

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

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(45) **Date of Patent:** **Aug. 19, 2025**

(54) **BRAIN COMPUTER INTERFACE FOR AUGMENTED REALITY**

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

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**Related U.S. Application Data**  
(63) Continuation of application No. 17/848,263, filed on Jun. 23, 2022, which is a continuation of application (Continued)

(51) **Int. Cl.**  
**G06F 3/01** (2006.01)  
**G06F 3/023** (2006.01)  
(Continued)

(52) **U.S. Cl.**  
CPC ..... **G06F 3/015** (2013.01); **G06F 3/016** (2013.01); **G06F 3/023** (2013.01); **G06F 3/14** (2013.01);  
(Continued)

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

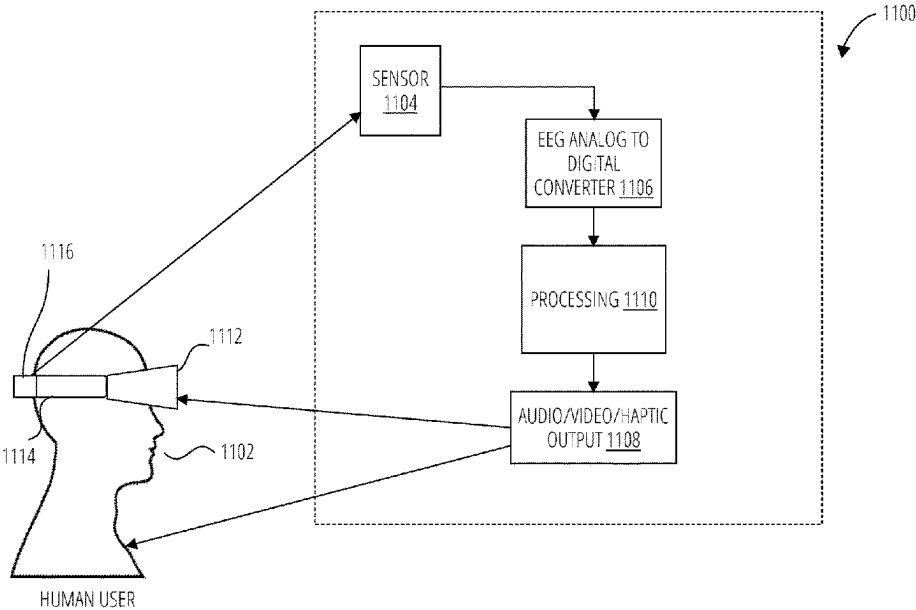
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(57) **ABSTRACT**  
An apparatus, system, and method of a brain computer interface in a headset including an augmented reality display, one or more sensors, a processing module, at least one biofeedback device, and a battery. The interface may include a printed circuit board that has the sensors to read bio-signals, provides biofeedback, and performs the processing, analyzing, and mapping of bio-signals into output. The output provides feedback via stimulation of multiple sensory brain systems of a user, including audio and visual on the augmented reality display, or audio and haptic in terms of vibration patterns that a human user may feel. All together this forms a closed-loop system, by detecting the bio-signal, then providing sensory-feedback, which in turn enhances the bio-signal.

**19 Claims, 25 Drawing Sheets**



**Related U.S. Application Data**

- No. 17/222,897, filed on Apr. 5, 2021, now Pat. No. 11,402,909, which is a continuation-in-part of application No. 17/141,162, filed on Jan. 4, 2021, now Pat. No. 11,237,635, and a continuation-in-part of application No. 16/749,892, filed on Jan. 22, 2020, now abandoned, said application No. 17/141,162 is a continuation-in-part of application No. 15/929,085, filed on Jan. 9, 2019, now Pat. No. 10,990,175, said application No. 17/222,897 is a continuation-in-part of application No. 15/498,158, filed on Apr. 26, 2017, now abandoned.
- (60) Provisional application No. 62/704,048, filed on Jan. 22, 2019, provisional application No. 62/752,133, filed on Oct. 29, 2018.
- (51) **Int. Cl.**  
**G06F 3/14** (2006.01)  
**G06F 3/16** (2006.01)  
**G06N 5/02** (2023.01)  
**G06N 20/00** (2019.01)  
**A61B 5/00** (2006.01)  
**H04W 84/18** (2009.01)
- (52) **U.S. Cl.**  
 CPC ..... **G06F 3/16** (2013.01); **G06N 5/02** (2013.01); **G06N 20/00** (2019.01); **A61B 5/0075** (2013.01); **H04W 84/18** (2013.01)

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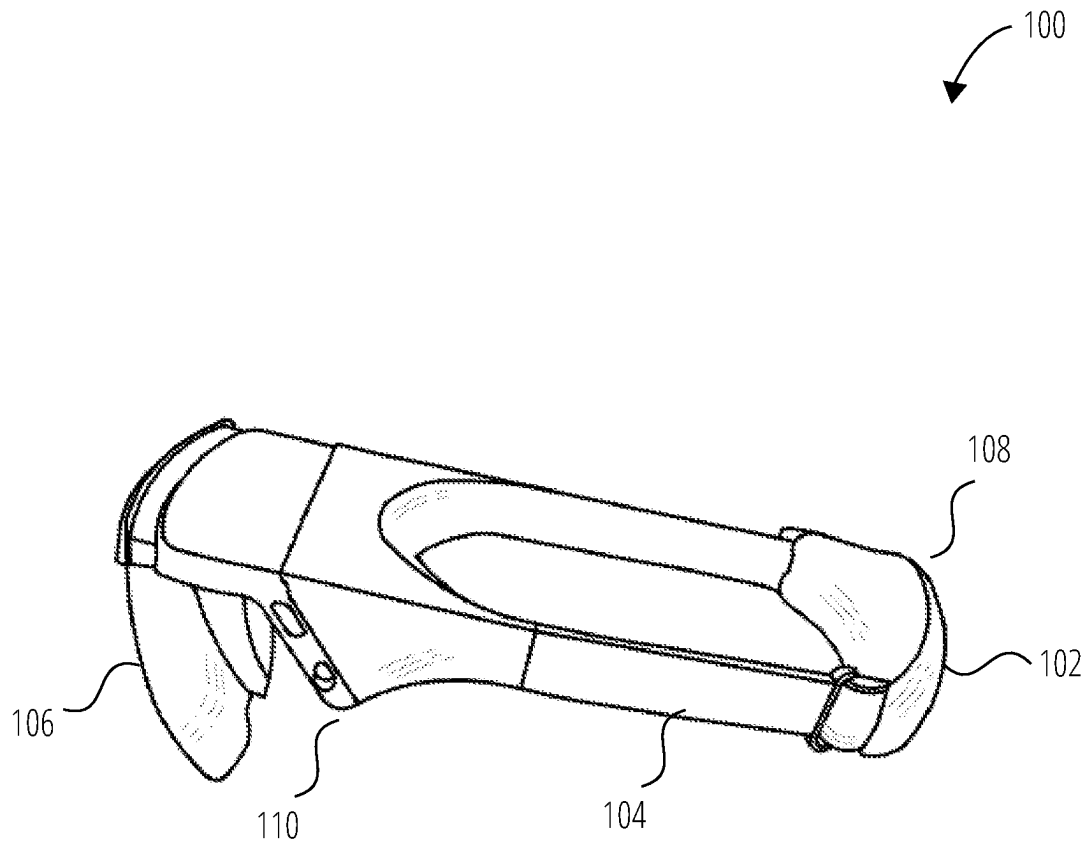


