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Bastani et al.

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(54) **VIRTUAL REALITY SYSTEM USING SUPER-RESOLUTION**

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(51) **Int. Cl.**

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G06T 5/00	(2006.01)
G06T 19/00	(2011.01)
G06T 3/40	(2006.01)

(52) **U.S. Cl.**
CPC ***G06K 9/40*** (2013.01); ***G06T 3/4053*** (2013.01); ***G06T 5/002*** (2013.01); ***G06T 19/006*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 3/017; G06F 1/163; G06F 3/011; G02B 2027/0134; G02B 27/017
USPC 382/264; 345/419; 348/51, 745, 43, 348/E13.068
See application file for complete search history.

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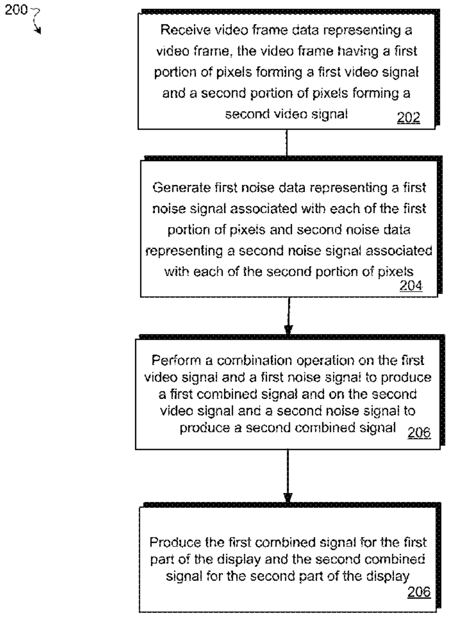
(57) **ABSTRACT**

Displaying video in an HMD may include introducing unperceived noise to the video frame signal in order to enhance dynamic range. For example, each of a viewer's left and right eyes have a field of view (FOV) corresponding to a portion of pixels shown on the HMD. For each of these portions of pixels, the VR system may combine a noise signal (e.g., zero-mean Gaussian white noise) with the video signals corresponding to each of the portions of pixels. The introduction of such noise may improve the dynamic range of the viewer. Further, in some implementations, the noise signal that is combined with the left video signal may be slightly different from the noise signal that is combined with the right video signal. Such slightly different noise signals may provide further improvement to the image seen by the viewer due to binocular summation.

20 Claims, 7 Drawing Sheets


200
Receive video frame data representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal 202
Generate first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels 204
Perform a combination operation on the first video signal and a first noise signal to produce a first combined signal and on the second video signal and a second noise signal to produce a second combined signal 206
Produce the first combined signal for the first part of the display and the second combined signal for the second part of the display 206

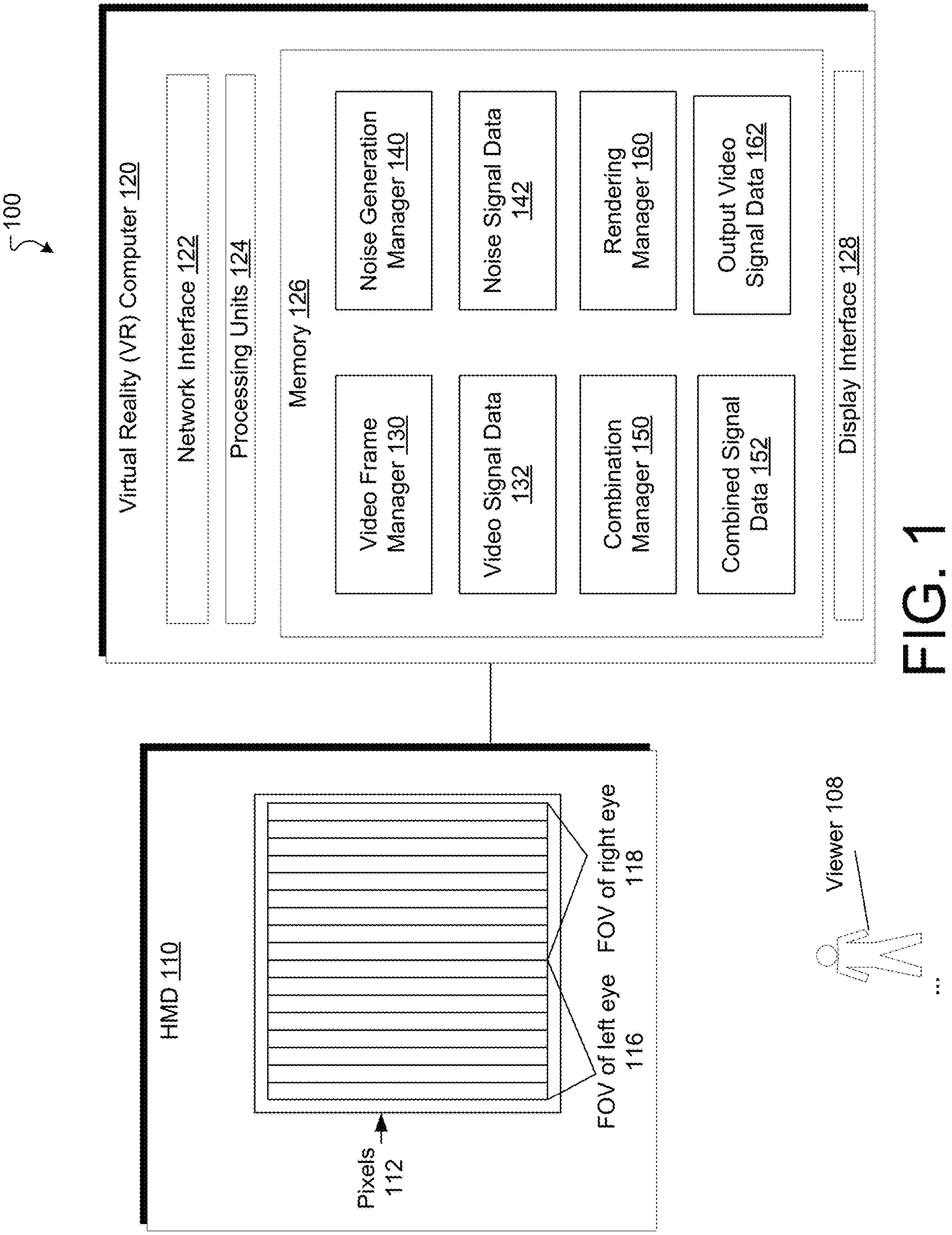

100
Virtual Reality (VR) Computer 120
Network Interface 122
Processing Units 124
Memory 126
Video Frame Manager 130
Noise Generation Manager 140
Video Signal Data 132
Noise Signal Data 142
Combination Manager 150
Rendering Manager 160
Combined Signal Data 152
Output Video Signal Data 162
Display Interface 128
HMD 110
Pixels 112
FOV of left eye 116
FOV of right eye 118
Viewer 108
...

