

ARTIFICIAL REALITY DEVICE ACCESSORIES TO INCREASE THERMAL BUDGET

TECHNICAL FIELD

[1] This disclosure generally relates to using accessories to dissipate heat generated by a computing device.

BACKGROUND

[2] Artificial reality is a form of reality that has been adjusted in some manner before presentation to a user, which may include, e.g., a virtual reality (VR), an augmented reality (AR), a mixed reality (MR), a hybrid reality, or some combination and/or derivatives thereof. Artificial reality content may include completely generated content or generated content combined with captured content (e.g., real-world photographs). The artificial reality content may include video, audio, haptic feedback, or some combination thereof, and any of which may be presented in a single channel or in multiple channels (such as stereo video that produces a three-dimensional effect to the viewer). Artificial reality may be associated with applications, products, accessories, services, or some combination thereof, that are, e.g., used to create content in an artificial reality and/or used in (e.g., perform activities in) an artificial reality. The artificial reality system that provides the artificial reality content may be implemented on various platforms, including a head-mounted display (HMD) connected to a host computer system, a standalone HMD, a mobile device or computing system, or any other hardware platform capable of providing artificial reality content to one or more viewers.

SUMMARY OF PARTICULAR EMBODIMENTS

[3] Any computing device—such as a smartphone, tablet computer, or laptop computer—naturally generates thermal energy, or heat, as it consumes power. This is true for any computing platform or computing device that can be used to implement an artificial reality system. The amount of heat generated can increase for a variety of reasons, including a user running too many applications on the computing device or a user running one or more application for long periods of time. Increased heat generation by the computing device can lead to overheating of the

computing device. Likewise, environmental factors, such as exposure to direct sunlight (solar load) or use in an otherwise hot environment (ambient temperature) can lead to overheating of the computing device. In some instances, overheating can cause a temporary reduction in functionality, such as a lowering of processing speed and/or an inability to remain powered on. In the same or other instances, overheating can cause permanent damages to device components and/or degrade product reliability.

[4] Since varying ambient temperature and solar load conditions significantly change a device's Thermal Design Power (TDP), there are inevitably operation environments (e.g., outdoors in the sun) where the device won't have enough thermal headroom to run many desired use cases or to run them for long periods of time. In other words, the device may cease to function properly due to overheating caused by some environments. TDP limits the sustained power consumption of a computing device because power consumption above the TDP limit may result in the device violating comfort, safety, or compliance thermal limits. For example, when the device reaches a certain temperature, it will be too hot to be comfortable against a user's head. This limited TDP is dictated by existing device design (e.g. limited surface area and coefficient of thermal spreading (CTS)).

[5] Disclosed systems provide a head mounted display (HMD) associated with an artificial reality system, wherein the head mounted display is configured to accommodate accessories, which accessories are particularly configured to increase the thermal design power (TDP) of the HMD.

[6] Disclosed systems provide techniques for increasing the TDP of an HMD through use of external components that can be attached to the HMD in certain environments and as needed. Furthermore, the disclosed systems allow for a variety of options for accessories to suit the needs, comfort and style of a particular user, which accessories may be switched out as desired and as needed. This technique is available for every type of HMD, regardless of capability to reduce heat generation or dispel heat, to cool down in a wide variety of environments, thus optimizing the capabilities of a particular HMD or artificial-reality device. To implement this system, an HMD may be configured with an attachment point to connect to one or more of the optional accessories.

[7] In particular embodiments, the thermal energy may be generated by one or more components (e.g., CPU, GPU, display etc.) of a computing system associated with a device (e.g., a laptop, a cellphone, a desktop, a wearable device). The one or more components may be a heat source. In particular embodiments, the device is in communication with a computing system on the HMD but may be otherwise physically separated from the HMD. As an example and not by way of limitation, this device may be a laptop device that is wired to the HMD or communicates wirelessly with the HMD. As another example and not by way of limitation, the device may be a wearable (e.g., a device strapped to a wrist), handheld device (e.g., a phone), or some other suitable device (e.g., a laptop, a tablet, a desktop) that is wired to the HMD or communicates wirelessly with the HMD. As another example and not by way of limitation, an onboard computing system of an HMD may be the cause of generation of thermal energy of one or more other devices.