FIG. 1

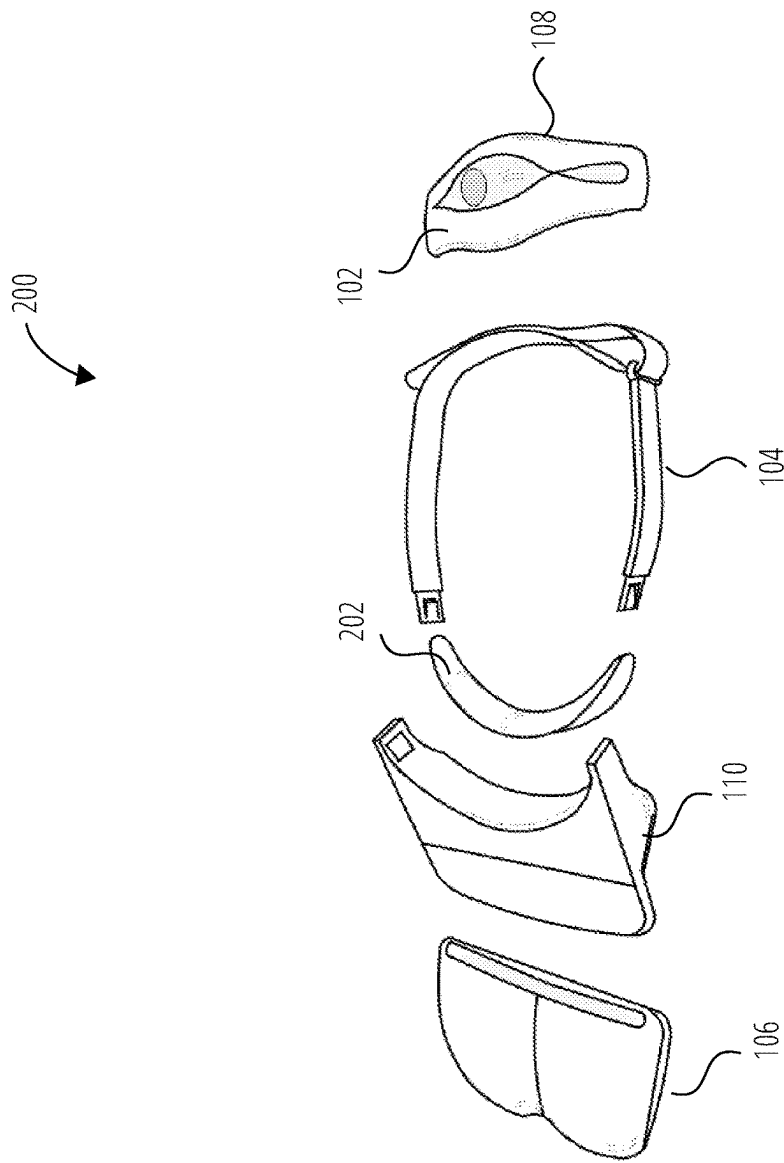


FIG. 2

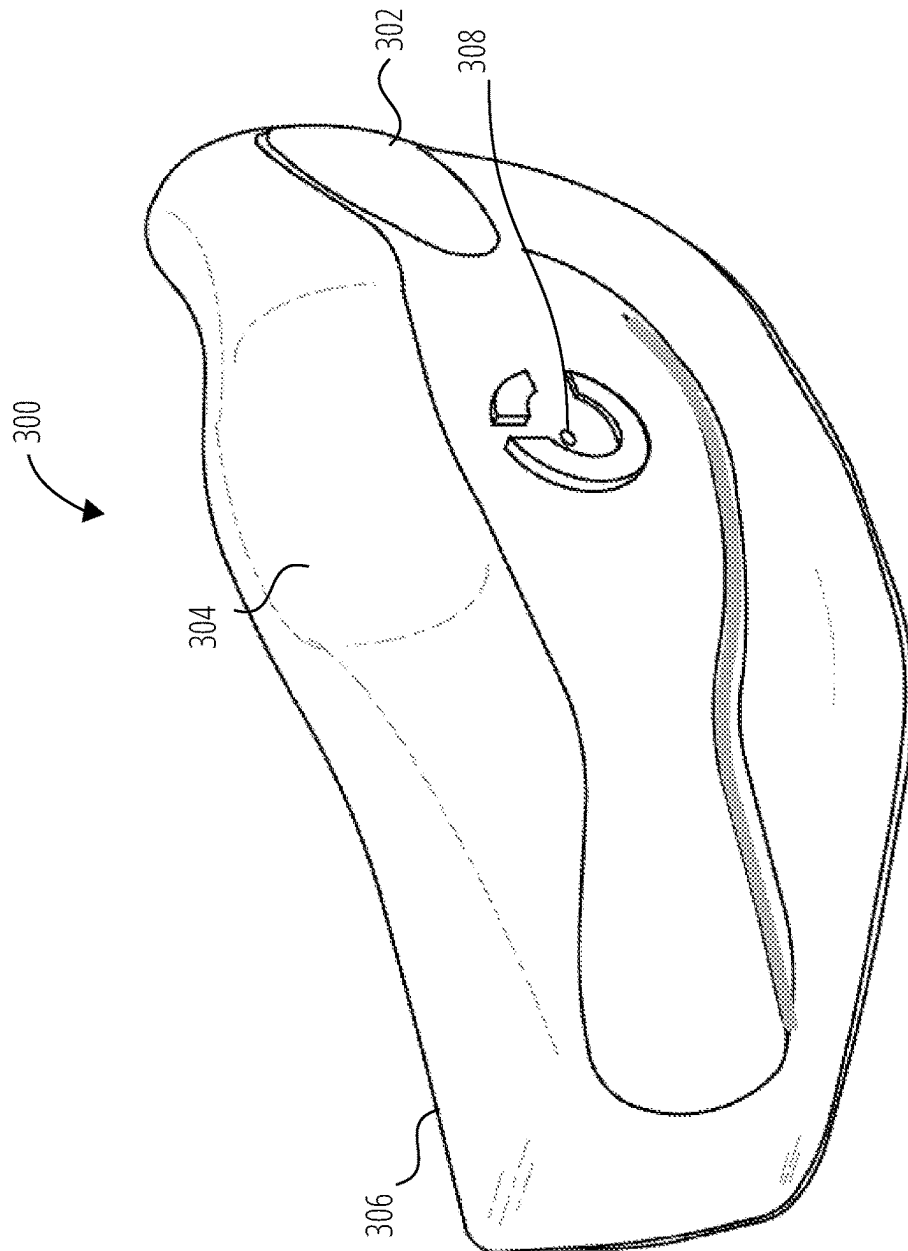


FIG. 3

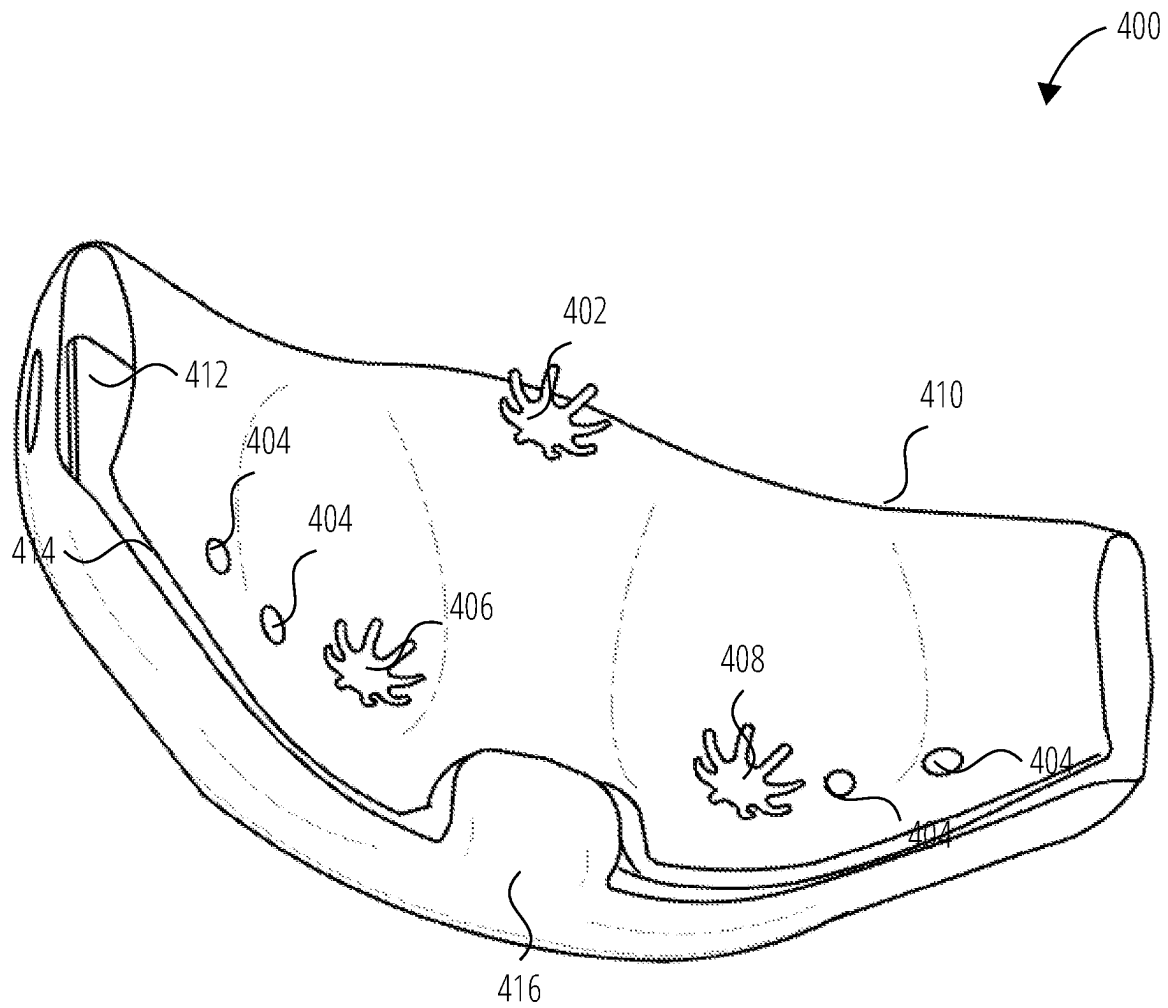


FIG. 4

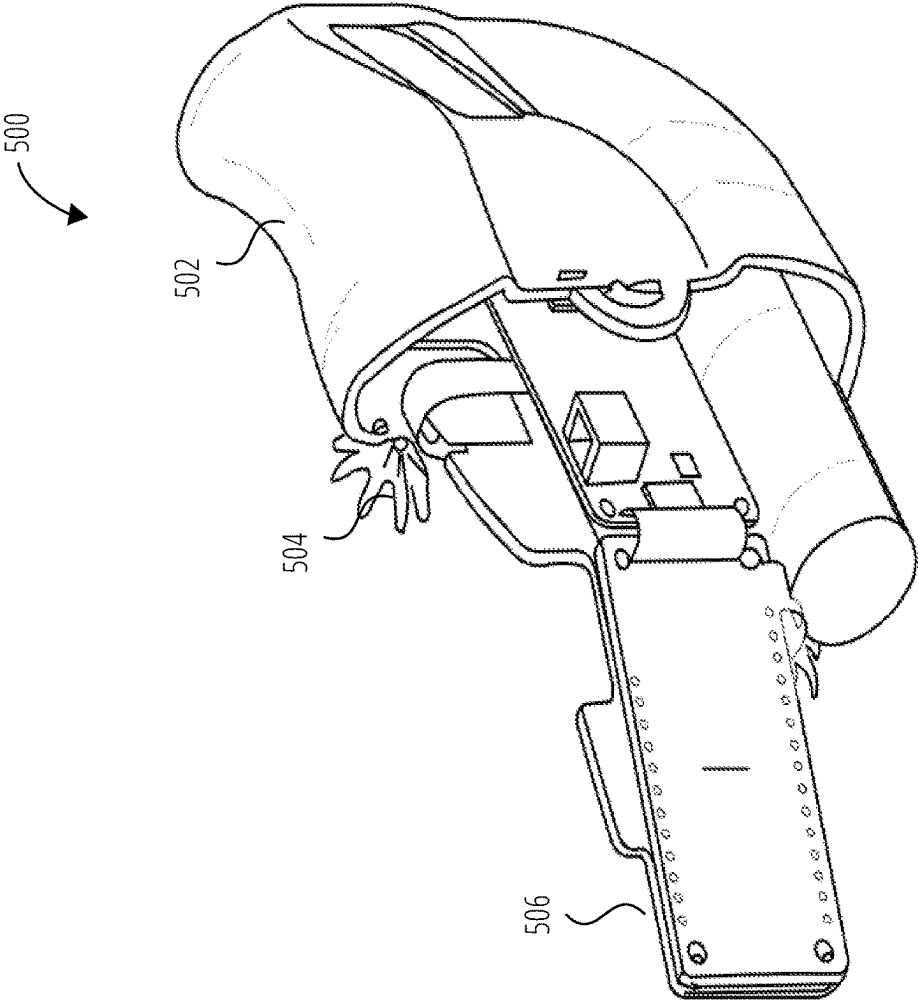


FIG. 5



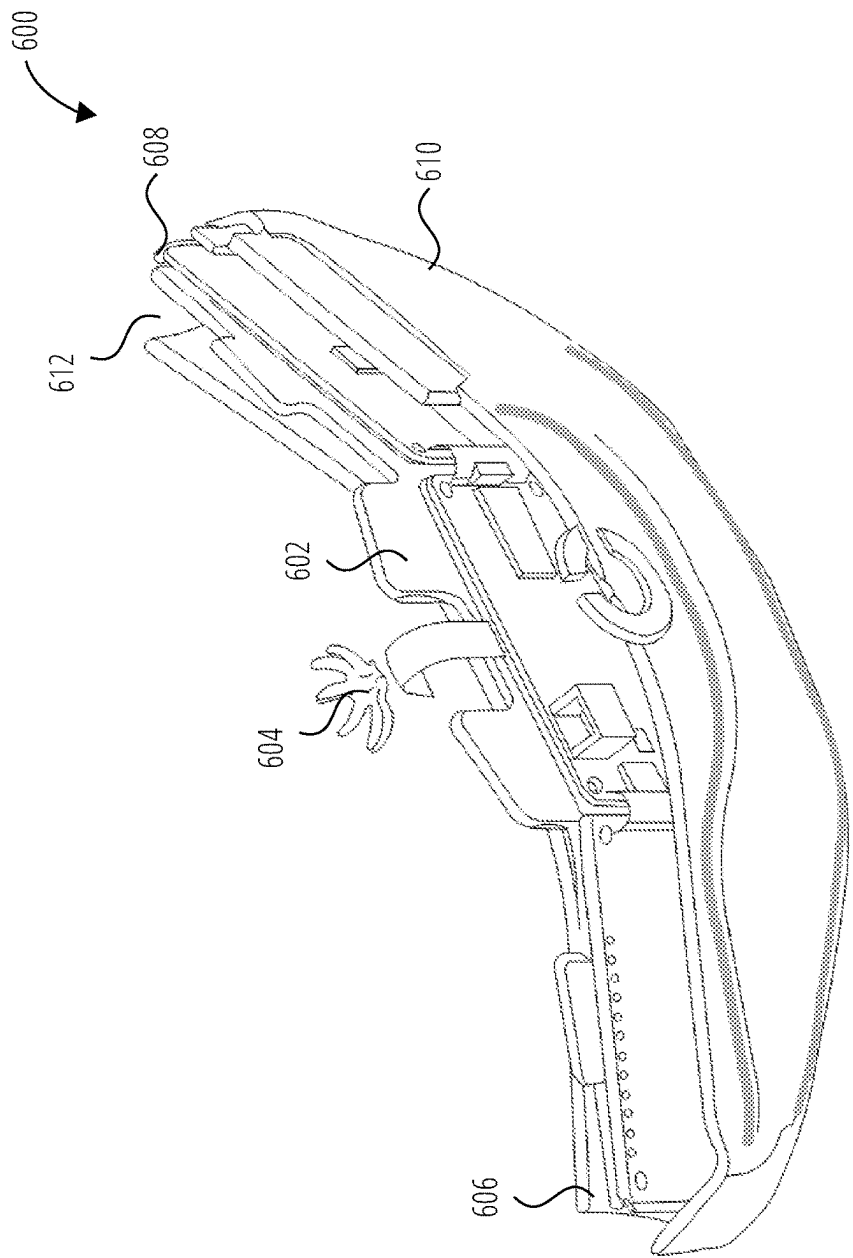


FIG. 6

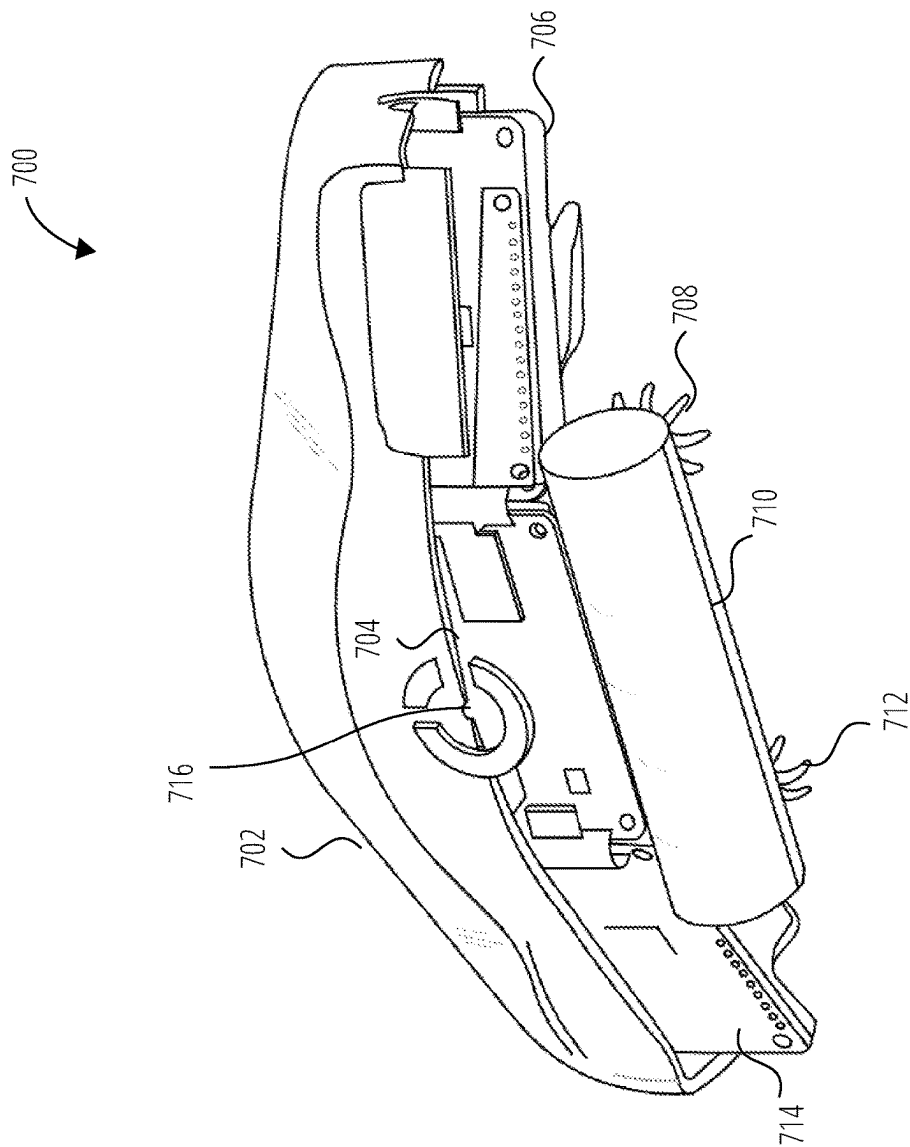
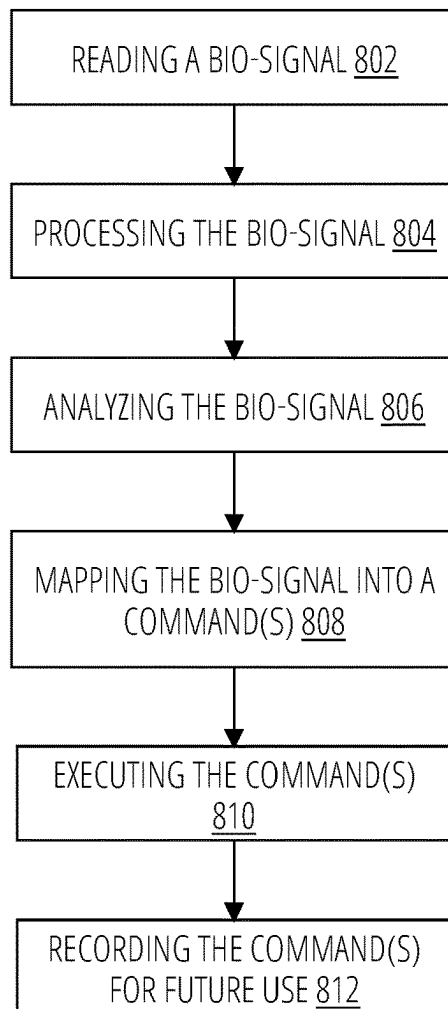