FIG. 1

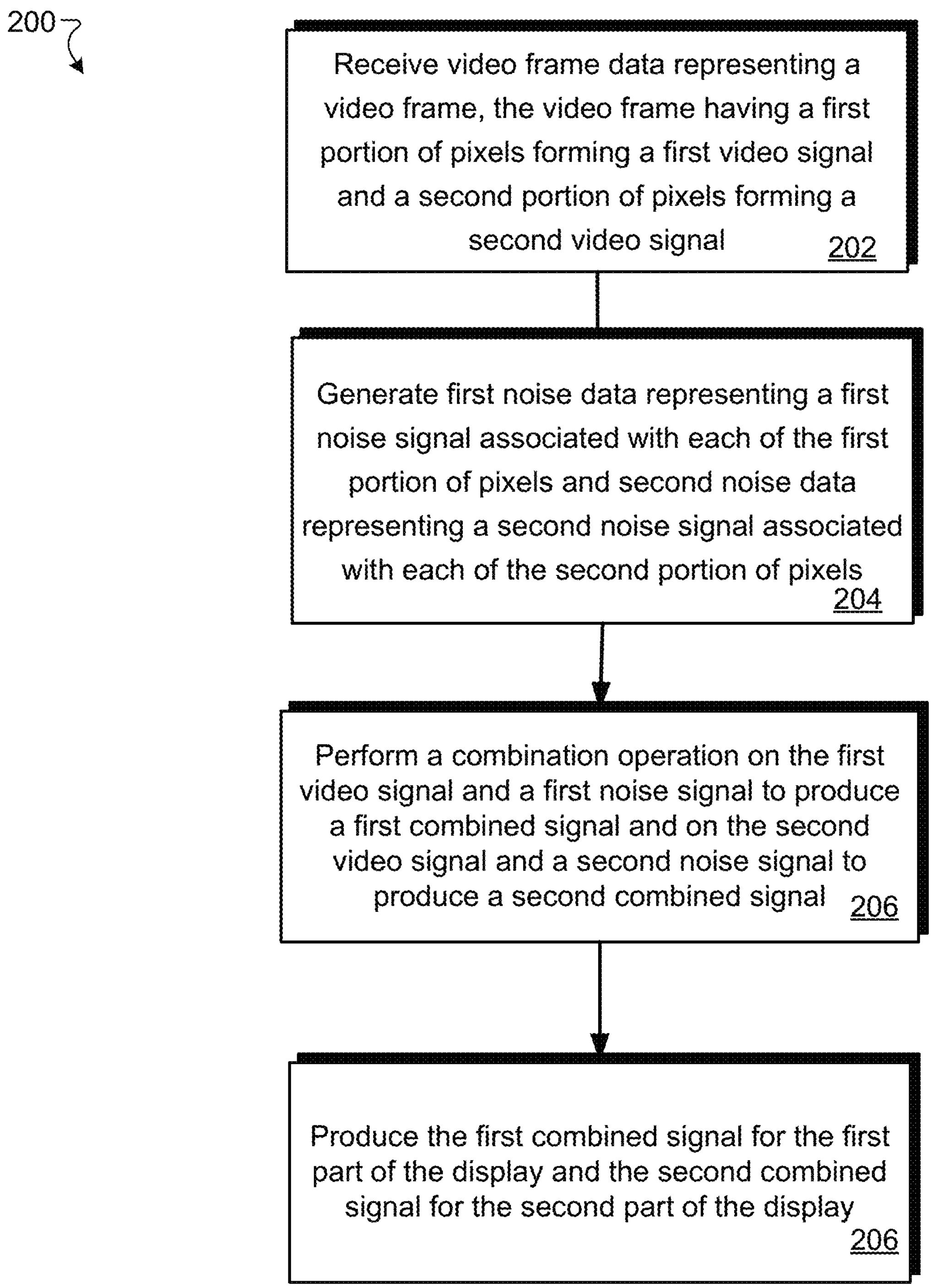

200
Receive video frame data representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal
202
Generate first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels
204
Perform a combination operation on the first video signal and a first noise signal to produce a first combined signal and on the second video signal and a second noise signal to produce a second combined signal
206
Produce the first combined signal for the first part of the display and the second combined signal for the second part of the display
206

FIG. 2

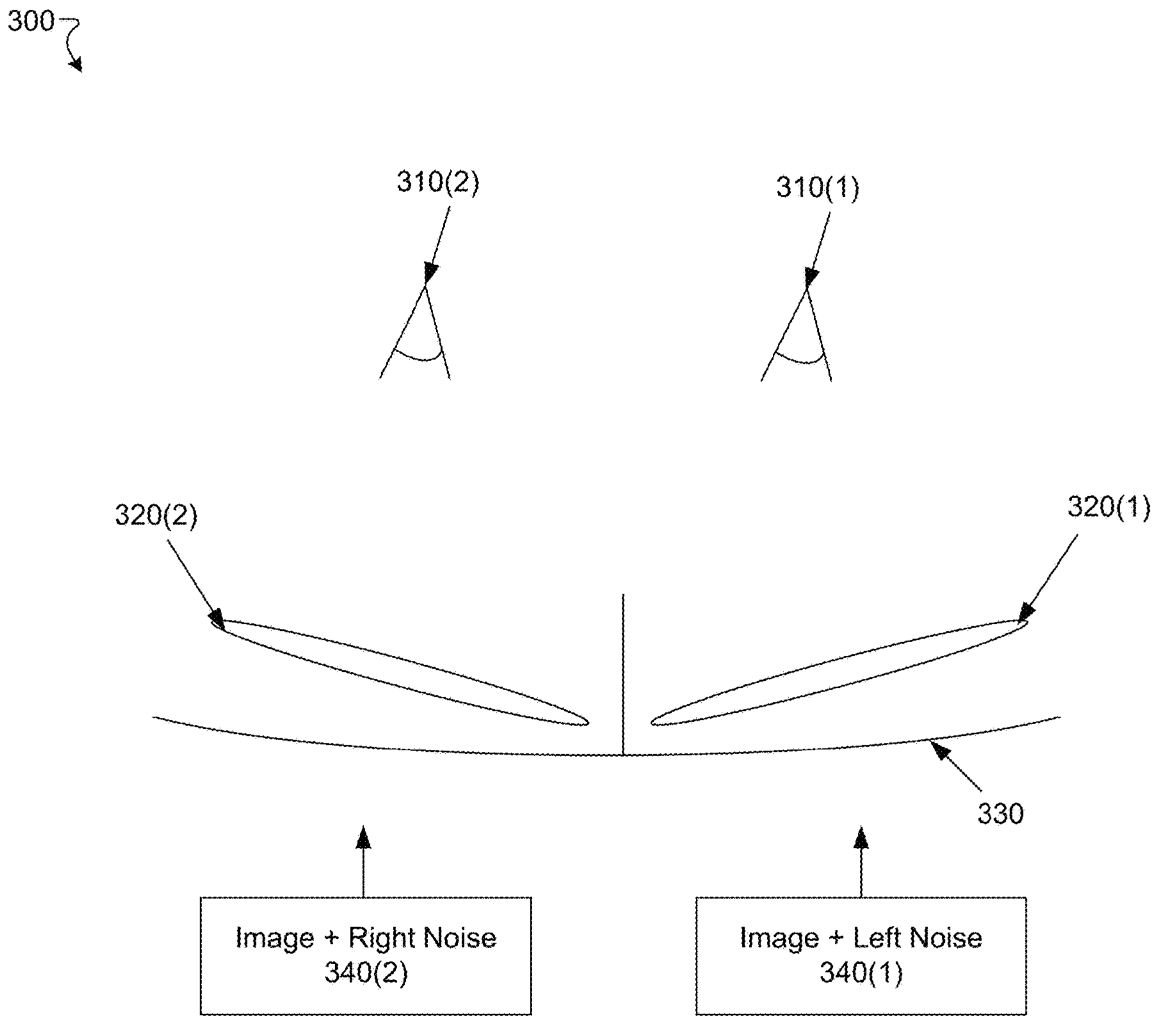

300
310(2)
310(1)
320(2)
320(1)
330
Image + Right Noise
340(2)
Image + Left Noise
340(1)