[8] Particular accessories provide users the ability to extend and/or increase their product TDP when they want to do so. In some embodiments, the particular accessories are active accessories, the active accessories possessing components that require energy to cool the computer components. In other embodiments, the particular accessories are passive accessories, the passive accessories possessing components that cool the computer components without requiring additional energy. With either active or passive accessories, the result is extension of thermal headroom available for the computing components. In some embodiments, both passive and active accessories may be used. In the same or other embodiments, both passive and active forms of heat dissipation may be used on the same accessory.

[9] Examples of either active or passive accessories include a visor with special (e.g., thermally conductive) contact points to the HMD, a docking station with special contact points, and a headband with special thermally conductive contact points.

[10] In some embodiments, the frame of the HMD is built with a special contact/mount/attachment point for these accessories. These contact points are specifically designed to promote heat spreading from the computing device to the accessory. These contact points are further configured to interface with the special contact points on the accessories themselves.

[11] In some embodiments, an accessory acts as a heat sink to an HMD or AR device. In another, an accessory dissipates generated and added heat to extend areas of the HMD user

body. In another embodiment, heat is stored in a heat storage medium. Furthermore, in some embodiments, an accessory can be used to increase/extend HMD or AR device TDP by either: 1) increasing the heat rejection to the environment air (e.g., passively, by using a larger surface area of the accessory, and/or actively, by using a fan or a thermoelectric cooler), 2) increasing the HMD or AR device heat rejection to the HMD user body (e.g., by having contact with extended areas of the HMD user body and use of the user's body as a heat sink), or 3) using phase change material (or other heat storage techniques) to transfer heat from the HMD or AR device to a heat storage medium in a short duration of time (e.g., during running a use-case with high power demand). The stored heat in the phase change material (or other heat storage device) in technique No. 3 may be dissipated over a period of time when there is less heat generation on the device.

[12] The embodiments disclosed herein are only examples, and the scope of this disclosure is not limited to them. Particular embodiments may include all, some, or none of the components, elements, features, functions, operations, or steps of the embodiments disclosed herein. Embodiments according to the invention are in particular disclosed in the attached claims directed to an apparatus and a system, wherein any feature mentioned in one claim category, e.g. apparatus, can be claimed in another claim category, e.g. system, as well. The dependencies or references back in the attached claims are chosen for formal reasons only. However any subject matter resulting from a deliberate reference back to any previous claims (in particular multiple dependencies) can be claimed as well, so that any combination of claims and the features thereof are disclosed and can be claimed regardless of the dependencies chosen in the attached claims. The subject-matter which can be claimed comprises not only the combinations of features as set out in the attached claims but also any other combination of features in the claims, wherein each feature mentioned in the claims can be combined with any other feature or combination of other features in the claims. Furthermore, any of the embodiments and features described or depicted herein can be claimed in a separate claim and/or in any combination with any embodiment or feature described or depicted herein or with any of the features of the attached claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[13] FIG. 1 illustrates an example augmented reality system.

[14] FIG. 2 illustrates an example computer system.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[15] FIG. 1 illustrates an example augmented reality system 100. The augmented reality system 100 may include a head-mounted display (HMD) 110 (e.g., glasses) comprising a frame 112, one or more displays 114, a computing system 120, and a one or more thermal contacting features 140. The thermal contacting features may be specially configured to interface with thermal contact points on accessories designed to store and/or dissipate thermal energy or heat, thus increasing the TDP of the HMD. The displays 114 may be transparent or translucent allowing a user wearing the HMD 110 to look through the displays 114 to see the real world and displaying visual artificial reality content to the user at the same time. The HMD 110 may include an audio device that may provide audio artificial reality content to users. The HMD 110 may include one or more cameras which can capture images and videos of environments. The HMD 110 may include an eye tracking system to track the vergence movement of the user wearing the HMD 110. The augmented reality system 100 may further include a controller comprising a trackpad and one or more buttons. The controller may receive inputs from users and relay the inputs to the computing system 120. The controller may also provide haptic feedback to users. The computing system 120 may be connected to the HMD 110 and the controller through cables or wireless connections. The computing system 120 may control the HMD 110 and the controller to provide the augmented reality content to and receive inputs from users. The computing system 120 may be a standalone host computer system, an on-board computer system integrated with the HMD 110, a mobile device, or any other hardware platform capable of providing artificial reality content to and receiving inputs from users.