FIG. 7

800  
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**FIG. 8**

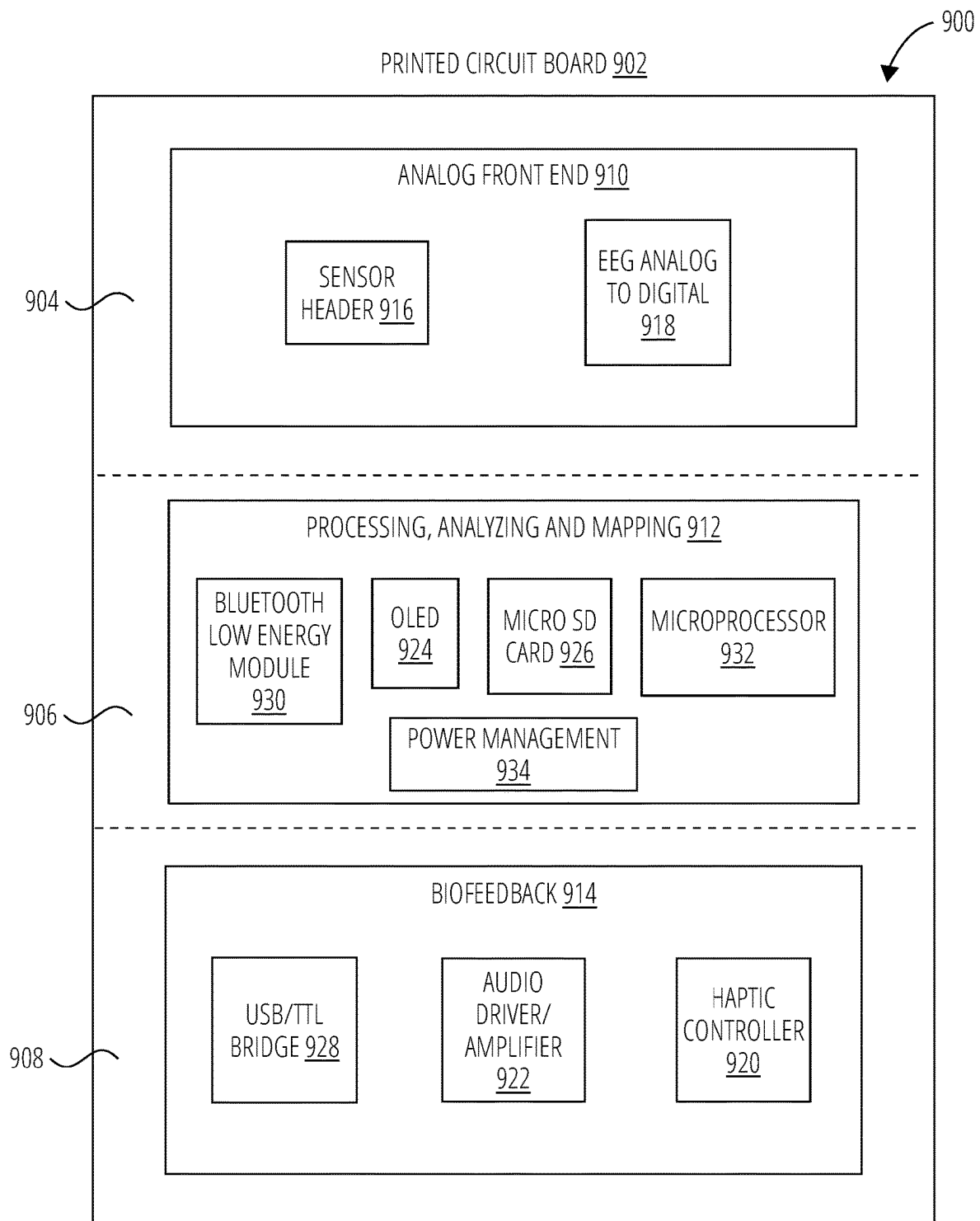
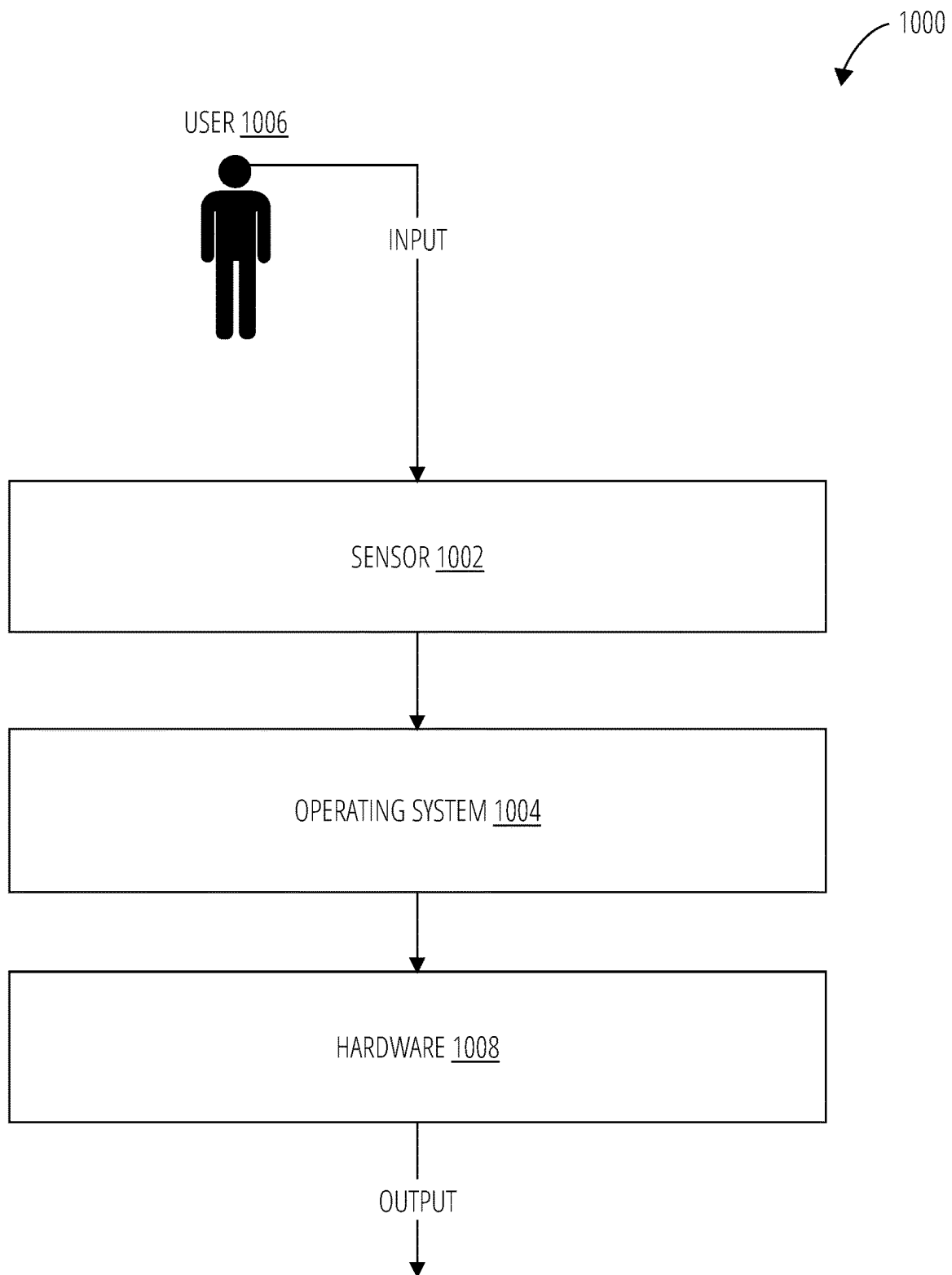