FIG. 3

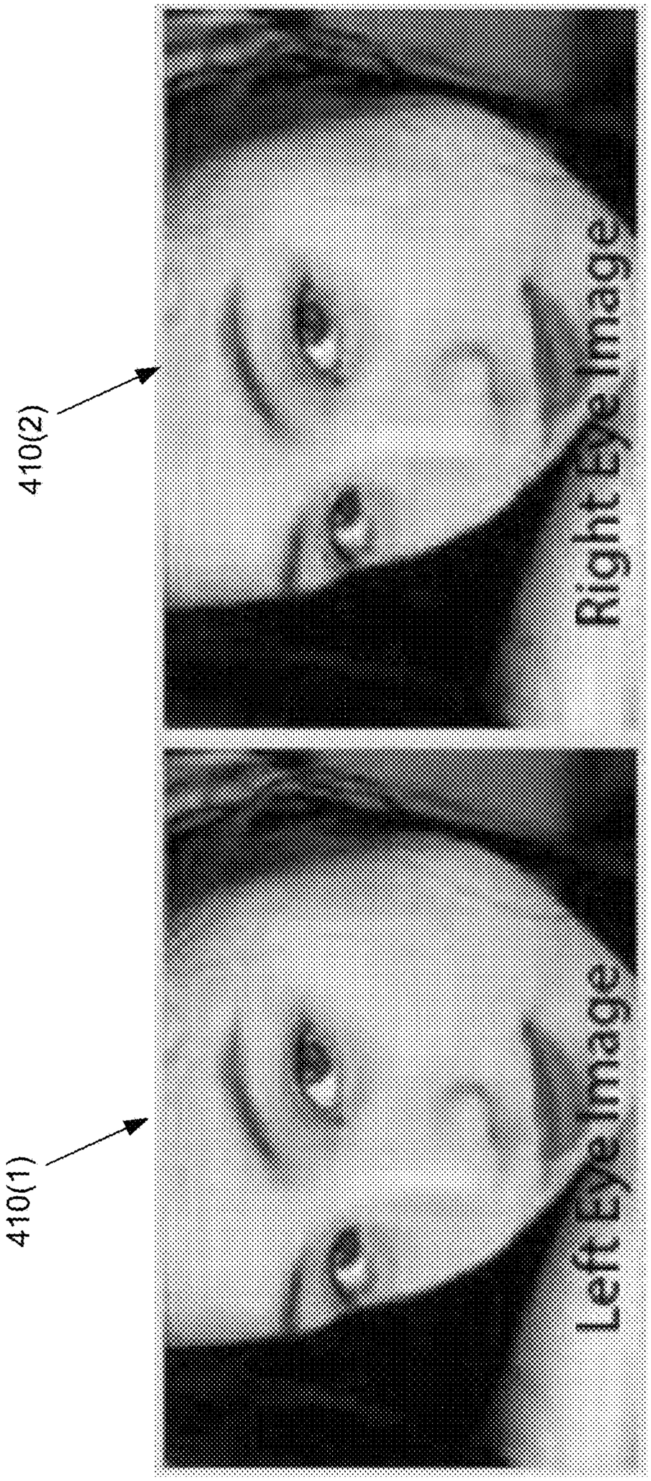
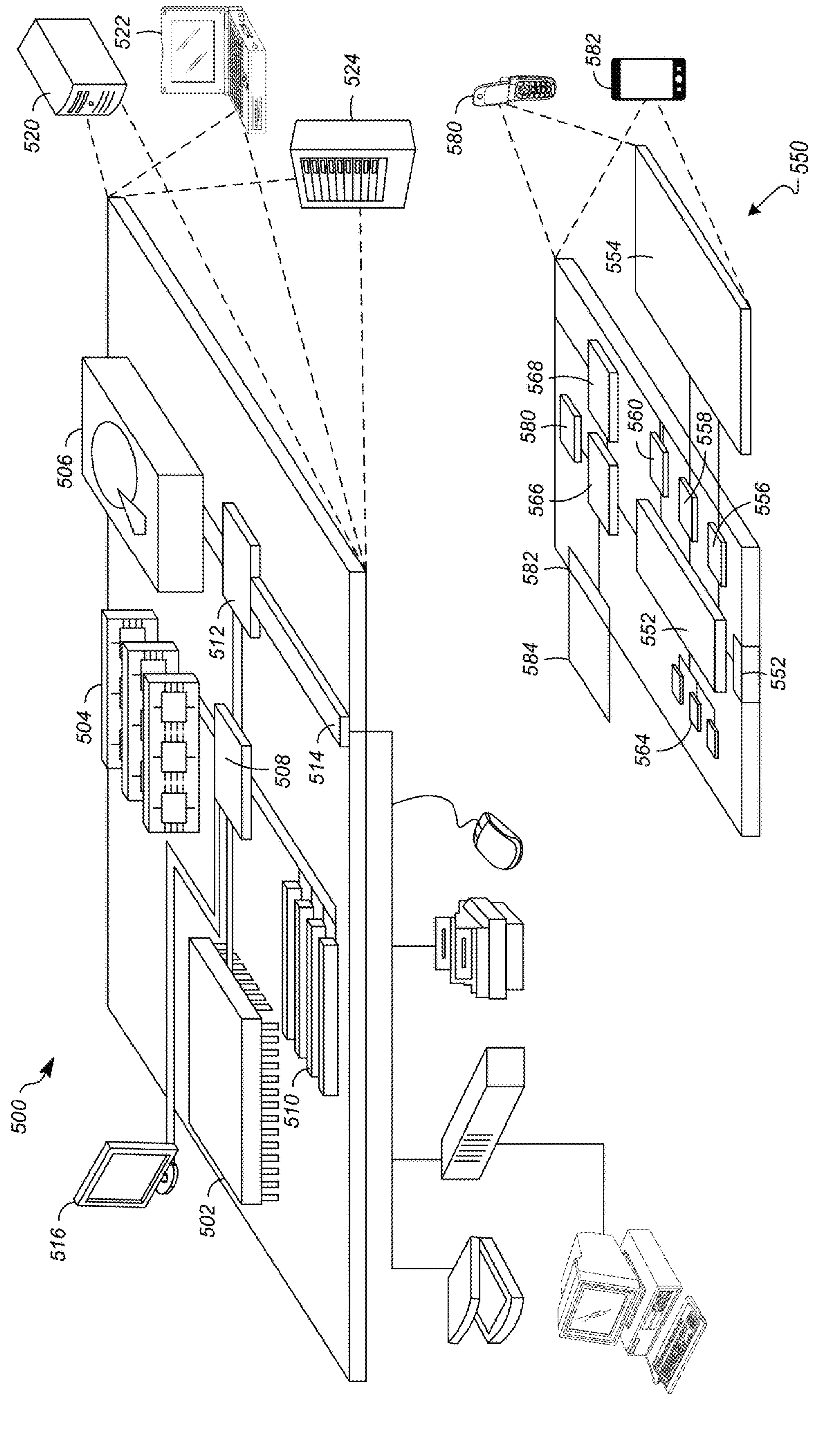


FIG. 4


500
502
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580
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584

