a portion of the haptic data and each channel being coupled to a different haptic output device of a plurality of haptic output devices;

receiving trigger data including at least one of: a position of a trigger of the peripheral device; or a range of the trigger of the peripheral device;

determining whether a trigger condition is reached based on the received trigger data;

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sending a haptic instruction including a trigger instruction, and the haptic effect definition data structure to the peripheral device after the trigger condition is reached; and

causing a plurality of haptic output devices to produce one or more haptic effects that are based on the haptic effect definition data structure at a trigger element and a surface of the peripheral device in response to the haptic instruction;

wherein the portion of the haptic data contained within each channel causes a corresponding haptic output device to produce one or more haptic effects at a corresponding user input element or surface of the peripheral device.

31. The non-transitory computer-readable medium of claim 30, further comprising:

modifying the haptic data of the haptic effect definition data structure based on received spatialized direction at least one of: a direction of the haptic effect; or a flow of the haptic effect; and

converting the haptic data of the haptic effect definition data structure from a first format to a second format.

32. The non-transitory computer-readable medium of claim 30, wherein the one or more haptic output devices comprise one or more targeted haptic output devices.

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