FIG. 9

**FIG. 10**

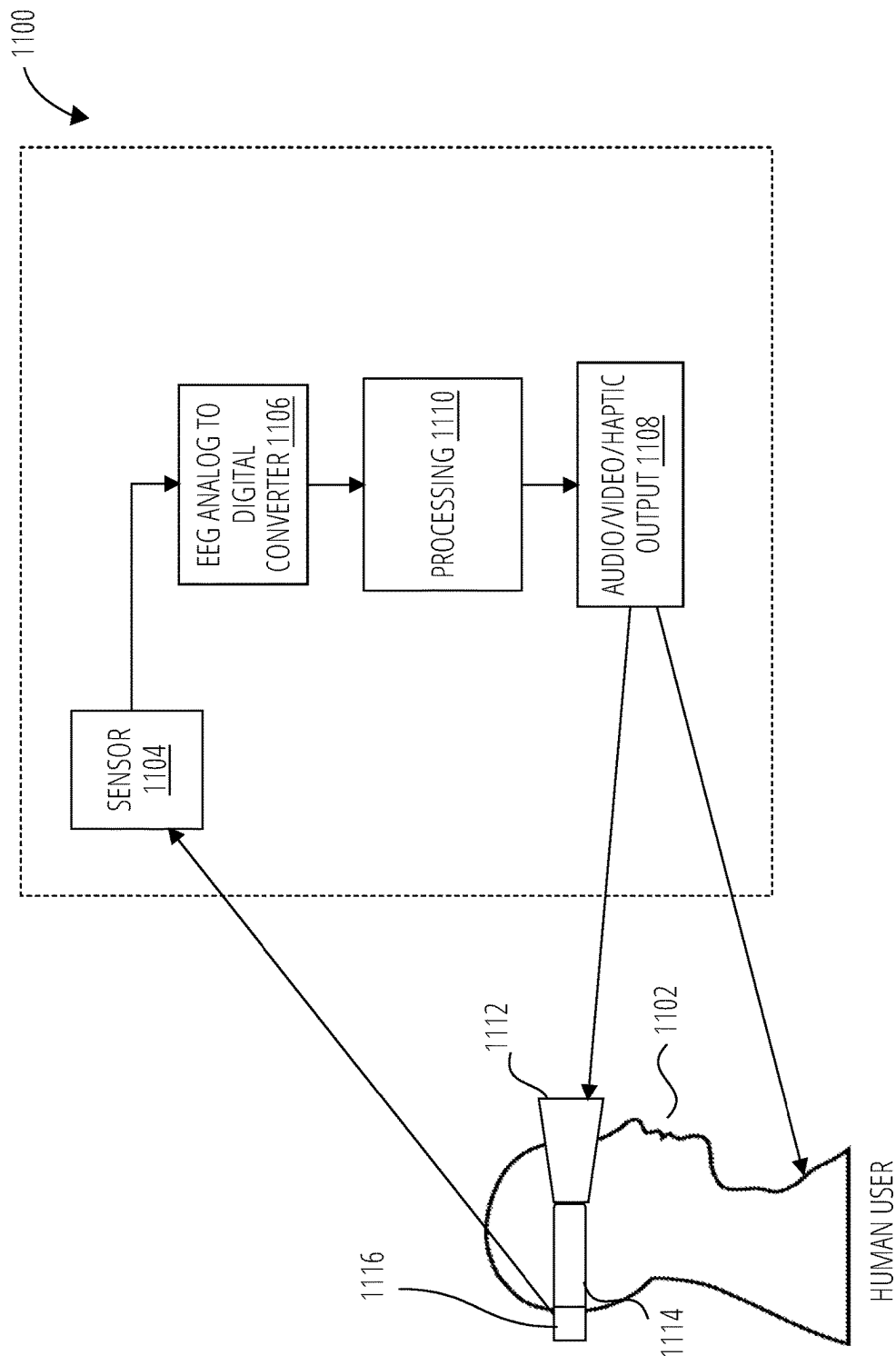


FIG. 11

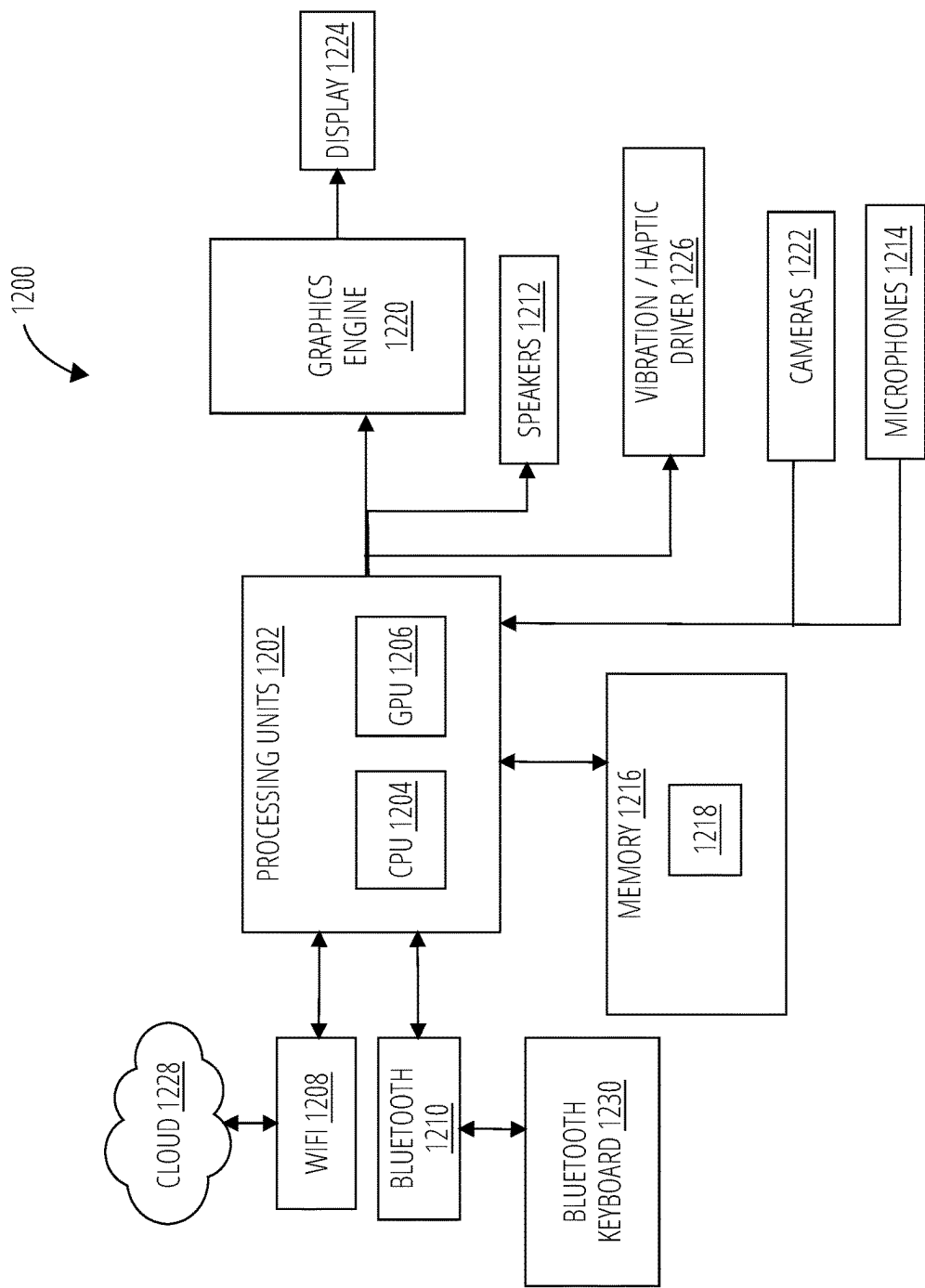


FIG. 12

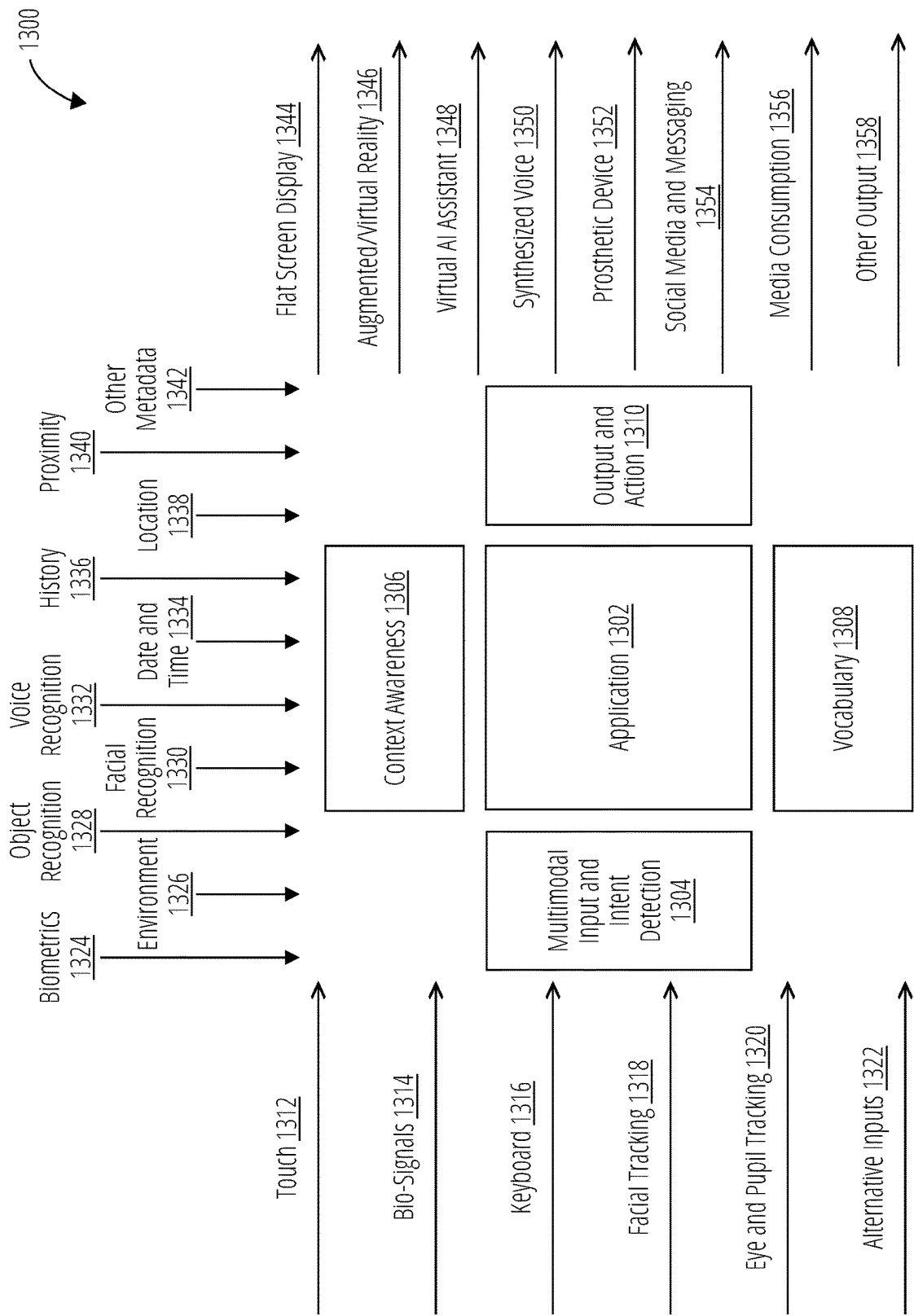


FIG. 13



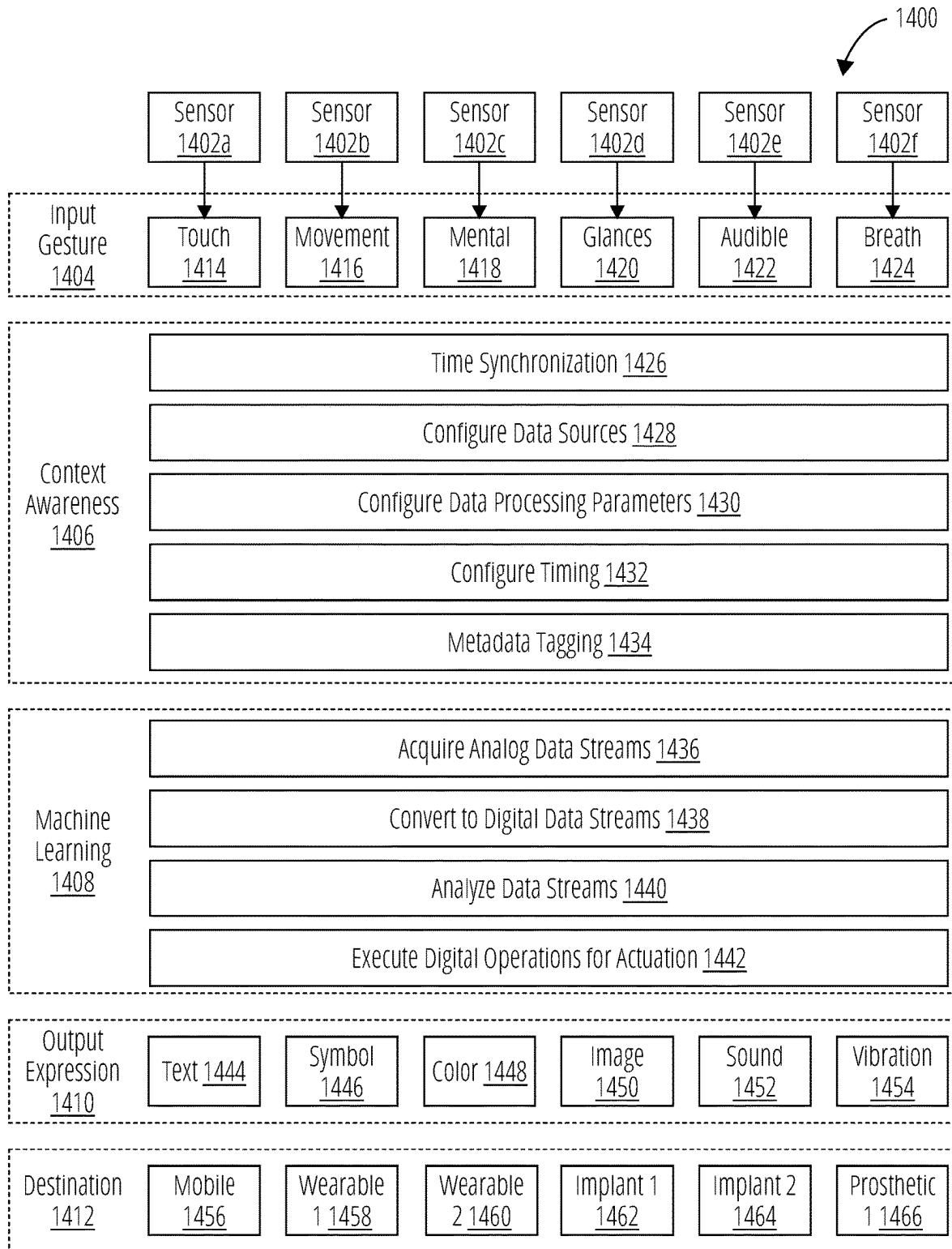


FIG. 14

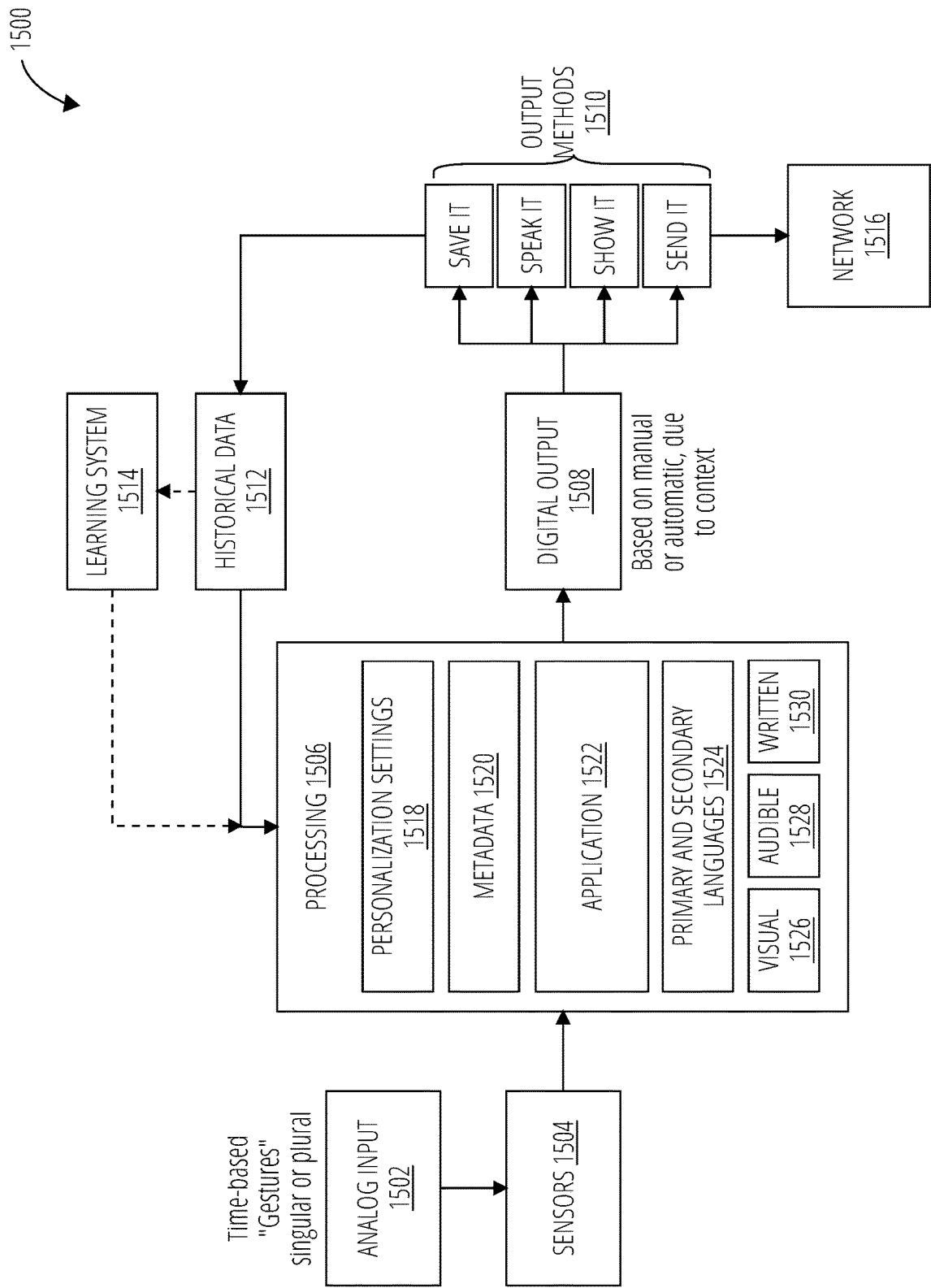


FIG. 15

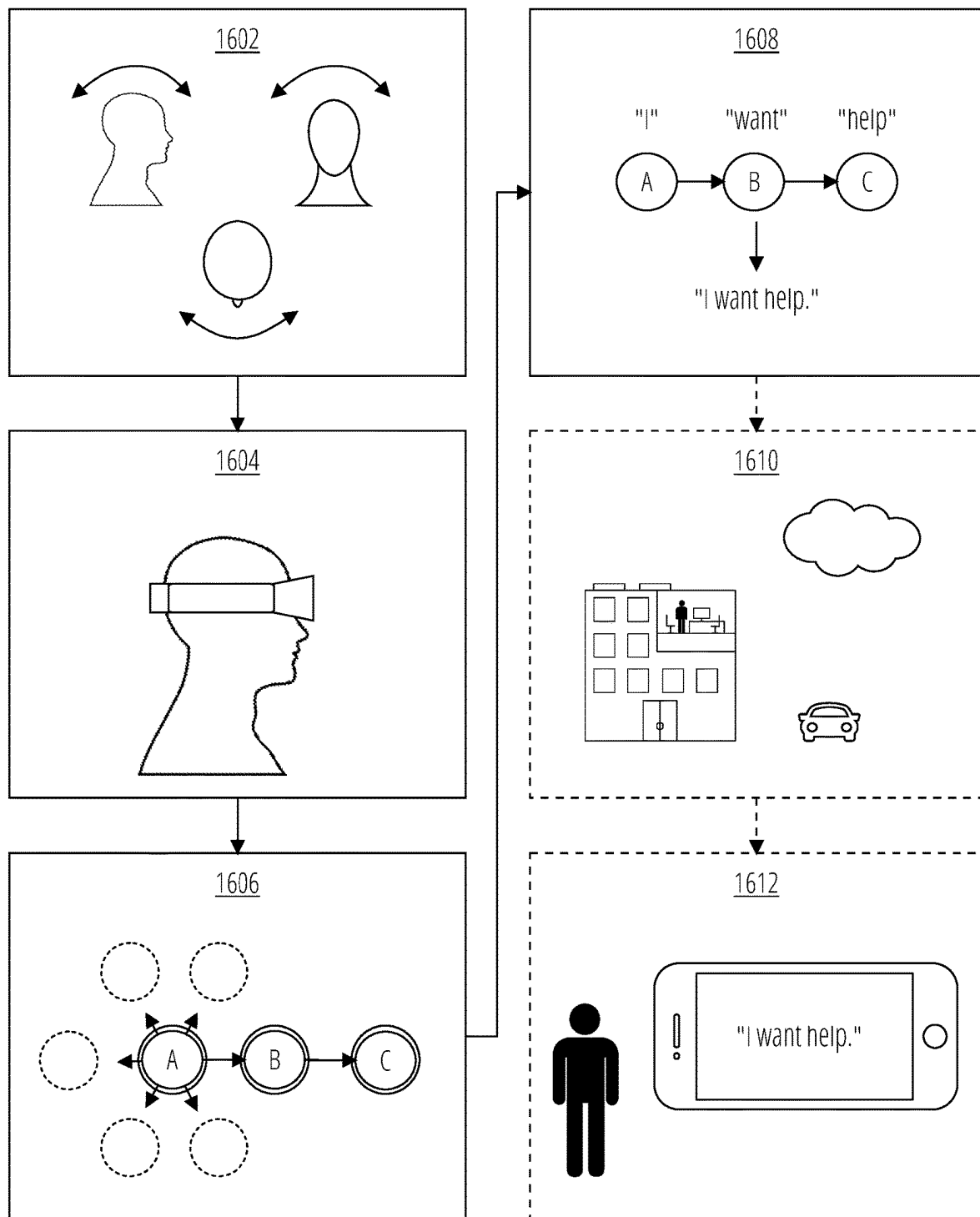


FIG. 16

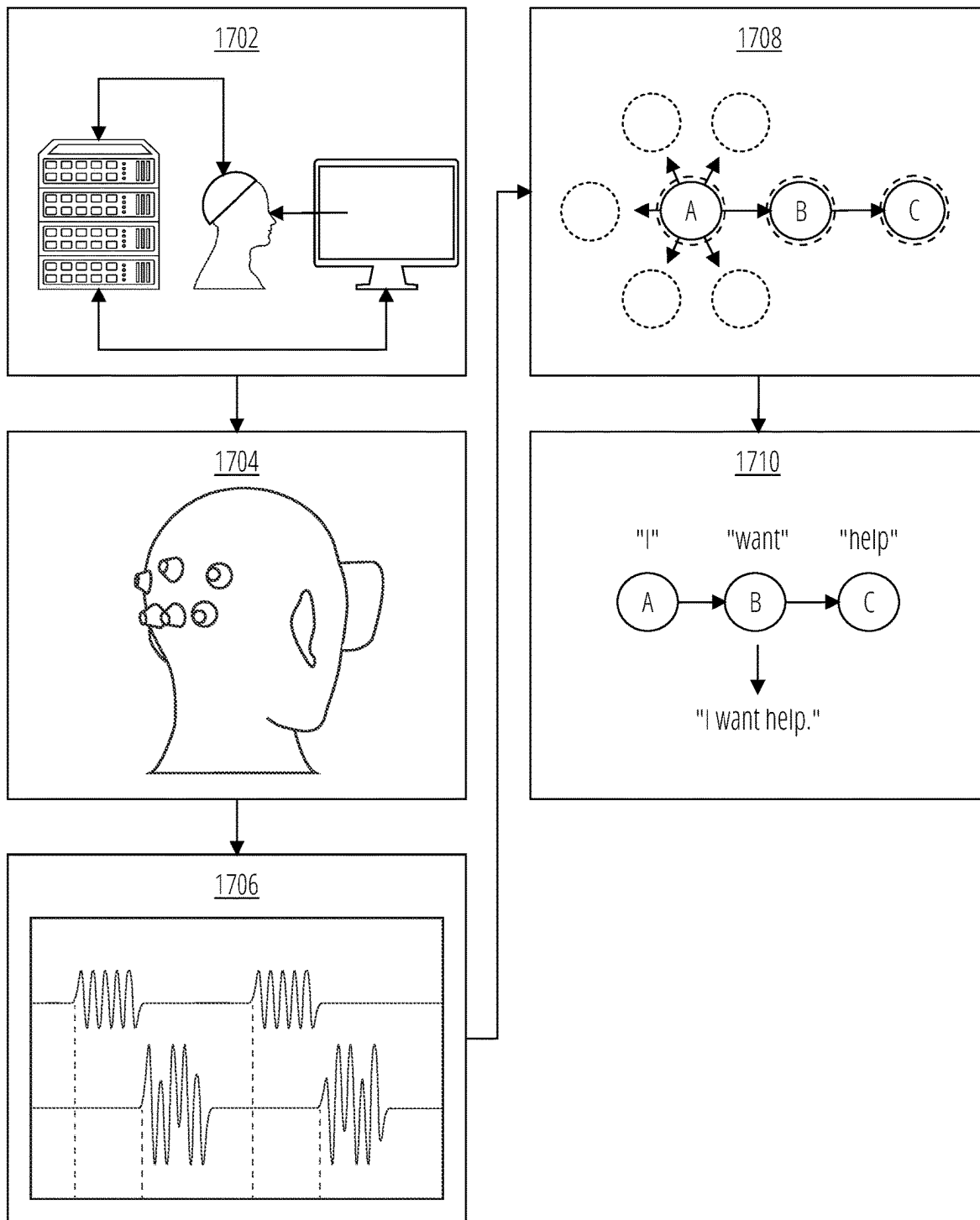


FIG. 17

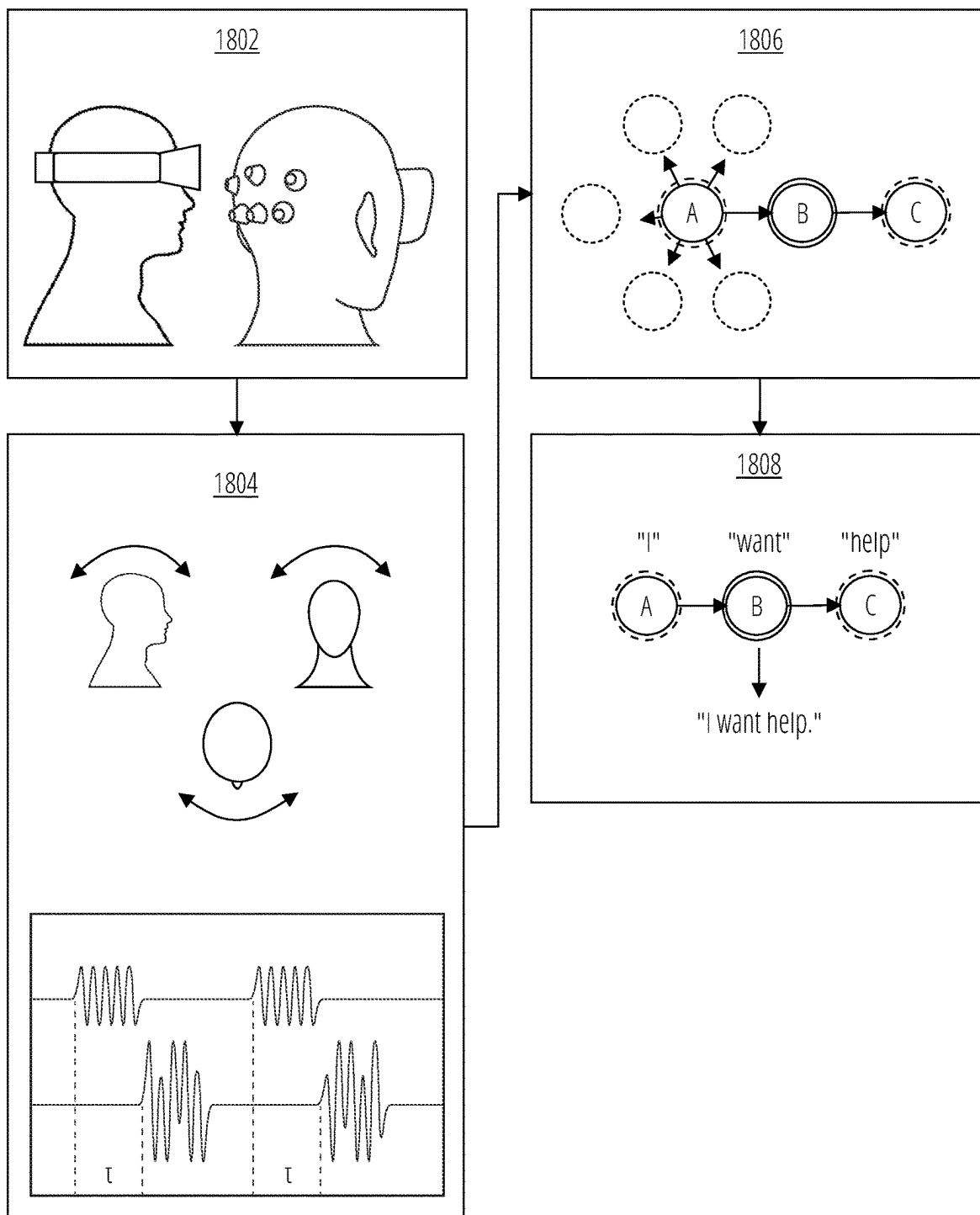


FIG. 18

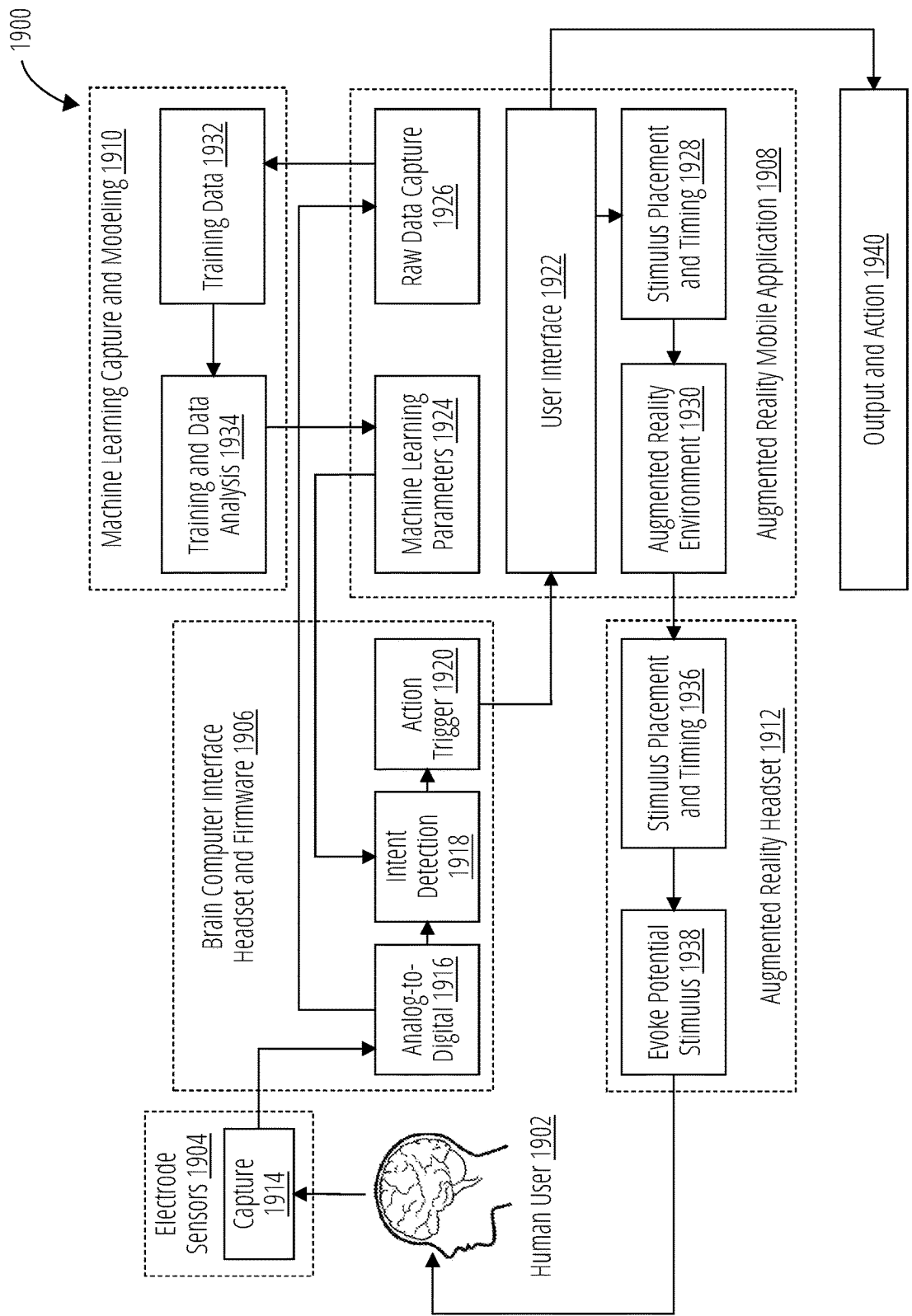


FIG. 19

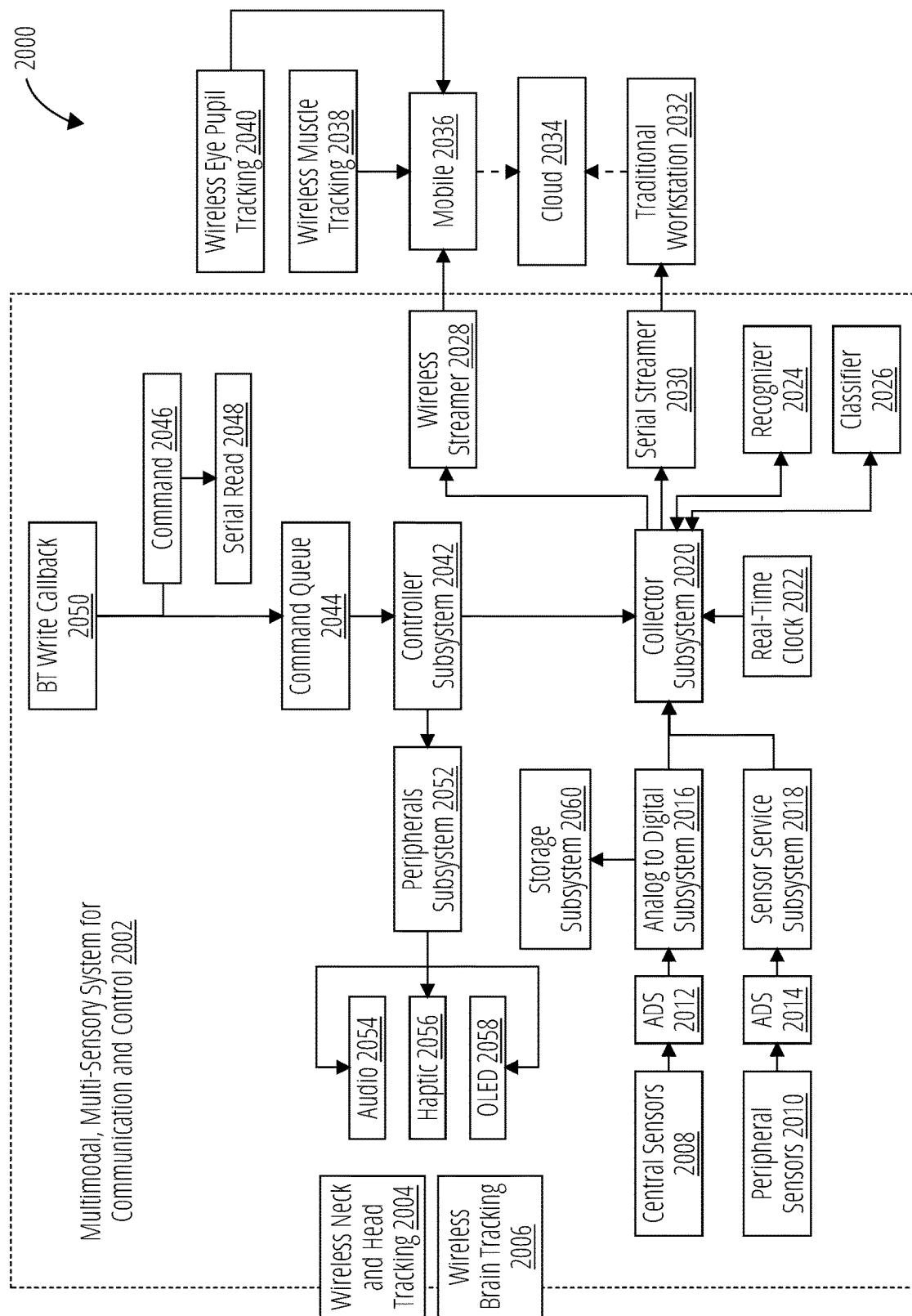


FIG. 20

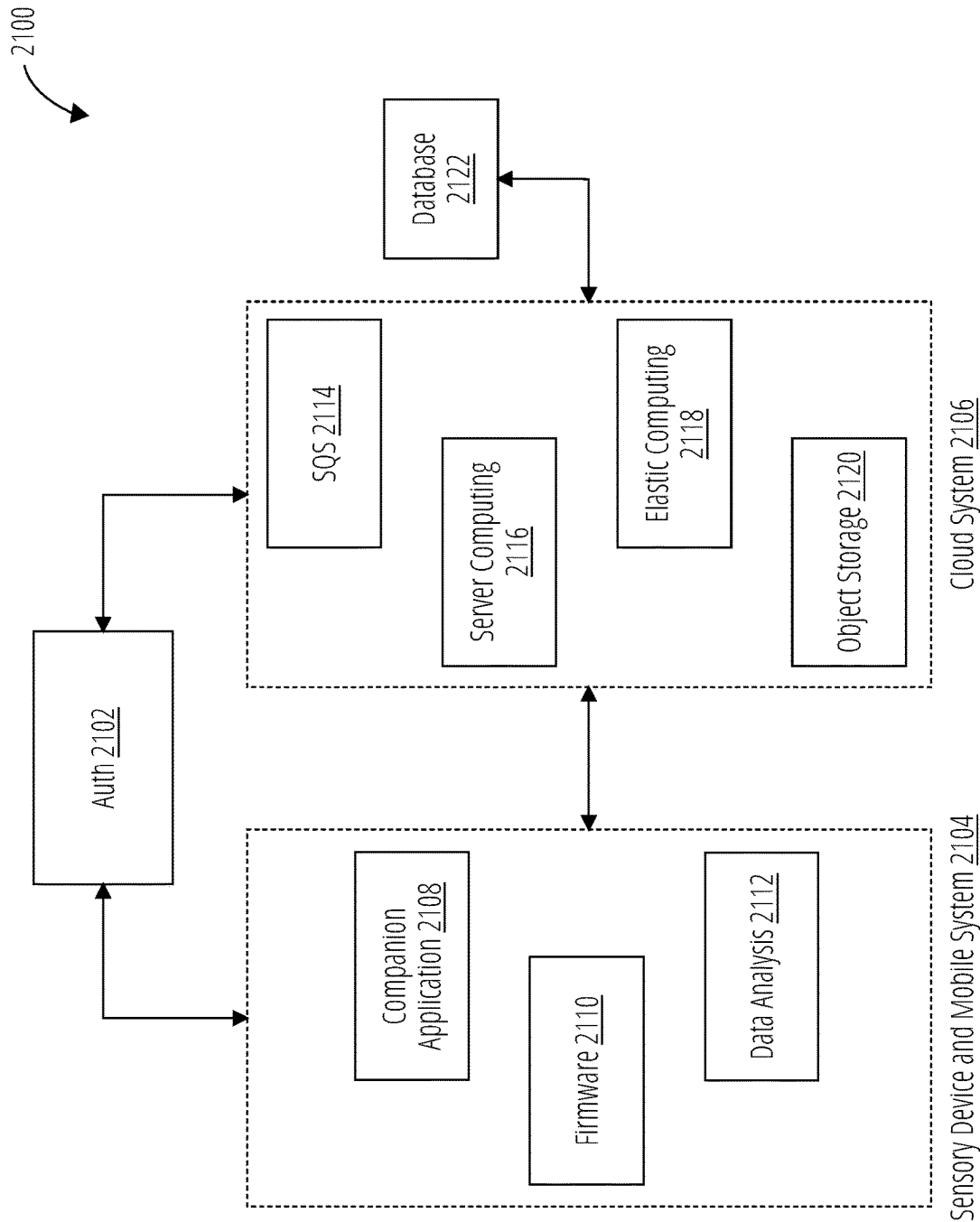


FIG. 21



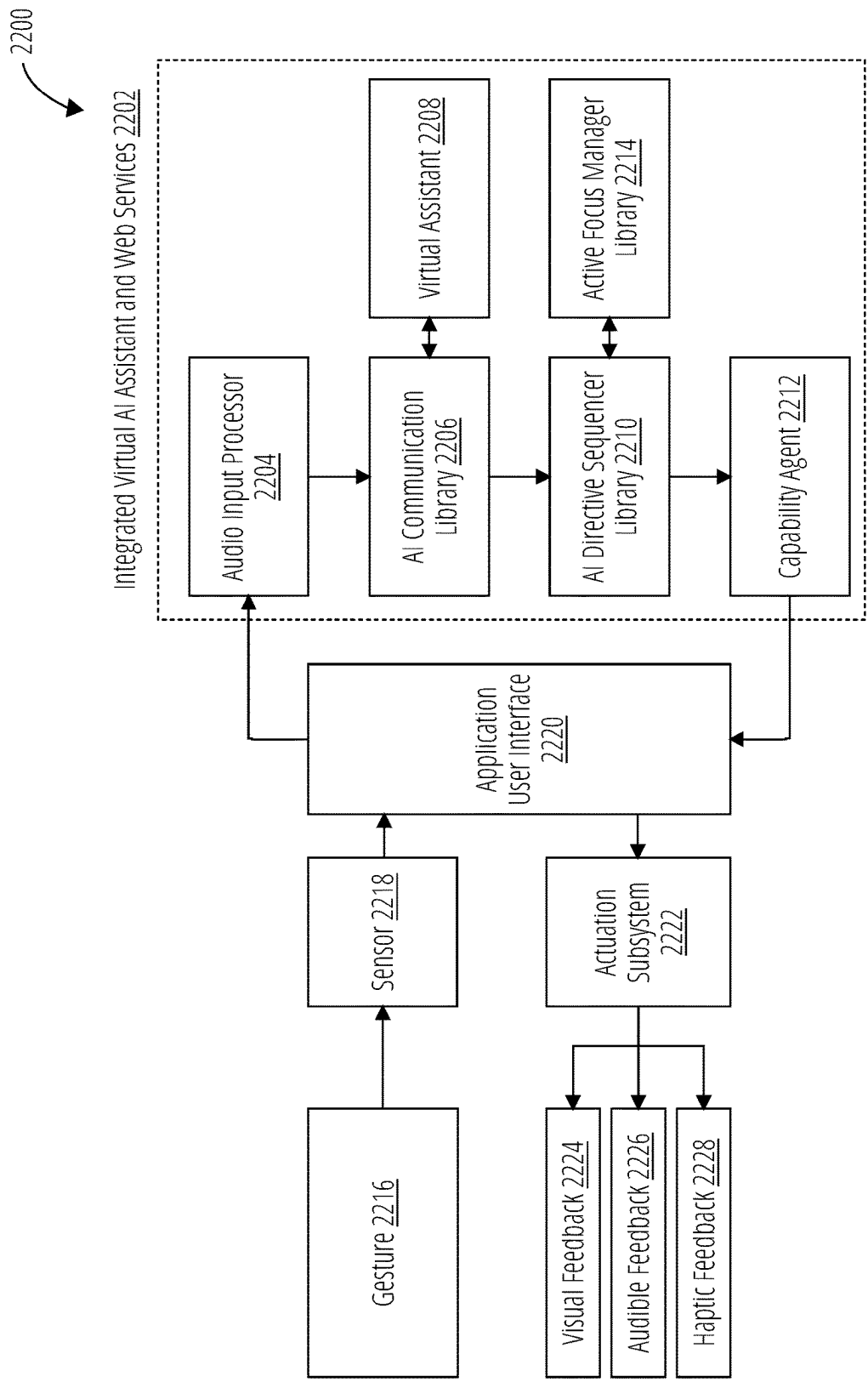
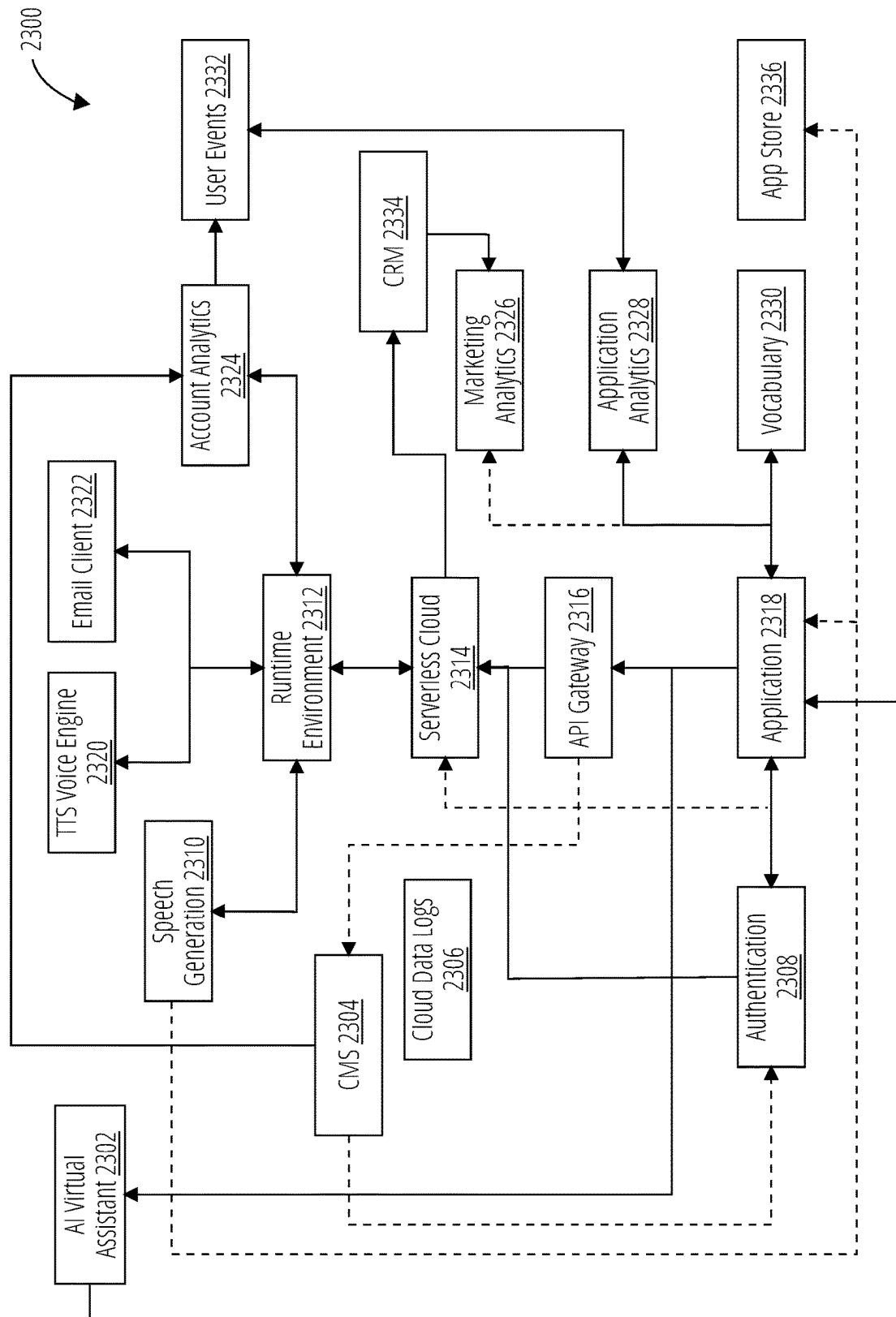


FIG. 22



**FIG. 23**

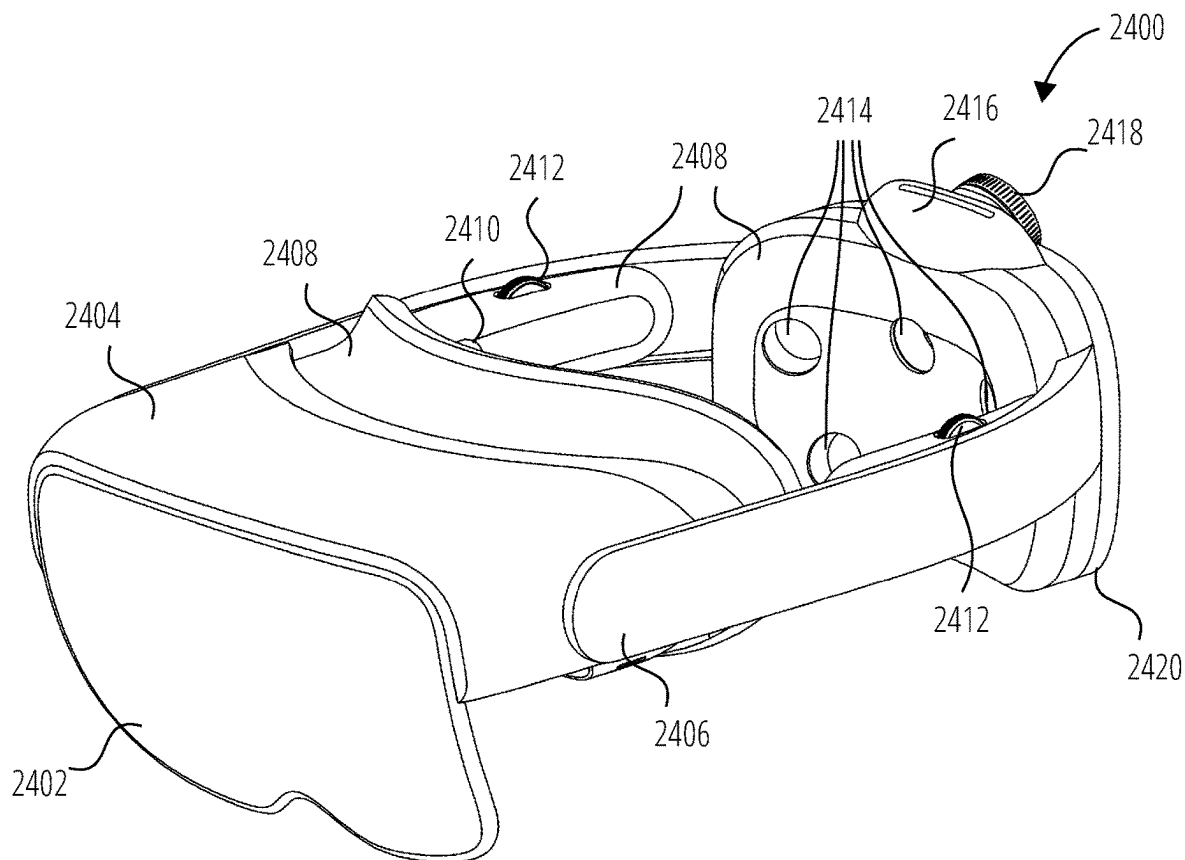