[16] Users of artificial reality systems may desire to use the artificial reality systems in a variety of locations, each with a different thermal base. For example and not by way of limitation, users may wish to use the artificial reality systems in direct sunlight, meaning that the HMD 110 will also be used in direct sunlight. One potential method of thermal energy dissipation is through use of a fan on different parts of the HMD 110. This method, however, though effective, requires extra power. Thus, use of a passive energy dissipation, e.g., through an increased surface area, may be desirable in some circumstances.

[17] One way to increase thermal budget is to increase the surface area thermally coupled to the HMD 110 through use of device accessories. By implementing device accessories,

the artificial reality experience can be improved by, for example, dissipating the thermal energy in an active or passive way using the device accessories. They may further be switched out and/or taken off as needed or when in an environment where the HMD 110's natural device cooling function is sufficient to maintain proper functioning of the device. They may be connected via a thermal contacting feature 140 on the HMD 110, e.g., at one or both temples, at the ends of frames, and/or at the bridge of the user's nose. Active heat dissipation, such as through use of fans and/or thermoelectric coolers may be effective and desirable in some circumstances. However, active heat dissipation also increases the power requirements of an HMD 110, which may be undesirable in other circumstances due to the small space for power storage. It may also be undesirable in some circumstances because fans increase the noise right next to a user's face. Accordingly, there is an interest in extending the surface area that can be exposed to the air, allowing for passive heat dissipation. Thus, some embodiments described herein allow for passive heat dissipation through accessories configured to interface with an HMD 110.

[18] In yet more embodiments, minimal active digital/analog components may be added to an accessory (e.g., platform thermal sensors) which allow a computing device to include accessory temperature in thermal management. For example, this may monitor temperature of the accessory surface areas in contact with the user and enforce skin/surface limits on these surfaces. In some embodiments there may be digital/analog interface(s) between the accessory and an AR device to communicate data (e.g., sensed temperature and/or control signals) between them. In some embodiments, this interface may be wired (through physical pins/contact). In some embodiments, this communication can be done wirelessly. An exchange of data between the accessory and AR device can be used for identification of the accessory by the AR device (e.g., accessory type, model, capability, etc.) instead of or in addition to communication of telemetry (e.g., sensed temperature) and control information between the accessory and the AR device.

[19] In another embodiment, a temperature associated with an accessory relative to primary HMD 110 or AR device may be used to control accessory and computing device thermal conduction/contact. This has the advantage of increasing the ability to limit or prevent the accessory from heating up the HMD 110 if the accessory is hotter than HMD 110. In cases where the accessory uses phase change material for heat storage, this control is helpful in stopping heat transfer to the phase change material when heat storage capacity is reached and allow the gradual

dissipation of heat for this material. In some embodiments, this gradual dissipation is achieved using an active electrical/magnetic contact, which electrically controls the amount of thermal contact between the device and the accessory high thermal contact when the accessory is colder and acts as a heat sink and low thermal contact (e.g., air gaps) when the accessory is hotter than the HMD 110. In other embodiments, this gradual dissipation is achieved passively using, e.g., bimetallic strips which engage as long as temperature is below a certain threshold.

[20] In some embodiments, there may be more than one of the described thermal contact points. In such an embodiment, each of the contact points may be capable of being controlled separately. The capability to independently control multiple thermal contact points can be used to reduce non-uniform distribution of temperature over a product. For example, in the context of an AR glasses form factor device with two temple arms, there may be a thermal contact point for an accessory on both left and right side temple arms. In such a case, if a thermal management framework detects that one temple arm is getting hotter than the other temple arm (e.g., due to higher power consumption from electronics on one side, or due to solar load exposure on one side), then thermal contact of left and right side temple arms could be set differently to promote higher heat extraction from the side getting hotter and prevent that side from reaching a comfort/safety limit earlier than the other side.

[21] In another embodiment, an accessory may include a mechanism for active cooling, such as one or more fans. This may be desirable, for example, in a particularly hot environment or when a user is exposed to sunlight for long periods of time while using the HMD 110.

[22] In yet another embodiment, one or more accessories may use a heat pipe for faster transfer of heat from the AR device to the one or more accessories.