FIG. 5

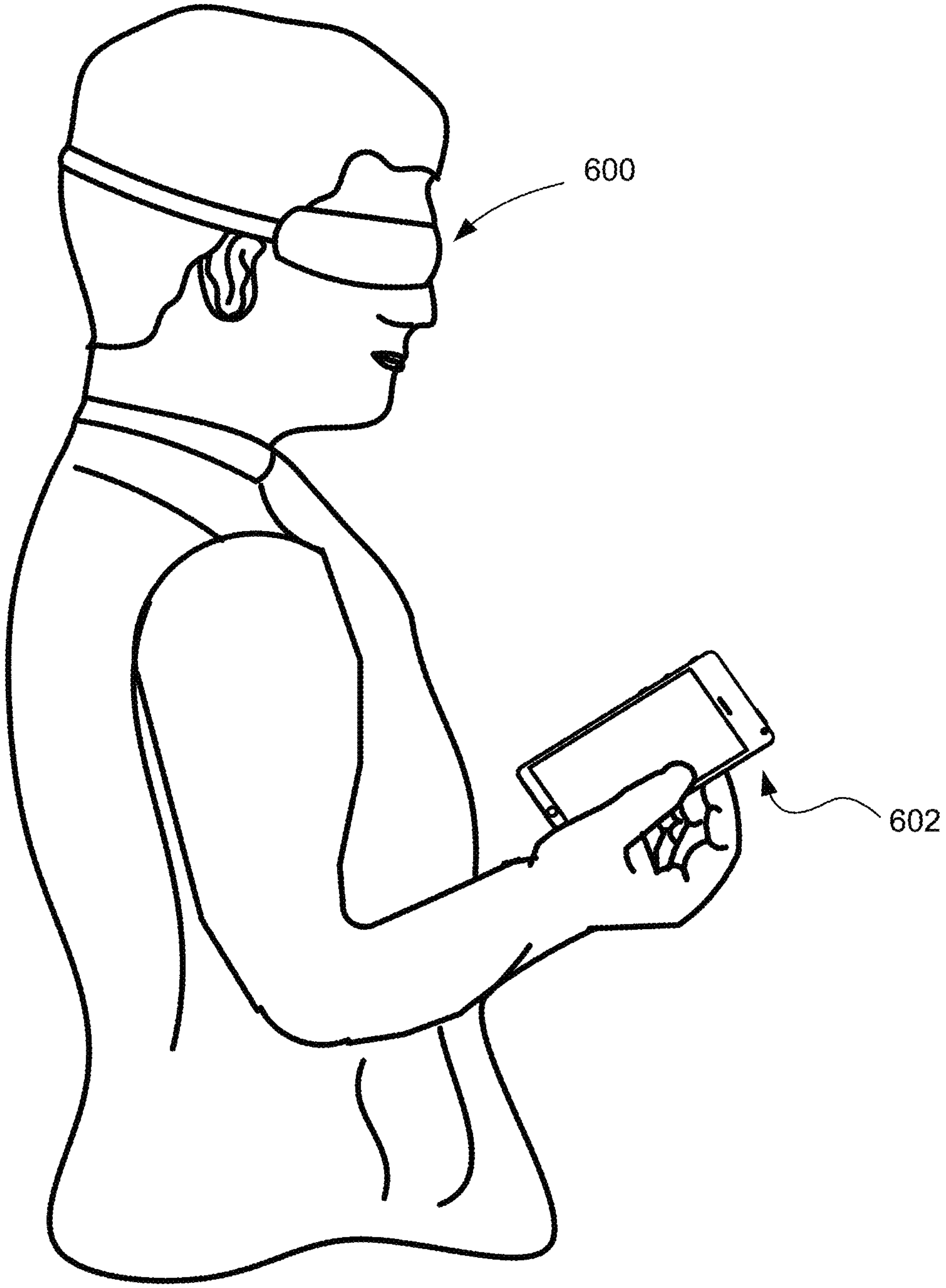

FIG. 6

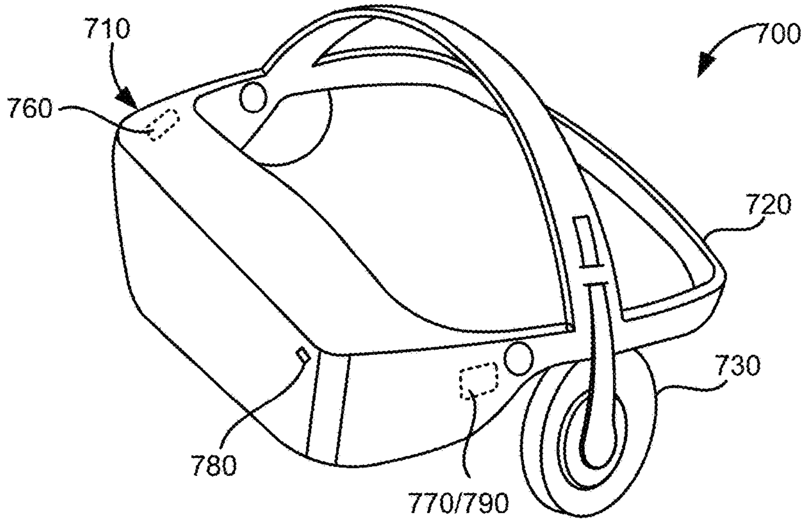

FIG. 7A

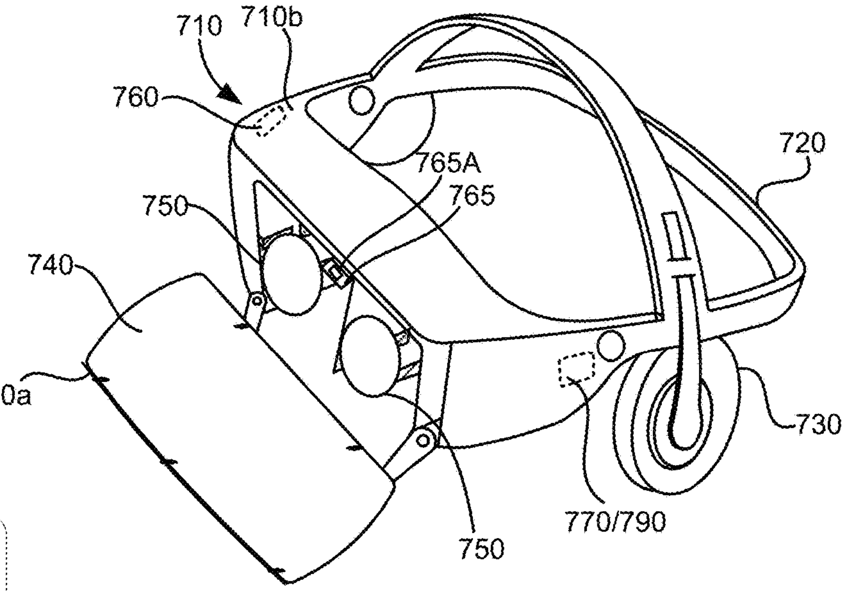

FIG. 7B

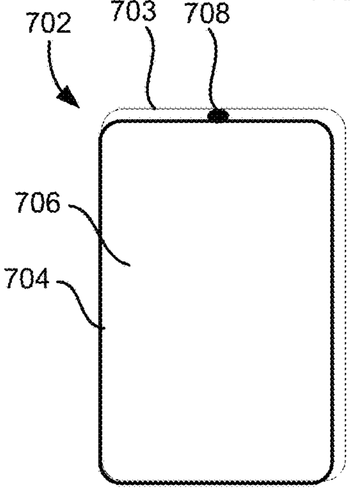

FIG. 7C

VIRTUAL REALITY SYSTEM USING SUPER-RESOLUTION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Patent Application No. 62/515,114, filed on Jun. 5, 2017, entitled "VIRTUAL REALITY SYSTEM USING SUPER-RESOLUTION," the disclosure of which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

This description relates to improving effective resolution in displays for virtual reality (VR) systems.

BACKGROUND

Virtual Reality (VR) and/or augmented reality (AR) can use head-mounted displays (HMDs) to provide the illusion of immersion for a human viewer in a virtual environment. To make the illusion realistic, the HMD provides as high a resolution and visual acuity within a display as possible. Such a realistic illusion can be achieved using a relatively high resolution display within a conventional HMD.

SUMMARY

In one general aspect, a method can include receiving, via controlling circuitry of a computer configured to output a video signal to a display, video frame data representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal, the first portion of pixels configured to be viewed in a first part of the display in a field of view (FOV) of a left eye of a viewer, the second portion of pixels configured to be viewed in a second part of the display in the FOV of a right eye of the viewer. The method can also include generating first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels. The method can further include performing, by the controlling circuitry, a combination operation on the first video signal and the first noise signal to produce a first combined signal and on the second video signal and the second noise signal to produce a second combined signal. The method can further include producing, via the controlling circuitry, the first combined signal for the first part of the display and the second combined signal for the second part of the display, thereby increasing a dynamic range by introducing high-frequencies in the first and second combined signals.

The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram that illustrates an example electronic environment in which improved techniques described herein may be implemented.

FIG. **2** is a flow chart that illustrates an example method of implementing the improved techniques as shown in FIG. **1**.

FIG. **3** is a diagram illustrating an example virtual reality (VR) system according to the improved techniques described herein.

FIG. **4** is a diagram illustrating example left and right images with noise added.

FIG. **5** illustrates an example of a computer device and a mobile computer device that can be used with circuits described here.

FIG. **6** is a diagram depicting an example VR head-mounted display (HMD).

FIGS. **7**A, **7**B, and **7**C are diagrams depicting the example VR HMD and controller.

DETAILED DESCRIPTION

In accordance with the implementations described herein, improved techniques of displaying video in an HMD involve introducing unperceived noise to the video frame signal in order to enhance dynamic range. For example, each of a viewer's left and right eyes have a field of view (FOV) corresponding to a portion of pixels shown on the HMD. For each of these portions of pixels, the VR system may combine a noise signal (e.g., zero-mean Gaussian white noise) with the video signals corresponding to each of the portions of pixels. The introduction of such noise may improve the dynamic range of the viewer. Further, in some implementations, the noise signal that is combined with the left video signal may be slightly different from the noise signal that is combined with the right video signal. Such slightly different noise signals may provide further improvement to the image seen by the viewer due to binocular summation.