FIG. 24A

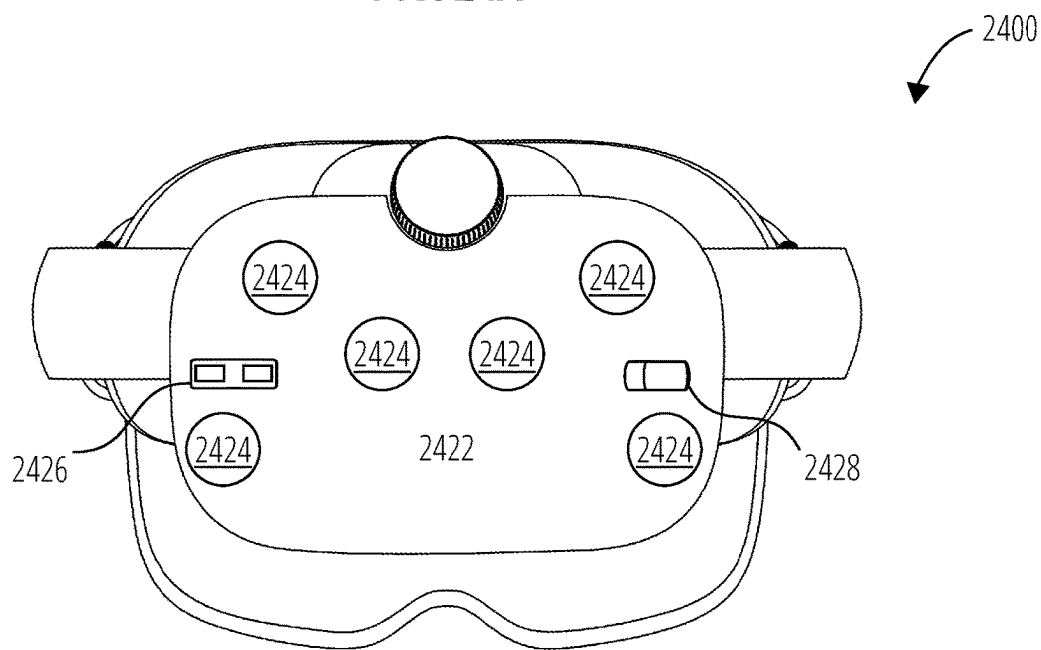
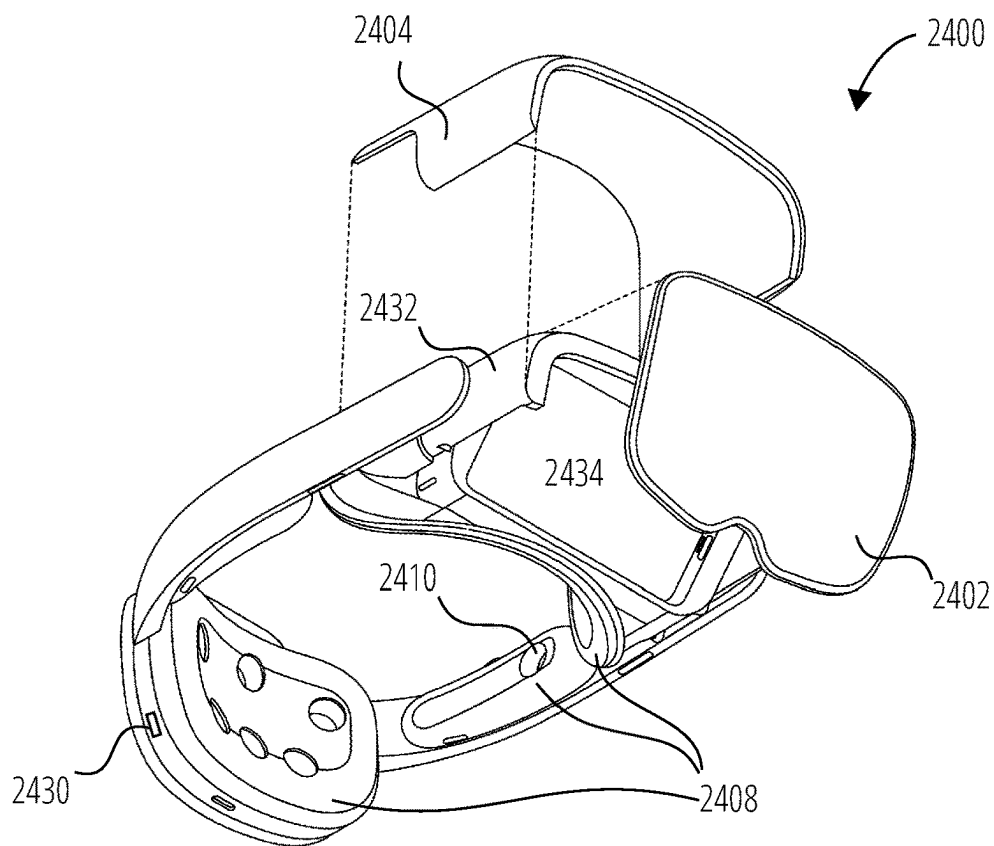
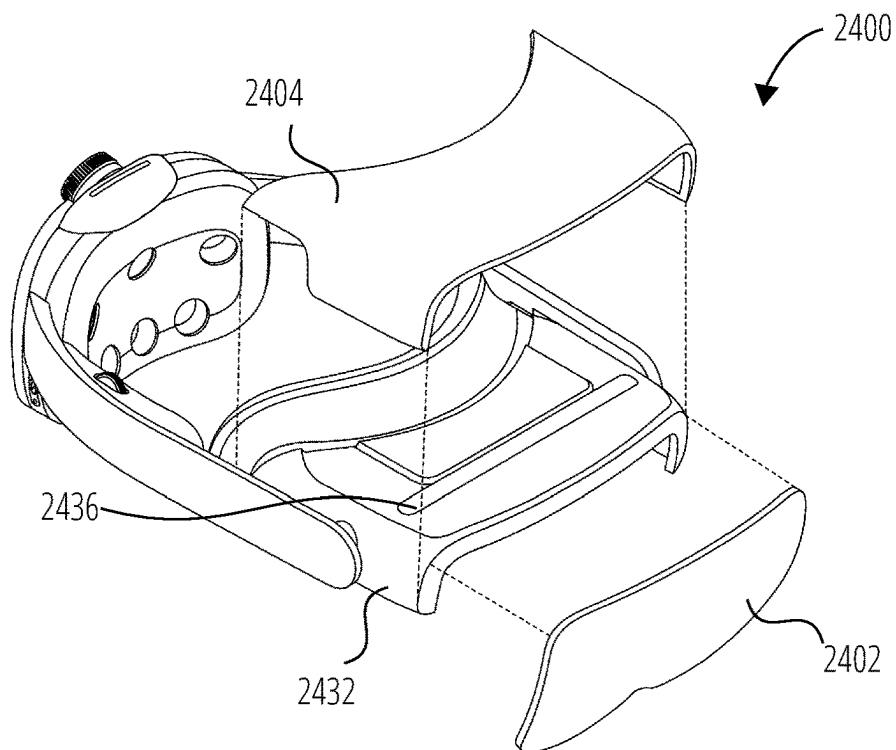


FIG. 24B



**FIG. 24C**



**FIG. 24D**

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# BRAIN COMPUTER INTERFACE FOR AUGMENTED REALITY

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. Non-provisional application Ser. No. 17/848,263, filed Jun. 23, 2022, which is a continuation of U.S. Non-provisional application Ser. No. 17/222,897, filed Apr. 5, 2021, which is a continuation-in-part of U.S. Non-provisional patent application Ser. No. 15/929,085, filed on Jan. 9, 2019, which claims the benefit of U.S. provisional patent application Ser. No. 62/752,133, filed on Oct. 29, 2018, and is a continuation-in-part of U.S. Non-provisional patent application Ser. No. 17/141,162, filed Jan. 4, 2021, which is a continuation-in-part of:

U.S. patent application Ser. No. 15/498,158, filed Apr. 26, 2017, entitled "Gesture Recognition Communication System"; U.S. patent application Ser. No. 16/749,892, filed Jan. 22, 2020, entitled "CONTEXT AWARE DUAL DISPLAY TO AUGMENT REALITY," which claims priority from Provisional application No. 62/704,048, filed on Jan. 22, 2019; and U.S. patent application Ser. No. 15/929,085, filed Jan. 9, 2019, entitled "BRAIN COMPUTER INTERFACE FOR AUGMENTED REALITY" which claims priority from Provisional application No. 62/752,133, filed on Oct. 29, 2018; each of which is incorporated herein by reference in its entirety.