[23] In some embodiments, an accessory may include a visor with a special chassis/frame which can mount on the HMD 110. Such a visor may serve multiple functions, for example, it may block the sun from a user's face, reduce solar load on HMD 110 and/or computing system 120, and act as a heatsink for HMD 110 and/or computing system 120. A visor may, for example, dissipate heat using one method through its large surface area and/or using another method through increasing contact with the user's skin. In other embodiments, an accessory may include a cap or hat, over-the-ear headphones or ear warmers, or clip-on shades (on the front of HMD 110) or clip-on heat storage cartridges on frame 112. In another embodiment, an accessory

may be a passive HMD 110 dock (passive dock without charging capabilities of chip), which may serve dual functions, to hold HMD 110 in the position desired by the user and to act as a heatsink for computing system 120. The passive HMD 110 dock may be able to dissipate heat using any of the methods described above, in particular the method of increased surface area exposed to air. Similarly, in an embodiment, an accessory may be an active HMD 110 dock, which may serve triple functions, to hold HMD 110 in the position desired by the user, to act as a heatsink with active cooling (e.g., using a fan), and to charge the computing system 120.

[24] In some embodiments, an accessory may include a headband with heat conductive contact with HMD 110 and specially designed outer material to promote fast heat transfer with air. Furthermore, the headband could utilize specially designed headband internal material (e.g., the material that is in contact with the user's head) to promote heat transfer to larger areas of the user's head. Alternatively, the headband can include phase change material to use the method described above.

[25] In some embodiments, an accessory may include a sport strap, connecting the frame arms from the back of the user's head to prevent HMD 110 from falling off during sport activities. The sport strap can include special outer surface structure to promote heat dissipation. Additionally or alternatively, the sport strap can include special inner surface material, designed or selected to promote heat dissipation to the user's head. Additionally or alternatively, the sport strap can include special phase change material to promote more short-term heat absorption from HMD 110 and gradual heat dissipation during device idle time.

[26] As a highlight enhancement, which may be added to any of the above embodiments, a physical contact point between an accessory and HMD 110/computing system 120 can be electronically and/or magnetically controlled. In some embodiments, the control may cause there to be heat conductive contact when the accessory serves as a heat sink to HMD 110/computing system 120 and not have heat conductive contact when the accessory heats up HMD 110/computing system 120 (e.g., when a visor frame is hotter than HMD 110). Similarly, as discussed above, the control may be done passively through a bimetallic strip that engages as long as temperature is below a threshold and then stops when that threshold is reached or exceeded.

[27] Additionally or alternatively, as a highlight enhancement, which may be added to any of the above embodiments, one or more digital/analog temperature sensors may be added to

the accessory, and this temperature data may be communicated to HMD 110/computing system 120 for use in runtime thermal management.

[28] **FIG. 2** illustrates an example computer system 200. In particular embodiments, one or more computer systems 200 perform one or more steps of one or more methods described or illustrated herein. In particular embodiments, one or more computer systems 200 provide functionality described or illustrated herein. In particular embodiments, software running on one or more computer systems 200 performs one or more steps of one or more methods described or illustrated herein or provides functionality described or illustrated herein. Particular embodiments include one or more portions of one or more computer systems 200. Herein, reference to a computer system may encompass a computing device, and vice versa, where appropriate. Moreover, reference to a computer system may encompass one or more computer systems, where appropriate.

[29] This disclosure contemplates any suitable number of computer systems 200. This disclosure contemplates computer system 200 taking any suitable physical form. As example and not by way of limitation, computer system 200 may be an embedded computer system, a system-on-chip (SOC), a single-board computer system (SBC) (such as, for example, a computer-on-module (COM) or system-on-module (SOM)), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a personal digital assistant (PDA), a server, a tablet computer system, an augmented/virtual reality device, or a combination of two or more of these. Where appropriate, computer system 200 may include one or more computer systems 200; be unitary or distributed; span multiple locations; span multiple machines; span multiple data centers; or reside in a cloud, which may include one or more cloud components in one or more networks. Where appropriate, one or more computer systems 200 may perform without substantial spatial or temporal limitation one or more steps of one or more methods described or illustrated herein. As an example and not by way of limitation, one or more computer systems 200 may perform in real time or in batch mode one or more steps of one or more methods described or illustrated herein. One or more computer systems 200 may perform at different times or at different locations one or more steps of one or more methods described or illustrated herein, where appropriate.