The methods and apparatus described herein can be particularly valuable in an HMD device using a mobile device with a mobile graphics processing unit (GPU). A mobile GPU may not be capable of producing high enough resolution (e.g., 10K per eye and an acuity better than 20/30 at about a 180-degree field of view (FOV) for a desirable virtual (e.g., immersive virtual, augmented virtual) experience. In other words, the resolution and acuity specifications for an HMD may not be feasible in the case of a VR system driven by a mobile GPU using a smartphone display. Such a mobile GPU may not have the computational power to manage the frame updates for such a large number of pixels. Accordingly, the techniques and apparatus described herein can be used to address these issues.

FIG. **1** is a diagram that illustrates an example electronic environment **100** in which the above-described improved HMDs may be implemented. As shown, in FIG. **1**, the electronic environment **100** includes a HMD **110** and a VR computer **120**. As shown in FIG. **1**, the HMD **110** is separate from the VR computer **120**. In some implementations in which the VR computer **120** is a smartphone with an LCD screen, the HMD **110** is included within the VR computer **120**. In some implementations, the VR computer **120** is directed to augmented-reality (AR) applications.

The HMD **110** is configured to display high-resolution video frames to a human viewer **108** to provide an immersive VR experience. In some implementations, the HMD includes a pair of goggles that holds a smartphone with a screen (e.g., a LCD screen). In some implementations, the HMD **110** includes standalone goggles connected to (e.g., via a cable or a network connection) the VR computer **120**. The HMD **110** includes an array of pixels **112**, e.g., LCD pixels. In some arrangements, the goggles include respective lenses for each of the left and right eyes of the viewer **108** to better image the video signal onto the eyes of the viewer **108**.

The VR computer **120** is configured to provide a video signal to the array of pixels **112**. The VR computer **120** includes a network interface **122**, one or more processing units **124**, and memory **126**.

In some embodiments, one or more of the components of the VR computer **120** can be, or can include processors (e.g., processing units **124**) configured to process instructions stored in the memory **126**. Examples of such instructions as depicted in FIG. **1** include a video frame manager **130**, a noise generation manager **140**, a combination manager **150**, and a rendering manager **160**. Further, as illustrated in FIG. **1**, the memory **126** is configured to store various data, which is described with respect to the respective managers that use such data.

The video frame manager **130** is configured to obtain video signal data **132**. In some implementations, the video frame manager **130** obtains the video signal data **132** from a local source (e.g., a local disk drive, a flash drive, and the like). In some implementations, the video frame manager obtains the video signal data **132** from another computer connected to the VR computer **120** over a network. In some implementations, the video frame manager **130** obtains the video signal data **132** directly from a video camera.

The video signal data **132** includes arrays of pixel values that represent video frames. For example, a high-definition video frame has 1920 rows and 1080 columns of pixels. Each video frame is shown to a viewer at a time determined by the refresh rate of the HMD **110** (e.g., 60 Hz). In some implementations, the number of pixels in such a video frame has the same number of pixels in the array **112**.

The noise generation manager **140** is configured to generate noise signal data **142** representing noise signals. In some implementations, the noise generation manager **140** generates the noise signal data **142** using a random number generator. In some implementations, the noise generation manager **140** is configured to generate the noise signal data **142** using output of a random process such as thermal noise, avalanche noise, environmental noise, quantum noise, and the like. In some implementations, the noise generation manager **140** is configured to generate a specified noise distribution. In some implementations, the noise generation manager **140** is configured to generate a zero-mean, white noise Gaussian of a specified variance. In some implementations, the noise generation manager **140** is configured to generate a non-Gaussian distribution (e.g., Poisson, Cauchy, etc.).

The noise generation manager **140** is configured to generate, for each video frame, noise signal data **142** for each of a first portion of pixels corresponding to the FOV of a left eye of the viewer **108** (i.e., first noise data) and a second portion of pixels corresponding to the FOV of a right eye of the user **108** (i.e., second noise data). In some implementations, the left noise data is slightly different from the right noise data. When the noise is different for the images seen by the left eye and the right eye of the viewer **108**, the viewer **108** may experience an additional increase in perceived dynamic range. For example, the perceived image as seen by both eyes may have sharper boundaries than those in the respective image seen by the left or right eye alone.

The noise signal data **142** include noise values generated by the noise generation manager **140**. There is a respective noise value corresponding to each of the pixels in each video frame represented by the video signal data **132**. In some implementations, the noise values are generated according to a specified distribution (e.g., zero-mean Gaussian white noise). In some implementations, the specified distribution for a first portion of pixels corresponding to the FOV of a left eye of the viewer **108** (e.g., a first noise signal) is slightly different than that for a second portion of pixels corresponding to the FOV of a right eye of the viewer **108** (e.g., a second noise signal). For example, if the distribution is zero-mean Gaussian white noise, then the variance of the white noise corresponding to the first portion of pixels may be slightly different from the variance corresponding to the second portion of pixels. Further, the noise signal data **142** includes noise values corresponding to each video frame represented by the video signal data **132**. In some implementations, noise values corresponding to a first video frame may be different from noise values corresponding to a second video frame.

In some implementations, a correlation between the first noise signal and the second noise signal is smaller than a threshold (e.g., **0.1**, **0.05**, **0.02**, **0.01** and smaller). In some implementations, the correlation between the first noise signal and the second noise signal is zero or almost zero. An advantage of using such uncorrelated noise is that it is possible to combine a video signal with such noise in a binocular system much more aggressively than noise with a nonzero, or larger correlation.

The combination manager **150** is configured to perform a combination operation on the pixel values of the video signal data **132** representing a video frame and corresponding noise values represented by the noise signal data **142** to produce combined signal data **152**. In some implementations, the combination operation includes summing pixel values and corresponding noise values. In some implementations, the combination operation includes a weighted sum of pixel values and corresponding noise values. In some implementations, the combination operation includes a Pythagorean sum (i.e., square root of a sum of squares) of pixel values and corresponding noise values.

The combined signal data **152** includes values of the combined signal to be sent to the HMD for display to the viewer **108**.

The rendering manager **160** is configured to prepare the combined signal data **152** for display on the HMD **110** to produce output video signal data. For example, in some implementations, the number of pixels in such a video frame may have a different number of pixels in the array **112**. In such a case, the rendering manager **169** is configured to interpolate the video signal data **132** such that each video frame has the same number of pixels as in the array **112**. The rendering manager **160** is also configured to send the output video signal data **162** to the HMD **110** via the display interface **128**.

The components (e.g., modules, processing units **124**) of the user device **120** can be configured to operate based on one or more platforms (e.g., one or more similar or different platforms) that can include one or more types of hardware, software, firmware, operating systems, runtime libraries, and/or so forth. In some implementations, the components of the VR computer **120** can be configured to operate within a cluster of devices (e.g., a server farm). In such an implementation, the functionality and processing of the components of the VR computer **120** can be distributed to several devices of the cluster of devices.

The components of the VR computer **120** can be, or can include, any type of hardware and/or software configured to process attributes. In some implementations, one or more portions of the components shown in the components of the VR computer **120** in FIG. **1** can be, or can include, a hardware-based module (e.g., a digital signal processor (DSP), a field programmable gate array (FPGA), a memory), a firmware module, and/or a software-based module (e.g., a module of computer code, a set of computer-readable instructions that can be executed at a computer). For example, in some implementations, one or more portions of the components of the VR computer **120** can be, or can include, a software module configured for execution by at least one processor (not shown). In some implementations, the functionality of the components can be included in different modules and/or different components than those shown in FIG. **1**.

Although not shown, in some implementations, the components of the user device **120** (or portions thereof) can be configured to operate within, for example, a data center (e.g., a cloud computing environment), a computer system, one or more server/host devices, and/or so forth. In some implementations, the components of the VR computer **120** (or portions thereof) can be configured to operate within a network. Thus, the components of the VR computer **120** (or portions thereof) can be configured to function within various types of network environments that can include one or more devices and/or one or more server devices. For example, the network can be, or can include, a local area network (LAN), a wide area network (WAN), and/or so forth. The network can be, or can include, a wireless network and/or wireless network implemented using, for example, gateway devices, bridges, switches, and/or so forth. The network can include one or more segments and/or can have portions based on various protocols such as Internet Protocol (IP) and/or a proprietary protocol. The network can include at least a portion of the Internet.