## BACKGROUND

When typical brain-computer interfaces (BCIs) are used, an external device or a computer and monitor are required to process and act upon the brain signals from the BCI. This typically but not always requires a wired connection between BCI, and a variety of separate systems and devices for processing data, as well as displaying and synchronizing visual information with the BCI. Usually, the devices used for the brain-computer interface may require multiple dangling wires, which present multiple points of failure in the sense that if any of those wires are damaged, the brain-computer interface may fail to function. Typically, setting up a BCI system is time intensive and mostly location dependent in a room or lab. Additionally, there is a delay in receiving feedback based on the bio-signal from the brain, and another human may be required to be present in order to read the results from a separate device.

In addition to these problems, the typical printed circuit board used in BCIs is often flat in shape and may fail to offer practical functioning in field conditions. Therefore, there is a need for a brain-computer interface with an improved form factor and adequate internal field computing resources.

## BRIEF SUMMARY

Disclosed herein are embodiments of a brain-computer interface and headset, which includes an augmented reality display, one or more sensors, a processing module, at least one biofeedback device, and a battery.

In some embodiments, the interface may include a printed circuit board that contoured in a shape that conforms to a human head. The board may be a flexible board or may be a board with separate sections linked together. In an embodiment, the board comprises three parts: a first area, a second area and a third area. The first area of the printed circuit board may comprise the analog front end and may input brain-to-surface (of the skin) bio-signals using strategically

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located sensors. The second area of the printed circuit board may perform the processing, analyzing and mapping of bio-signals into an output, including haptic, audio, and visual outputs to the augmented reality glasses. The third area of the printed circuit board may provide haptic and audio feedback. After experiencing feedback from all, or any of these three sensory modalities-audio, visual and haptic, a user may generate new and different bio-signals from the brain, and as such a feedback loop may result in creating and strengthening neural pathways that lead to successful behaviors and actions by the user of the headset.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced.

FIG. 1 illustrates a headset **100** in accordance with one embodiment.

FIG. 2 illustrates a disassembled BCI headset **200** in accordance with one embodiment.

FIG. 3 illustrates a headset **300** in accordance with one embodiment.

FIG. 4 illustrates a headset **400** in accordance with one embodiment.

FIG. 5 illustrates a cross section of headset **500** in accordance with one embodiment.

FIG. 6 illustrates a cross section of headset **600** in accordance with one embodiment.

FIG. 7 illustrates a cross section view of headset **700** in accordance with one embodiment.

FIG. 8 illustrates a method **800** in accordance with one embodiment.

FIG. 9 illustrates a device **900** in accordance with one embodiment.

FIG. 10 illustrates a BCI+AR system **1000** in accordance with one embodiment.

FIG. 11 illustrates a BCI+AR environment **1100** in accordance with one embodiment.

FIG. 12 illustrates an augmented reality device logic **1200** in accordance with one embodiment.

FIG. 13 illustrates a block diagram of nonverbal multi-input and feedback device **1300** in accordance with one embodiment.

FIG. 14 illustrates a block diagram of a single framework of a nonverbal multi-input and feedback device **1400** in accordance with one embodiment.

FIG. 15 illustrates a block diagram of nonverbal multi-input and feedback device **1500** in accordance with one embodiment.

FIG. 16 illustrates a logical diagram of a user wearing an augmented reality headset in accordance with one embodiment.

FIG. 17 a logical diagram of a user wearing an augmented reality headset in accordance with one embodiment.

FIG. 18 illustrates a diagram of a use case including a user wearing an augmented reality headset in accordance with one embodiment.

FIG. 19 illustrates a flow diagram **1900** in accordance with one embodiment.

FIG. 20 illustrates a flow diagram **2000** in accordance with one embodiment.

FIG. 21 illustrates a block diagram **2100** in accordance with one embodiment.

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FIG. 22 illustrates a block diagram 2200 in accordance with one embodiment.

FIG. 23 illustrates a block diagram 2300 in accordance with one embodiment.

FIG. 24A illustrates an isometric view of a BCI headset system 2400 in accordance with one embodiment.

FIG. 24B illustrates a rear view of a BCI headset system 2400 in accordance with one embodiment.

FIG. 24C illustrates an exploded view of a BCI headset system 2400 in accordance with one embodiment.

FIG. 24D illustrates an exploded view of a BCI headset system 2400 in accordance with one embodiment.

#### DETAILED DESCRIPTION

The present disclosure addresses problems of comfort, wireless mobility, usability, reliability and other constraints found in conventional BCI systems utilizing a novel contoured shape and consolidated on-board processing of bio-signal data utilizing a specially-designed printed circuit board within the headset. This ability to internally process bio-signals may reduce or eliminate the need for an external mobile device or computer to do the bio-signals processing.

The bio-signal data is collected from the sensors on or connected to the headset, input into the printed circuit board on the headset, processed on the headset, and then output to transducers including but not limited to visual, auditory, and haptic transducers. In an embodiment, the circuit board may have a variety of sensors connected to the analog front end. For example, the mounted EEG electrodes may be utilized, but there may also be EMG sensors attached to an arm or other body part wired to the circuit board for processing data from multiple sources, not just EEG on the head.

The output may for example be applied to an augmented reality headset that a user may wear. The senses that may be stimulated as biofeedback may include, e.g. output commands sent to inflatable bags for pressure, temperature for increasing therapeutic sensation, electrical stimulation, or even a command to an external device or system such as a prosthetic hand/arm/leg or wheelchair for controlled movement.

In response to these outputs, new and altered neural signals of the user's brain may be reinforced, thus establishing a feedback loop that may result in discovering unique and creative ways to translate intentions into new experiences by the user of the headset.

The headset may function standalone without reliance on an external mobile device or computer, making it portable and self-sufficient as a "read-only" device, i.e., no ability to display augmented reality. Alternatively, it may communicate wirelessly with a mobile device or computer, providing output based on the bio-signals from the user of the headset. The headset is a unique design that consolidates more processing power into a smaller package than conventional BCI headsets. The portability factor may make a significant impact on individuals who want to have this experience in locations that are away from modern conveniences, as well as for people who are disabled. For example, one of the uses of this device may include an augmented assisted communications device or a remote control device. The systems and devices described in this disclosure may assist people who otherwise have a hard time communicating or enough physical ability to control their environment well. The brain signals of such people may be able to communicate their thoughts or remotely control objects in their environment, as opposed to verbal or hand-based communications.

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Non-limiting examples of the configurations of the BCI or BCI+headset include:

BCI as a fully integrated system with AR

BCI as an accessory that can be bolted onto another AR/VR/Mixed Reality system

BCI as a reference design that can be miniaturized to a completely detached solution (e.g. BCI in a baseball cap and AR in a pair of smart glasses-worn separately but connected wirelessly)

BCI that can be miniaturized as an implantable under the skin and communicate wirelessly with a pair of smart AR contact lenses.

One embodiment comprises a fully self-contained EEG (electroencephalography) headset device that is specifically designed for the sensing and reporting of Visual Evoked Potential (VEP) matches, and optionally interfacing to a host computing device as a human Interface Device (HID) over Generic Attributes (GATT) device keyboards or mouse interfaces. In an embodiment, the Visual Evocation may be a steady state Visual Evoked Potential (SSVEP).

#### Evoked Potentials

Signals can be recorded from cerebral cortex, brain stem, spinal cord, peripheral nerves and muscles. Typically the term "evoked potential" is reserved for responses involving either recording from, or stimulation of, central nervous system structures. Evoked potentials are mainly classified by the type of stimulus: somatosensory, auditory, visual. But they could be also classified according to stimulus frequency, wave latencies, potential origin, location, and derivation.

Examples of VEPs that may be used with devices and systems disclosed herein include, but are not limited to:

- Monocular pattern reversal
- Sweep visual evoked potential
- Binocular visual evoked potential
- Chromatic visual evoked potential
- Hemi-field visual evoked potential
- Flash visual evoked potential
- LED Goggle visual evoked potential
- Motion visual evoked potential
- Multifocal visual evoked potential
- Multi-channel visual evoked potential
- Multi-frequency visual evoked potential
- Stereo-elicited visual evoked potential
- Steady state visually evoked potential
- Code modulated visual evoked potentials
- Chaotic code modulated evoked potentials
- C1
- P100
- P200
- P300
- P600

Auditory evoked potentials (AEPs) are a subclass of event-related potentials (ERPs). ERPs are brain responses that are time-locked to some "event," such as a sensory stimulus, a mental event (such as recognition of a target stimulus), or the omission of a stimulus. For AEPs, the "event" is a sound. AEPs (and ERPs) are very small electrical voltage potentials originating from the brain recorded from the scalp in response to an auditory stimulus, such as different tones, speech sounds, etc. Examples of Auditory Evoked Potentials that may be used with devices and systems disclosed herein include, but are not limited to:

- Brainstem auditory evoked potentials
- C1

P100  
P200  
P300  
P600

Somatosensory Evoked Potentials (SSEPs) are evoked potentials recorded from the brain or spinal cord when stimulating peripheral nerve repeatedly. Examples of SSEPs that may be used with devices and systems disclosed herein include, but are not limited to:

Steady-state vibration (haptic) somatosensory evoked potentials  
Modulated Vibration (haptic) somatosensory evoked potentials  
Stereo-elicited vibration (haptic) evoked potentials  
Multi-frequency vibration (haptic) evoked  
C1  
P100  
P200  
P300

The self-contained device may comprise a headband or other external scalp sensor contact arrangement with one or more sensors. The device may also include support circuitry, such as a sensor amplifier, CPU, Analog to Digital (A2D) converter, and BLE (Bluetooth Low Energy) that interfaces with the HID over GATT protocol to a host. Acting as a HID wireless keyboard or mouse interface, this self-contained device may be used to control any HID interface compatible devices including but not limited to desktop computer, mobile devices and home appliances and media and entertainment equipment.

The device may be configurable for: (a) VEP matches on different frequencies that the device may monitor; (b) power threshold for the frequency; and (c) the number of consecutive repeated cycles over the threshold. The device may generate a configurable associated HID keyboard or mouse report to the HID Host. This capability may allow for direct control over iOS, Android, OSX, Windows, and Linux devices.

#### Artificial Intelligence (AI)

There are numerous machine learning methods that may be used to process biosignals. Examples include, but are not limited to:

PSDA-Power Spectral Density Analysis  
CCA-Canonical Correlation  
CNN-Convolutional Neural Network  
DNN-Deep Neural Network  
RNN-Recurrent Neural Network

Multithreaded processing for simultaneous processing of data from multiple sources concurrently may be used. For example, Machine Learning for processing EEG (brain) and EMG (arm) simultaneously requires time synchronization between the two data streams and processing of EEG and EMG independently, but also processing the data as a combined set (i.e., sensor fusion). The disclosed systems and apparatuses make it possible to support sensor fusion onboard and wirelessly. Examples may include fusing streaming data from another sensor with the EEG sensors to decrease the uncertainty level of the output; and processing either the raw data, the features, or the combined 'simmer' data.

The systems and methods may support concurrent processing of biosignal data from multiple data sources and sensors (EEG, EMG, EOG, EYE TRACKING, MOTION,

ECG), which requires a machine learning approach for efficient and rapid processing of big data on constrained devices.

On the communication application side (Speech Generating Application that runs on the AR portion of the headset), there is other AI running specifically for the Natural Language Processing, Natural Language Understanding aspects. Various embodiments of the system may utilize: Syntactic prediction models-Linear Word or Phrase prediction based on tree structured logic so that it makes grammatical sense in a chosen language (e.g. Spanish syntax is different than Portuguese syntax); Semantic prediction models-Non-linear Word or Phrase prediction based on graph data from other sources and multiple meanings of a word or phrase (the same word or phrase can mean different things with the same language); and Combined Syntactic/Semantic models-Ability to graph complex meaning associated with words or phrases and assemble or compose an expression in a non-linear way such that the "meaning" of the expression is understood and contextually relevant.

Embodiments of the system may provide user configurable graphical interfaces that allows them to choose between a variety of keyboard configurations including radial word prediction for rapid sentence composition, traditional QWERTY and alphabetical keyboards, clustered linotype keyboards, word and phrase prediction, save words and phrases for future use in predictive models.

Embodiments of the system may use at least one sensor or meta-data source to automatically configure or allow a user to manually configure respective predicted words to be more context aware and semantically relevant and understandable. This may result in language that may be composed non-linearly. For example, a syntactical predictive model attempts to get the next word based on the previous word or words, upon a set of syntactical rules. However, with context awareness and semantic processing, one can predict a phrase with a set of letters or words that would normally be later in the phrase. For example, typing "Fish" in a syntactical only system may predict several words after "Fish" such as "Swim", "Are", "Can", "Eat" which may not be relevant to the user requiring more effort to continue typing to get the words they want to say. By integrating sensors to inform a semantic understanding, such as chronofencing with real-time clock and geofencing with GPS and/or wi-fi connection identification, at typical dinner time, a user could type "Fish" and the semantic+syntactical predictive model could suggest "I'd like to eat Fish and chips" based on sensor data and language customization and favorites.

Meta-data sources may include, but are not limited to:

Magnetic/Mechanical Sensors: Compass; Magnetometer; Strain sensors; Search-coil magnetometer; Fluxgate magnetometer; Superconductor magnetometer; Hall effect sensor; Magnetoresistive magnetometers; Spin-valve transistors; Giant magnetoimpedance magnetic sensors; Magnetodiode; Magnetotransistor; Magnetostrictive magnetometers; Magneto-optical sensor; MEMS Based Magnetometers; Ball/tilt/foot switch; Sole pressure switch; Pressure sensors; Contact sensors; Mechanical switches

Environmental Sensors: Barometer; Humidity; Light sensor; Thermal sensor; Ambient air temperature and pressure; Photometer

Location sensors: GPS receiver; Automatic Vehicle Identification (AVI) readers; Real-Time Location Systems (RTLS); Wi-Fi Location-Based Services; Satellite systems

Temporal sensors: Real-Time clock; Calendar; Seasonal data

Motion sensors: Accelerometer; Gyroscope; Pressure sensor; Gravity sensor; Inclinometer; Pedometer; Rotation sensor; Speedometer; Rotational vector sensor; Orientation sensor; Radar sensors

Imaging/Video sensors: Digital camera; 3D camera; Optical sensor; Infrared sensor; Ultrasound sensor; Lidar sensor

Proximity sensors: Proximity sensor; Touch sensor; RFID; Tactile sensor; NFC

Acoustic sensors: Microphone; Silicon microphones; Acoustic wave devices; Surface acoustic wave,

Sonar Medical/Biometric sensors: EEG; ECG; EMG; EOG; EDA; Photoplethysmogram; Blood pressure and arterial tonometry; Respiration; Dosage control/detection; Stress sensors; Heart rate sensors; electrooculography (EOG); electrodermal activity sensors; ECG sensors; vascular implant sensors; Retinal implant sensors; Corneal implant sensors; Wearable optical sensors such as contact lenses, glasses or visors; In-ear acoustic sensors; Cochlear implant sensors

Chemical sensors: Oxygen saturation; Aroma sensors; Metal-oxide; Semi conductive polymers; Conductive electro active polymers; Electrochemical gas sensors; Actinometer

Optical sensors: Photoplethysmography sensors; Fiber optic sensors; Infrared sensors; Radio Frequency (RF) sensors; Ultraviolet sensors

Force sensors: Force sensitive resistor; Mass sensors; Fingerprint sensors; Air pressure sensors

Photoelectric sensors: Oximeter

Any of the sensors above may be part of the system, or external to the system. If external to the system, the system may have wired or wireless connection to the external sensors. If wireless, this connection may be directly via a dedicated wireless network connection, or via an open or semi-secure wireless network.

The BCI may utilize AI for pattern-recognition and personalization. Traditional BCI+AI solutions are limited to fixed locations, expensive equipment, and ultra-high-speed continuous Internet connections.

The BCI may utilize an "Offline-First" design approach. The Offline-First techniques optimize and personalize the BCI performance even when offline.