[30] In particular embodiments, computer system 200 includes a processor 202, memory 204, storage 206, an input/output (I/O) interface 208, a communication interface 210, and a bus 212. Although this disclosure describes and illustrates a particular computer system having a particular number of particular components in a particular arrangement, this disclosure contemplates any suitable computer system having any suitable number of any suitable components in any suitable arrangement.

[31] In particular embodiments, processor 202 includes hardware for executing instructions, such as those making up a computer program. As an example and not by way of limitation, to execute instructions, processor 202 may retrieve (or fetch) the instructions from an internal register, an internal cache, memory 204, or storage 206; decode and execute them; and then write one or more results to an internal register, an internal cache, memory 204, or storage 206. In particular embodiments, processor 202 may include one or more internal caches for data, instructions, or addresses. This disclosure contemplates processor 202 including any suitable number of any suitable internal caches, where appropriate. As an example and not by way of limitation, processor 202 may include one or more instruction caches, one or more data caches, and one or more translation lookaside buffers (TLBs). Instructions in the instruction caches may be copies of instructions in memory 204 or storage 206, and the instruction caches may speed up retrieval of those instructions by processor 202. Data in the data caches may be copies of data in memory 204 or storage 206 for instructions executing at processor 202 to operate on; the results of previous instructions executed at processor 202 for access by subsequent instructions executing at processor 202 or for writing to memory 204 or storage 206; or other suitable data. The data caches may speed up read or write operations by processor 202. The TLBs may speed up virtual-address translation for processor 202. In particular embodiments, processor 202 may include one or more internal registers for data, instructions, or addresses. This disclosure contemplates processor 202 including any suitable number of any suitable internal registers, where appropriate. Where appropriate, processor 202 may include one or more arithmetic logic units (ALUs); be a multi-core processor; or include one or more processors 202. Although this disclosure describes and illustrates a particular processor, this disclosure contemplates any suitable processor.

[32] In particular embodiments, memory 204 includes main memory for storing instructions for processor 202 to execute or data for processor 202 to operate on. As an example

and not by way of limitation, computer system 200 may load instructions from storage 206 or another source (such as, for example, another computer system 200) to memory 204. Processor 202 may then load the instructions from memory 204 to an internal register or internal cache. To execute the instructions, processor 202 may retrieve the instructions from the internal register or internal cache and decode them. During or after execution of the instructions, processor 202 may write one or more results (which may be intermediate or final results) to the internal register or internal cache. Processor 202 may then write one or more of those results to memory 204. In particular embodiments, processor 202 executes only instructions in one or more internal registers or internal caches or in memory 204 (as opposed to storage 206 or elsewhere) and operates only on data in one or more internal registers or internal caches or in memory 204 (as opposed to storage 206 or elsewhere). One or more memory buses (which may each include an address bus and a data bus) may couple processor 202 to memory 204. Bus 212 may include one or more memory buses, as described below. In particular embodiments, one or more memory management units (MMUs) reside between processor 202 and memory 204 and facilitate accesses to memory 204 requested by processor 202. In particular embodiments, memory 204 includes random access memory (RAM). This RAM may be volatile memory, where appropriate. Where appropriate, this RAM may be dynamic RAM (DRAM) or static RAM (SRAM). Moreover, where appropriate, this RAM may be single-ported or multi-ported RAM. This disclosure contemplates any suitable RAM. Memory 204 may include one or more memories 204, where appropriate. Although this disclosure describes and illustrates particular memory, this disclosure contemplates any suitable memory.

[33] In particular embodiments, storage 206 includes mass storage for data or instructions. As an example and not by way of limitation, storage 206 may include a hard disk drive (HDD), a floppy disk drive, flash memory, an optical disc, a magneto-optical disc, magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more of these. Storage 206 may include removable or non-removable (or fixed) media, where appropriate. Storage 206 may be internal or external to computer system 200, where appropriate. In particular embodiments, storage 206 is non-volatile, solid-state memory. In particular embodiments, storage 206 includes read-only memory (ROM). Where appropriate, this ROM may be mask-programmed ROM, programmable ROM (PROM), erasable PROM (EPROM), electrically erasable PROM (EEPROM), electrically alterable ROM (EAROM), or flash memory or a combination of two or

more of these. This disclosure contemplates mass storage 206 taking any suitable physical form. Storage 206 may include one or more storage control units facilitating communication between processor 202 and storage 206, where appropriate. Where appropriate, storage 206 may include one or more storages 206. Although this disclosure describes and illustrates particular storage, this disclosure contemplates any suitable storage.