The network interface **122** includes, for example, Ethernet adaptors, Token Ring adaptors, and the like, for converting electronic and/or optical signals to electronic form for use by the VR computer **120**. The set of processing units **124** include one or more processing chips and/or assemblies. The memory **126** includes both volatile memory (e.g., RAM) and non-volatile memory, such as one or more ROMs, disk drives, solid state drives, and the like. The set of processing units **124** and the memory **126** together form control circuitry, which is configured and arranged to carry out various methods and functions as described herein.

In some embodiments, one or more of the components of the VR computer **120** can be, or can include, processors configured to process instructions stored in a memory. For example, a video frame manager **130** (and/or a portion thereof), a noise generation manager **140** (and/or a portion thereof), a combination manager **150** (and/or a portion thereof), and a rendering manager **160** can be a combination of a processor and a memory configured to execute instructions related to a process to implement one or more functions.

In some implementations, the memory **126** can be any type of memory such as a random-access memory, a disk drive memory, flash memory, and/or so forth. In some implementations, the memory **126** can be implemented as more than one memory component (e.g., more than one RAM component or disk drive memory) associated with the components of the VR computer **120**. In some implementations, the memory **126** can be a database memory. In some implementations, the memory **126** can be, or can include, a non-local memory. For example, the memory **126** can be, or can include, a memory shared by multiple devices (not shown). In some implementations, the memory **126** can be associated with a server device (not shown) within a network and configured to serve the components of the VR computer **120**. As illustrated in FIG. **1**, the memory **126** is configured to store various data, including video frame data **132** and time interval data **142**.

FIG. **2** is a flow chart depicting an example method **200** of displaying video frames to a viewer via a HMD (e.g., HMD **110**). The method **200** may be performed by software constructs described in connection with FIG. **1**, which reside in memory **126** of the VR computer **120** and are run by the set of processing units **124**.

At **202**, the video frame manager **130** receives video frame data (e.g., video signal data **132**) representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal. The first portion of pixels is configured to be viewed in a first part of the display in a field of view (FOV) **116** of a left eye of a viewer (e.g., viewer **108**). The second portion of pixels is configured to be viewed in a second part of the display in the FOV **118** of a right eye of the viewer.

At **204**, the noise generation manager **140** generates first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels.

At **206**, the combination manager **150** performs a combination operation on the first video signal and the first noise signal to produce a first combined signal and on the second video signal and the second noise signal to produce a second combined signal.

At **208**, the rendering manager **160** produces the first combined signal for the first part of the display and the second combined signal for the second part of the display.

FIG. **3** is a diagram illustrating a top view of an example VR physical environment **300**. In the physical environment **300**, a HMD **330** is split into two halves, each corresponding to a left eye **310**(**1**) and a right eye **310**(**2**) of a user. The HMD **330** as shown in FIG. **3** includes respective lenses **320**(**1**) and **320**(**2**) configured to focus a first portion of a combined signal (i.e., a video signal+left noise) **340**(**1**) onto a retina of the left eye **310**(**1**) and a second portion of a combined signal (i.e., a video signal+right noise) **340**(**2**) onto a retina of the right eye **310**(**2**). In the arrangement shown in FIG. **3**, the HMD **330** is then separated into a left half and a right half such that the first portion of the combined signal **340**(**1**) is displayed to the only the left eye **310**(**1**) and the second portion of the combined signal **340**(**2**) is displayed only to the right eye **310**(**2**).

The lenses **320**(**1**) and **320**(**2**) are standard lenses used to project video images onto retinas. In some implementations, the HMD **330** includes a set of goggles in which each lens **320**(**1**) and **320**(**2**) is embedded in a respective eye hole in the goggles.

As described above, the noise that is combined with the video signal has a sufficiently small amplitude so as to be undetectable on its own to the viewer (e.g., viewer **108**). That is, the eyes **310**(**1**) and **310**(**2**) each have a threshold amplitude above which a light signal may be detected. Adding the undetectable (i.e., subthreshold) noise to the video signal then increases the dynamic range of the detection mechanisms of the eyes **310**(**1**) and **310**(**2**).

When the left noise differs from the right noise, the the perceived image is sharper than an image with the left noise and right noise being identical. Moreover, video signals that have subthreshold components may, with the introduction of the noise signals, become visible to the viewer.

As an illustration of the increase in dynamic range of the video signal with the introduction of a noise signal, consider the frequency distribution of the video and noise signals. The noise signal, with high likelihood, has a much larger amount of high-frequency content than does the video signal alone. In this way, the high frequencies introduced by the noise signal may give the viewer the appearance of an emphasis of fine details of an image formed by the combined signals **340**(**1**) and **340**(**2**). In this way, the dynamic range increase may simulate a resolution increase to the viewer. Such a simulated resolution increase can improve the viewer's experience using the VR system.

FIG. **4** is a diagram illustrating an example left eye image **410**(**1**) and an example right eye image **410**(**2**) of a video frame with noise, i.e., left noise and right noise, added as described above. In this case, the left noise differs from the right noise. The images **410**(**1**) and **410**(**2**), despite the left noise and right noise each being undetectable, i.e., subthreshold, on their own, when combined with the video signal produce noticeably different images. For example, the left side of the face in the image **410**(**1**) appears sharper than the left side of the face in the image **410**(**2**). As stated above, the sharpness or lack thereof of features in each picture depends upon the nature of the noise signal used for each eye.

FIG. **5** illustrates an example of a generic computer device **500** and a generic mobile computer device **550**, which may be used with the techniques described here.

As shown in FIG. **5**, computing device **500** is intended to represent various forms of digital computers, such as laptops, desktops, workstations, personal digital assistants, servers, blade servers, mainframes, and other appropriate computers. Computing device **550** is intended to represent various forms of mobile devices, such as personal digital assistants, cellular telephones, smart phones, and other similar computing devices. The components shown here, their connections and relationships, and their functions, are meant to be exemplary only, and are not meant to limit implementations of the inventions described and/or claimed in this document.

Computing device **500** includes a processor **502**, memory **504**, a storage device **506**, a high-speed interface **508** connecting to memory **504** and high-speed expansion ports **510**, and a low speed interface **512** connecting to low speed bus **514** and storage device **506**. Each of the components **502**, **504**, **506**, **508**, **510**, and **512**, are interconnected using various busses, and may be mounted on a common motherboard or in other manners as appropriate. The processor **502** can process instructions for execution within the computing device **500**, including instructions stored in the memory **504** or on the storage device **506** to display graphical information for a GUI on an external input/output device, such as display **516** coupled to high speed interface **508**. In other implementations, multiple processors and/or multiple buses may be used, as appropriate, along with multiple memories and types of memory. Also, multiple computing devices **500** may be connected, with each device providing portions of the necessary operations (e.g., as a server bank, a group of blade servers, or a multi-processor system).

The memory **504** stores information within the computing device **600**. In one implementation, the memory **504** is a volatile memory unit or units. In another implementation, the memory **504** is a non-volatile memory unit or units. The memory **504** may also be another form of computer-readable medium, such as a magnetic or optical disk.

The storage device **506** is capable of providing mass storage for the computing device **500**. In one implementation, the storage device **506** may be or contain a computer-readable medium, such as a floppy disk device, a hard disk device, an optical disk device, or a tape device, a flash memory or other similar solid state memory device, or an array of devices, including devices in a storage area network or other configurations. A computer program product can be tangibly embodied in an information carrier. The computer program product may also contain instructions that, when executed, perform one or more methods, such as those described above. The information carrier is a computer- or machine-readable medium, such as the memory **504**, the storage device **506**, or memory on processor **502**.

The high speed controller **508** manages bandwidth-intensive operations for the computing device **500**, while the low speed controller **512** manages lower bandwidth-intensive operations. Such allocation of functions is exemplary only. In one implementation, the high-speed controller **508** is coupled to memory **504**, display **516** (e.g., through a graphics processor or accelerator), and to high-speed expansion ports **510**, which may accept various expansion cards (not shown). In the implementation, low-speed controller **512** is coupled to storage device **506** and low-speed expansion port **514**. The low-speed expansion port, which may include various communication ports (e.g., USB, Bluetooth, Ethernet, wireless Ethernet) may be coupled to one or more input/output devices, such as a keyboard, a pointing device, a scanner, or a networking device such as a switch or router, e.g., through a network adapter.

The computing device **500** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a standard server **520**, or multiple times in a group of such servers. It may also be implemented as part of a rack server system **524**. In addition, it may be implemented in a personal computer such as a laptop computer **522**. Alternatively, components from computing device **500** may be combined with other components in a mobile device (not shown), such as device **550**. Each of such devices may contain one or more of computing device **500**, **550**, and an entire system may be made up of multiple computing devices **500**, **550** communicating with each other.

Computing device **550** includes a processor **552**, memory **564**, an input/output device such as a display **554**, a communication interface **566**, and a transceiver **568**, among other components. The device **550** may also be provided with a storage device, such as a microdrive or other device, to provide additional storage. Each of the components **550**, **552**, **564**, **554**, **566**, and **568**, are interconnected using various buses, and several of the components may be mounted on a common motherboard or in other manners as appropriate.

The processor **552** can execute instructions within the computing device **550**, including instructions stored in the memory **564**. The processor may be implemented as a chipset of chips that include separate and multiple analog and digital processors. The processor may provide, for example, for coordination of the other components of the device **550**, such as control of user interfaces, applications run by device **550**, and wireless communication by device **550**.

Processor **552** may communicate with a user through control interface **558** and display interface **556** coupled to a display **554**. The display **554** may be, for example, a TFT LCD (Thin-Film-Transistor Liquid Crystal Display) or an OLED (Organic Light Emitting Diode) display, or other appropriate display technology. The display interface **656** may comprise appropriate circuitry for driving the display **554** to present graphical and other information to a user. The control interface **558** may receive commands from a user and convert them for submission to the processor **552**. In addition, an external interface **562** may be provided in communication with processor **552**, so as to enable near area communication of device **550** with other devices. External interface **562** may provide, for example, for wired communication in some implementations, or for wireless communication in other implementations, and multiple interfaces may also be used.

The memory **564** stores information within the computing device **550**. The memory **564** can be implemented as one or more of a computer-readable medium or media, a volatile memory unit or units, or a non-volatile memory unit or units. Expansion memory **574** may also be provided and connected to device **550** through expansion interface **572**, which may include, for example, a SIMM (Single In Line Memory Module) card interface. Such expansion memory **574** may provide extra storage space for device **550**, or may also store applications or other information for device **550**. Specifically, expansion memory **574** may include instructions to carry out or supplement the processes described above, and may include secure information also. Thus, for example, expansion memory **574** may be provided as a security module for device **550**, and may be programmed with instructions that permit secure use of device **550**. In addition, secure applications may be provided via the SIMM cards, along with additional information, such as placing identifying information on the SIMM card in a non-hackable manner.

The memory may include, for example, flash memory and/or NVRAM memory, as discussed below. In one implementation, a computer program product is tangibly embodied in an information carrier. The computer program product contains instructions that, when executed, perform one or more methods, such as those described above. The information carrier is a computer- or machine-readable medium, such as the memory **564**, expansion memory **574**, or memory on processor **552**, that may be received, for example, over transceiver **568** or external interface **562**.

Device **550** may communicate wirelessly through communication interface **566**, which may include digital signal processing circuitry where necessary. Communication interface **566** may provide for communications under various modes or protocols, such as GSM voice calls, SMS, EMS, or MMS messaging, CDMA, TDMA, PDC, WCDMA, CDMA2000, or GPRS, among others. Such communication may occur, for example, through radio-frequency transceiver **568**. In addition, short-range communication may occur, such as using a Bluetooth, WiFi, or other such transceiver (not shown). In addition, GPS (Global Positioning System) receiver module **570** may provide additional navigation- and location-related wireless data to device **550**, which may be used as appropriate by applications running on device **550**.

Device **550** may also communicate audibly using audio codec **560**, which may receive spoken information from a user and convert it to usable digital information. Audio codec **560** may likewise generate audible sound for a user, such as through a speaker, e.g., in a handset of device **550**. Such sound may include sound from voice telephone calls, may include recorded sound (e.g., voice messages, music files, etc.) and may also include sound generated by applications operating on device **550**.

The computing device **550** may be implemented in a number of different forms, as shown in the figure. For example, it may be implemented as a cellular telephone **580**. It may also be implemented as part of a smart phone **582**, personal digital assistant, or other similar mobile device.

FIG. **6** illustrates an example implementation of a head-mounted display. In FIG. **6**, a user wearing an HMD **600** is holding a portable handheld electronic device **602**. The handheld electronic device **602** may be, for example, a smartphone, a controller, a joystick, or another portable handheld electronic device(s) that may be paired with, and communicate with, the HMD **600** for interaction in the immersive virtual environment generated by the HMD **600**. The handheld electronic device **602** may be operably coupled with, or paired with the HMD **600** via, for example, a wired connection, or a wireless connection such as, for example, a WiFi or Bluetooth connection. This pairing, or operable coupling, of the handheld electronic device **602** and the HMD **600** may provide for communication between the handheld electronic device **602** and the HMD **600** and the exchange of data between the handheld electronic device **602** and the HMD **700**. This may allow the handheld electronic device **602** to function as a controller in communication with the HMD **600** for interacting in the immersive virtual environment generated by the HMD **700**. That is, a manipulation of the handheld electronic device **702**, such as, for example, a beam or ray emitted by the handheld electronic device **602** and directed to a virtual object or feature for selection, and/or an input received on a touch surface of the handheld electronic device **702**, and/or a movement of the handheld electronic device **702**, may be translated into a corresponding selection, or movement, or other type of interaction, in the immersive virtual environment generated by the HMD **700**. For example, the HMD **700**, together with the handheld electronic device **702**, may generate a virtual environment as described above, and the handheld electronic device **602** may be manipulated to effect a change in scale, or perspective, of the user relative to the virtual features in the virtual environment as described above.

FIGS. 7A and 7B are perspective views of an example HMD, such as, for example, the HMD **600** worn by the user in FIG. **6**, and FIG. 7C illustrates an example handheld electronic device, such as, for example, the handheld electronic device **602** shown in FIG. **6**.

The handheld electronic device **702** may include a housing **703** in which internal components of the device **702** are received, and a user interface **704** on an outside of the housing **703**, accessible to the user. The user interface **704** may include a touch sensitive surface **706** configured to receive user touch inputs. The user interface **704** may also include other components for manipulation by the user such as, for example, actuation buttons, knobs, joysticks and the like. In some implementations, at least a portion of the user interface **704** may be configured as a touchscreen, with that portion of the user interface **704** being configured to display user interface items to the user, and also to receive touch inputs from the user on the touch sensitive surface **706**. The handheld electronic device **702** may also include a light source **708** configured to selectively emit light, for example, a beam or ray, through a port in the housing **703**, for example, in response to a user input received at the user interface **704**.

The HMD **700** may include a housing **710** coupled to a frame **720**, with an audio output device **730** including, for example, speakers mounted in headphones, also be coupled to the frame **720**. In FIG. 7B, a front portion **710***a* of the housing **710** is rotated away from a base portion **710***b* of the housing **710** so that some of the components received in the housing **710** are visible. A display **740** may be mounted on an interior facing side of the front portion **710***a* of the housing **710**. Lenses **750** may be mounted in the housing **710**, between the user's eyes and the display **740** when the front portion **710***a* is in the closed position against the base portion **710***b* of the housing **710**. In some implementations, the HMD **700** may include a sensing system **760** including various sensors and a control system **770** including a processor **790** and various control system devices to facilitate operation of the HMD **700**.

In some implementations, the HMD **700** may include a camera **780** to capture still and moving images. The images captured by the camera **780** may be used to help track a physical position of the user and/or the handheld electronic device **702** in the real world, or physical environment relative to the virtual environment, and/or may be displayed to the user on the display **740** in a pass through mode, allowing the user to temporarily leave the virtual environment and return to the physical environment without removing the HMD **700** or otherwise changing the configuration of the HMD **700** to move the housing **710** out of the line of sight of the user.