[34] In particular embodiments, I/O interface 208 includes hardware, software, or both, providing one or more interfaces for communication between computer system 200 and one or more I/O devices. Computer system 200 may include one or more of these I/O devices, where appropriate. One or more of these I/O devices may enable communication between a person and computer system 200. As an example and not by way of limitation, an I/O device may include a keyboard, keypad, microphone, monitor, mouse, printer, scanner, speaker, still camera, stylus, tablet, touch screen, trackball, video camera, another suitable I/O device or a combination of two or more of these. An I/O device may include one or more sensors. This disclosure contemplates any suitable I/O devices and any suitable I/O interfaces 208 for them. Where appropriate, I/O interface 208 may include one or more device or software drivers enabling processor 202 to drive one or more of these I/O devices. I/O interface 208 may include one or more I/O interfaces 208, where appropriate. Although this disclosure describes and illustrates a particular I/O interface, this disclosure contemplates any suitable I/O interface.

[35] In particular embodiments, communication interface 210 includes hardware, software, or both providing one or more interfaces for communication (such as, for example, packet-based communication) between computer system 200 and one or more other computer systems 200 or one or more networks. As an example and not by way of limitation, communication interface 210 may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or other wire-based network or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a WI-FI network. This disclosure contemplates any suitable network and any suitable communication interface 210 for it. As an example and not by way of limitation, computer system 200 may communicate with an ad hoc network, a personal area network (PAN), a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), or one or more portions of the Internet or a combination of two or more of these. One or more portions of one or more of these networks may

be wired or wireless. As an example, computer system 200 may communicate with a wireless PAN (WPAN) (such as, for example, a BLUETOOTH WPAN), a WI-FI network, a WI-MAX network, a cellular telephone network (such as, for example, a Global System for Mobile Communications (GSM) network), or other suitable wireless network or a combination of two or more of these. Computer system 200 may include any suitable communication interface 210 for any of these networks, where appropriate. Communication interface 210 may include one or more communication interfaces 210, where appropriate. Although this disclosure describes and illustrates a particular communication interface, this disclosure contemplates any suitable communication interface.

[36] In particular embodiments, bus 212 includes hardware, software, or both coupling components of computer system 200 to each other. As an example and not by way of limitation, bus 212 may include an Accelerated Graphics Port (AGP) or other graphics bus, an Enhanced Industry Standard Architecture (EISA) bus, a front-side bus (FSB), a HYPERTRANSPORT (HT) interconnect, an Industry Standard Architecture (ISA) bus, an INFINIBAND interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCIe) bus, a serial advanced technology attachment (SATA) bus, a Video Electronics Standards Association local (VLB) bus, or another suitable bus or a combination of two or more of these. Bus 212 may include one or more buses 212, where appropriate. Although this disclosure describes and illustrates a particular bus, this disclosure contemplates any suitable bus or interconnect.

[37] Herein, a computer-readable non-transitory storage medium or media may include one or more semiconductor-based or other integrated circuits (ICs) (such, as for example, field-programmable gate arrays (FPGAs) or application-specific ICs (ASICs)), hard disk drives (HDDs), hybrid hard drives (HHDs), optical discs, optical disc drives (ODDs), magneto-optical discs, magneto-optical drives, floppy diskettes, floppy disk drives (FDDs), magnetic tapes, solid-state drives (SSDs), RAM-drives, SECURE DIGITAL cards or drives, any other suitable computer-readable non-transitory storage media, or any suitable combination of two or more of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

[38] Herein, “or” is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A or B” means “A, B, or both,” unless expressly indicated otherwise or indicated otherwise by context. Moreover, “and” is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A and B” means “A and B, jointly or severally,” unless expressly indicated otherwise or indicated otherwise by context.

[39] The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, feature, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Furthermore, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Additionally, although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.