In some implementations, the HMD **700** may include a gaze tracking device **765** to detect and track an eye gaze of the user. The gaze tracking device **765** may include, for example, an image sensor **765**A, or multiple image sensors **765**A, to capture images of the user's eyes, for example, a particular portion of the user's eyes, such as, for example, the pupil, to detect, and track direction and movement of, the user's gaze. In some implementations, the HMD **700** may be configured so that the detected gaze is processed as a user input to be translated into a corresponding interaction in the immersive virtual experience.

Various implementations of the systems and techniques described here can be realized in digital electronic circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms "machine-readable medium" "computer-readable medium" refers to any computer program product, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term "machine-readable signal" refers to any signal used to provide machine instructions and/or data to a programmable processor.

To provide for interaction with a user, the systems and techniques described here can be implemented on a computer having a display device (e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor) for displaying information to the user and a keyboard and a pointing device (e.g., a mouse or a trackball) by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback (e.g., visual feedback, auditory feedback, or tactile feedback); and input from the user can be received in any form, including acoustic, speech, or tactile input.

The systems and techniques described here can be implemented in a computing system that includes a back end component (e.g., as a data server), or that includes a middleware component (e.g., an application server), or that includes a front end component (e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the systems and techniques described here), or any combination of such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication (e.g., a communication network). Examples of communication networks include a local area network ("LAN"), a wide area network ("WAN"), and the Internet.

The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the specification.

It will also be understood that when an element is referred to as being on, connected to, electrically connected to, coupled to, or electrically coupled to another element, it may be directly on, connected or coupled to the other element, or one or more intervening elements may be present. In contrast, when an element is referred to as being directly on, directly connected to or directly coupled to another element, there are no intervening elements present. Although the terms directly on, directly connected to, or directly coupled to may not be used throughout the detailed description, elements that are shown as being directly on, directly connected or directly coupled can be referred to as such. The claims of the application may be amended to recite exemplary relationships described in the specification or shown in the figures.

While certain features of the described implementations have been illustrated as described herein, many modifications, substitutions, changes and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the scope of the implementations. It should be understood that they have been presented by way of example only, not limitation, and various changes in form and details may be made. Any portion of the apparatus and/or methods described herein may be combined in any combination, except mutually exclusive combinations. The implementations described herein can include various combinations and/or sub-combinations of the functions, components and/or features of the different implementations described.

In addition, the logic flows depicted in the figures do not require the particular order shown, or sequential order, to achieve desirable results. In addition, other steps may be provided, or steps may be eliminated, from the described flows, and other components may be added to, or removed from, the described systems. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A method, comprising:

receiving, via controlling circuitry of a computer configured to output a video signal to a display, video frame data representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal, the first portion of pixels configured to be viewed in a first part of the display in a field of view (FOV) of a left eye of a viewer, the second portion of pixels configured to be viewed in a second part of the display in the FOV of a right eye of the viewer;

generating first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels;

performing, by the controlling circuitry, a combination operation on the first video signal and the first noise signal to produce a first combined signal and on the second video signal and the second noise signal to produce a second combined signal; and

producing, via the controlling circuitry, the first combined signal for the first part of the display and the second combined signal for the second part of the display, thereby increasing a dynamic range by introducing high-frequencies in the first and second combined signals.

2. The method of claim **1**, wherein each of the first noise signal and the second noise signal includes zero-mean Gaussian white noise.

3. The method of claim **2**, wherein a variance of the zero-mean Gaussian white noise of the first noise signal is different from the variance of the zero-mean Gaussian white noise of the second noise signal.

4. The method of claim **1**, wherein a correlation between the first noise signal and the second noise signal is smaller than a threshold.

5. The method of claim **1**, wherein an amplitude of each of the first noise signal and the second noise signal is less than a level at which each of the first noise signal and the second noise signal may be detected by the viewer.

6. The method of claim **1**, wherein the video frame is a first video frame,

wherein the video frame data further represents a second video frame, the second video being sampled at the first portion of pixels to form a third video signal and the second portion of pixels to form a fourth video signal,

wherein the method further comprises:

performing a combination operation on the third video signal and a third noise signal to produce a third combined signal and on the fourth video signal and a fourth noise signal to produce a fourth combined signal, the third noise signal being different from the first noise signal, the fourth noise signal being different from the second noise signal.

7. The method of claim **1**, wherein the combination operation is performed during a rendering of the first video signal and the second video signal for output on the display.

8. The method of claim **1**, wherein performing the combination operation includes:

summing the first video signal and the first noise signal and summing the second video signal and the second noise signal.

9. The method of claim **1**, wherein the display is a head-mounted display (HMD) in a virtual reality system.

10. A computer program product comprising a non-transitory storage medium, the computer program product including code that, when executed by processing circuitry of a user device configured to output a video signal to a display, causes the processing circuitry to perform a method, the method comprising:

receiving video frame data representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal, the first portion of pixels configured to be viewed in a first part of the display in a field of view (FOV) of a left eye of a viewer, the second portion of pixels configured to be viewed in a second part of the display in the FOV of a right eye of the viewer;

generating first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels;

performing a combination operation on the first video signal and the first noise signal to produce a first combined signal and on the second video signal and the second noise signal to produce a second combined signal; and

producing the first combined signal for the first part of the display and the second combined signal for the second part of the display, thereby increasing a dynamic range by introducing high-frequencies in the first and second combined signals.

11. The computer program product of claim **10**, wherein each of the first noise signal and the second noise signal includes zero-mean Gaussian white noise.

12. The computer program product of claim **11**, wherein a variance of the zero-mean Gaussian white noise of the first noise signal is different from the variance of the zero-mean Gaussian white noise of the second noise signal.

13. The computer program product of claim **10**, wherein a correlation between the first noise signal and the second noise signal is smaller than a threshold.

14. The computer program product of claim **10**, wherein an amplitude of each of the first noise signal and the second noise signal is less than a level at which each of the first noise signal and the second noise signal may be detected by the viewer.

15. The computer program product of claim **10**, wherein the video frame is a first video frame,

wherein the video frame data further represents a second video frame, the second video being sampled at the first portion of pixels to form a third video signal and the second portion of pixels to form a fourth video signal,

wherein the method further comprises:

performing a combination operation on the third video signal and a third noise signal to produce a third combined signal and on the fourth video signal and a fourth noise signal to produce a fourth combined signal, the third noise signal being different from the first noise signal, the fourth noise signal being different from the second noise signal.

16. The computer program product of claim **10**, wherein the combination operation is performed during a rendering of the first video signal and the second video signal for output on the display.

17. An electronic apparatus configured to output a video signal to a display, the electronic apparatus comprising:

memory; and

controlling circuitry coupled to the memory, the controlling circuitry being configured to:

receive video frame data representing a video frame, the video frame having a first portion of pixels forming a first video signal and a second portion of pixels forming a second video signal, the first portion of pixels configured to be viewed in a first part of the display in a field of view (FOV) of a left eye of a viewer, the second portion of pixels configured to be viewed in a second part of the display in the FOV of a right eye of the viewer;

generate first noise data representing a first noise signal associated with each of the first portion of pixels and second noise data representing a second noise signal associated with each of the second portion of pixels;

perform a combination operation on the first video signal and a first noise signal to produce a first combined signal and on the second video signal and a second noise signal to produce a second combined signal; and

produce the first combined signal for the first part of the display and the second combined signal for the second part of the display, thereby increasing a dynamic range by introducing high-frequencies in the first and second combined signals.

18. The electronic apparatus of claim **17**, wherein each of the first noise signal and the second noise signal includes zero-mean Gaussian white noise.

19. The electronic apparatus of claim **18**, wherein a variance of the zero-mean Gaussian white noise of the first noise signal is different from the variance of the zero-mean Gaussian white noise of the second noise signal.

20. The electronic apparatus of claim **17**, wherein a correlation between the first noise signal and the second noise signal is smaller than a threshold.

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