When online, Machine Learning (ML) training is applied to create an individualized Recognizer-Categorizer (RC). Derived outputs of the ML training are stored into an Expert system (ES) knowledgebase in the cloud.

The ML & ES are not used in a conventional real-time system. The Synthesized Insights (SIs) derived from the ML & ES are used in a novel way to generate individualized executable Recognizer-Categorizers that may be automatically loaded into the BCI device (e.g., storage of the printed circuit board) for offline usage.

The present disclosure is directed to methods including AI utilized in the cloud to enhance resource constrained IoT. The apparatuses in the disclosure include wearable and implantable devices that run individualized code locally generated by AI where a continuous, ultra-broadband streaming connection to the cloud is not reliable.

This disclosure provides solutions to adding AI to mobile device that cannot support AI locally or in a mobile context. In addition to processing brainwave data utilizing AI, the methods and systems developed for this BCI+AI may also be generally applicable to a wide-range of resource-constrained IoT, wearable and implantable devices.

In embodiments of a BCI headset, several AI techniques may be utilized. ML may be utilized as an auto-tuning dynamic noise reducer, a feature extractor, and a Recognizer-Categorizer. It is also a pipeline of training data input into the ES knowledgebase. The ES evaluates recognized brainwave patterns that are leveraged into the offline RCs. The ES has the knowledge to create personalized and AI optimized RCs that may operate locally on Resource Constrained Devices (RCDs). An RCD may be a device that has limited processing and storage capabilities, and that often runs on batteries. This may offer a superior robustness and functionality for BCI that conventional techniques would not. Offline ML training feedback is incorporated by storing EEG EPOCs of successful recognition matches for re-integration into training sets synchronized upon the next online session.

The BCI headset may be a battery-powered, wireless, consumer-grade bio-signal sensing device comprising a two-sensor, three-contact point (2 sensors, ground-reference), a processor, and BLE (Bluetooth Low Energy) connectivity, specifically designed for the detection and processing of SSVEP brain signals to act as a BCI by monitoring cranial points ( $O_1$ - $O_2$ ).

The present disclosure is directed to a brain computer interface in a headset that may correlate the printed circuit board (PCB) with brain waves and other bio-signal sources that are being processed. The PCB may utilize a microcontroller that includes a Bluetooth low energy module, a microprocessor, and a USB bridge. Further, in an embodiment, the EEG Analog-to-Digital processor includes an analog front end that receives channels using Texas Instruments ADS1299, which sends out signals through a serial peripheral interface (SPI) buffer to a microprocessor. The brain waves may be recorded using a micro SD. Additionally, the user may download music, sounds, or any haptic sequences, into the micro SD. In an embodiment, the headset may include a motor amplifier OLED module, which may be a 2 line by 180-pixel OLED such as an I2C OLED. From a visual perspective, the OLED module provides a feedback mechanism that may allow the user to view and or modify onboard BCI settings.

The haptic Motor Controller may include a built-in microcontroller chip that includes fundamental haptic vibrations. The user may stack those vibrations and may also create vibrations based on audio, or setup the haptic vibrations to make the headset vibrate to the music.

Audio feedback may include various fundamental tones. In an embodiment, the user may Add, Modify, or Manage audio feedback on the brain computer interface.

### Operating Modes

Four modes of operation of the BCI headset may include: Raw, Simmer, Cooked, and human interface device-keyboard (HID-KB).

Raw Mode:

The raw mode may stream the full bio-signal sensor data stream, which may include an EEG sensor stream, for further processing locally or in the cloud via a mobile or desktop internet connected device which may filter, recognize, or interact with the data. This mode is useful for training an AI and/or cloud-based recognition system.

Simmer Mode:

The simmer mode is a hybrid combination between the Raw and Cooked modes. The on-board processor may intersperse the raw data stream with custom (Cooked) messages. This mode is most useful when training an AI



and/or cloud-based recognition system and comparing it to the local recognizer and diagnoses.

Cooked Mode:

The cooked mode is a fully processed custom message that may be generated by the local recognizer and diagnoses. No Raw data is passed. This reduces the bandwidth needed for operation.

Hid-Kb Mode:

The HID-KB mode configures the headset interface to appear to be a standard Bluetooth keyboard. This allows the headset to work with many applications including but not limited to desktop computer, mobile devices and home appliances and media and entertainment equipment. One advantage of HID-KB mode is to allow SSVEP to be used with the operating system accessibility features. It also may allow the headset the universal access to be utilized with many computers and operating systems that can utilize a Bluetooth keyboard. In an embodiment, the printed circuit board can emulate a Bluetooth keyboard and output to a mobile device, a computer, a car windshield, a plane windshield, a motorcycle visor, a motorcycle helmet, virtual reality glasses, mixed reality glasses, or the augmented reality glasses at least one of: a letter; a character; a number, and combinations thereof.

#### Device Construction

The two main sensors may be moved to the center or front of the user's head, the headset may efficiently detect and track various brain waves, such as beta waves or theta waves. The headset's implementation is not limited to two sensors but has the ability to have up to eight sensors, a ground, and a reference.

The headset and printed circuit board are sensitive to visually evoked potentials, audio evoked potentials, and motion evoked potentials. They are also sensitive to steady state visually evoked potentials in the AR headset, which includes a blinking light.

In one embodiment of the printed circuit board, the printed circuit board is limited in functionality to visually evoked potentials, which allows for even faster processing entirely on the printed circuit board, and without the use of the cloud or an external computer.

In another embodiment of the printed circuit board, the printed circuit board is limited in functionality to audio evoked potentials, which allows for even faster processing entirely on the printed circuit board, and without the use of the cloud or an external computer.

In another embodiment of the printed circuit board, the printed circuit board is limited in functionality to haptic evoked potentials, which allows for even faster processing entirely on the printed circuit board, and without the use of the cloud or an external computer.

The printed circuit board may be preconfigured to map certain inputs from EEG (Electroencephalography), ECG (Electrocardiography), EMG (Electromyography), EOG (ElectroOculography), functional near-infrared spectroscopy (fNIRS), ECG, EEG, or other bio-signals, to particular types of feedback. The printed circuit board is configurable in terms of sound, music, words, visuals that are projected, and haptic files. The printed circuit board also has defaults of sound files, haptic files, certain algorithms for feature extraction, and pattern matching.

For example, the headset can be preconfigured to output the letter "A" when the printed circuit board reads the signal

10 hertz. Similarly, all alphabet, numbers, words, music and haptic vibrations may be mapped to an audio, visual or haptic input.

Furthermore, such pre-configurations can be customized to each user, such that there may exist customized vibration files, sound files, or different algorithms that are specific to a customer or user. These pre-configurations may be implemented wirelessly from an application, so the user does not have to plug into the USB of the printed circuit board.

For example, given three frequencies, 7, 11, and 19 hertz, accessibility controls may be set to move to previous item, next item, or select item respectively. For example, if the printed circuit board reads the signal 7 hertz, then the "previous item" control may pop up on the AR headset.

In an embodiment, each user may have a dedicated 'private cloud' with all of their own data, personalized files and preferences, allowing the BCI to synchronize with the server when it connects to the internet.

In an embodiment, Over the Air downloads or firmware updates may be pushed to the BCI. The updates may be event-based changes or full system updates.

The connection used to attach the printed circuit board to the augmented reality glasses may be severed, thus enabling the printed circuit board to be connected to another pair of augmented reality glasses while maintaining all the functionality of the printed circuit board. The headset is capable of functioning with different augmented reality glasses, such as Microsoft Hololens™, Magic Leap™, and other products that can provide augmented reality through a visual display for a human being.

In an embodiment, a system of a brain computer interface in a headset includes: an augmented reality display; one or more sensors for reading a bio-signal from a user; a processing module, including a processor that analyzes the bio-signal and maps the bio-signal into an output for a digital interaction device, wherein the digital interaction device includes at least one of the augmented reality display, a digital interaction device in close proximity to the user, a remotely located digital interaction device, and combinations thereof; at least one biofeedback device in communication with the processing module, wherein the at least one biofeedback device is configured to provide feedback to at least one of the user, the digital interaction device, and combinations thereof; and a battery, wherein the battery provides power to at least one of the augmented reality display, the one or more sensors, the processing module, the at least one biofeedback device, and combinations thereof.

In an embodiment, a method of implementing a brain computer interface (BCI) in a headset includes utilizing an augmented reality display; utilizing one or more sensors for reading a bio-signal from a user; utilizing a processing module, including a processor that analyzes the bio-signal and maps the bio-signal into an output for a digital interaction device, wherein the digital interaction device includes at least one of the augmented reality display, a digital interaction device in close proximity to the user, a remotely located digital interaction device, and combinations thereof; utilizing at least one biofeedback device in communication with the processing module, wherein the at least one biofeedback device is configured to provide feedback to at least one of the user, the digital interaction device, and combinations thereof; and utilizing a battery, wherein the battery provides power to at least one of the augmented reality display, the one or more sensors, the processing module, the at least one biofeedback device, and combinations thereof.

The headset addresses the difficult commercial problem of resource constraints in BCI headsets, while improving func-

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tionality over conventional designs. The headset may also liberate users with full mobility, which makes it possible for researchers to perform true longitudinal studies in the field, as well as end users greater freedom to explore and interact with their environment.

The bio-signals are processed and analyzed in real-time. By doing more processing on the printed circuit board, costs are reduced by eliminating additional electronic equipment and reducing the amount of costly time and effort to setup and use it, thereby enabling more frequent use.

Furthermore, the latency of feedback responses is reduced through the augmented reality, haptic, and/or audio systems.

Referring now to the drawings, FIG. 1 illustrates an embodiment of a headset 100 that comprises a PCB 102, a strap 104, a display 106, a contoured sleeve 108, and a visual display source 110. The display 106 and visual display source 110 may be any AR headset, and is not limited thereto. The PCB 102 is curved in shape to contour around the back of a human head. The contoured sleeve 108 secures the PCB 102 and other items such as batteries. The strap 104 may circumvent the PCB 102 and around the back of the human head and maintain the headset 100 in contact with the back of the human head. In some embodiments, the strap 104 traverses the contoured sleeve 108; however, the strap 104 may also traverse the outside rear surface of the contoured sleeve 108 or may be manufactured as a part of the contoured sleeve 108. The strap 104 may couple the PCB 102 electrically and physically to the display 106 and the visual display source 110. The PCB 102 may output a video signal to a user through the visual display source 110 and display 106. In some embodiments, the display 106 provides augmented reality images. The headset 100 is an exemplary example of a headset useful for the systems and methods of this disclosure, and is not limited to the components shown in FIG. 1 or FIG. 2.

In FIG. 2, the disassembled BCI headset 200 comprises a PCB 102, a strap 104, a display 106, a contoured sleeve 108, a visual display source 110, and a pad 202. The pad 202 may be located on the visual display source 110 and provides a cushion between a user's forehead and the portion of the visual display source 110 in contact with the user's forehead. The disassembled BCI headset 200 is an exemplary example of a headset useful for the systems and methods of this disclosure, and is not limited to the components shown in FIG. 2.

FIG. 3 shows a front oblique view of headset 300 comprising a contoured sleeve 306, a cover 302, a led 308, and a PCB 304. The contoured sleeve 306 may include a PCB 304. The first area of the PCB 304 may include an analog front end and allows the headset 300 to read EEG (Electroencephalography), ECG (Electrocardiography), EMG (Electromyography), or other bio-signals. The cover 302 provides access to the PCB through the contoured sleeve 306.

In an embodiment, there is a hole (led 308) in the contoured sleeve 306 that allows a multicolor LED light to be piped out and visible externally to provide a user with color coded status indications such as power on/off, flickering, if there is data/activity, color coded for different modes, etc. The led 308 may be in the center of the contoured sleeve 306 but is not limited thereto. In an embodiment, this functional lighting indicator may be a single led light, multiple led lights, animated lights, etc. The light indicator functionality may be personalized for the individual user.

Referring to FIG. 4, a portion of a headset 400 comprises a contoured sleeve 410, a sensor 402, a sensor 406, a sensor 408, additional sensors 404, a PCB 412, a slit 414, and a

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clasp 416. The contoured sleeve 410 may include three sunburst-type shapes on the portion of the headset that are formed to contact the human's head, the shapes representing sensor 402, sensor 406 and sensor 408. The shapes representing the sensors may be any shape. In an embodiment, the shape is recessed into the contoured sleeve 410. The recessed area enables the sensors to be more comfortable and stable. In some embodiments, the sensors may be adjusted up, down, left, or right. The sensor 402, sensor 406 and sensor 408 detect brain signals, and apply them to the PCB 412, where the PCB 412 processes brain signals. There are 4 additional sensors 404. These additional sensors may also sense brain signals and apply them to the PCB 412 for further processing.

In another embodiment of the headset 400, the headset has four additional sensors 404, instead of seven total sensors.

Different embodiments of the PCB 412 may utilize cables between break points in the printed circuit board, such that the layout of sensors can be six 1x1s or three 2x1s, or three 1x2s.

The contoured sleeve 410 may include a slit 414 between the rear surface and the bottom surface. The slit 414 may be opened by releasing the clasp 416 and spreading apart the bottom and rear of the contoured sleeve 410. This slit 414 may serve to allow exchangeability of different kinds of head straps.

Referring to FIG. 5, a cross section of headset 500 according to an embodiment includes a contoured sleeve 502, a third area 506 of the printed circuit board, and a sensor 504 attached to the contoured sleeve 502 of the headset. Although three areas are shown, the printed circuit board may be a single flexible board where the positioning of the components on the board is not critical.

The third area 506 provides haptic feedback. The bio-signals may be processed and analyzed in real-time. The bio-signals are processed locally in the headset 400 and therefore are not streamed online or in the cloud. This is referred to as localization.

Referring to FIG. 6, a cross section of headset 600 according to one embodiment includes a contoured sleeve 610, a first area 608, a second area 602, a third area 606, and a sensor 604. The top of the contoured sleeve 610 has been removed to show the embedded printed circuit board in the headset. A sensor 604 is attached to the third area 606 of the printed circuit board. The cross section of headset 600 also shows the first area 608 and the second area 602 of the printed circuit board. In an embodiment, there is a channel 612 area where an AR headset strap may pass through the inside of the BCI. The channel 612 may be present from one side of the BCI to the other (near the third area 606). In an embodiment, there is a hole on either side of the BCI where both ends of the AR headset strap may come through.

Referring to FIG. 7, a cross section view of headset 700 comprises a contoured sleeve 702, a first area 706, a second area 704, a third area 714, a battery 710, a sensor 708, and a sensor 712. The battery 710 may be a LiPo, LiOn, etc., battery and may be a custom shape/designed battery.

The cross-section view of headset 600 with the bottom of the case removed shows a PCB inside of contoured sleeve 702 and demonstrates how the PCB is embedded into the headset. The first area 706, the second area 704 and the third area 714 are shown on the PCB. A battery 710 is located in the bottom portion of the headset. There is a sensor 708 and a sensor 712 attached to the battery 710. The headset 600 may also have a status led 716.

Referring to FIG. 8, a method 800 includes the steps involved to implement a brain computer interface in a

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headset. The steps include reading a bio-signal using the first area of the PCB as an analog front end (block **802**), processing the captured bio-signal (block **804**), analyzing the bio-signal (block **806**), mapping the bio-signal into command(s) (block **808**), executing the command(s) (block **810**), and recording the command(s) for future use (block **812**).

The method **800** may be a closed loop method for reading brainwaves via the BCI and writing to the brain via bio-feedback through the user's somatosensory system (sight, sound, vibrations/haptics). In an embodiment, the closed loop system reads the visual cortex via the occipital lobe (visual) and writes to the somatosensory cortex (senses).

In an embodiment, the processor analyzes the bio-signal and maps the bio-signal into an output for a digital interaction device. The digital interaction device may include at least one of the augmented reality display, a digital interaction device in close proximity to the user, a remotely located digital interaction device, and combinations thereof. Digital interaction devices in close proximity to the user may include a smart phone, a tablet, a computer, etc. Remotely located digital interaction devices may include remotely located computers, tablets, smart phones, monitors, etc.

In an embodiment, the command is at least one of the following: do nothing; log the data for later use; play an audio file; manipulate a visual element; play a vibration pattern; send a message or command to another device; remotely control a prosthetic limb; turn on/off the lights; change a tv channel, and combinations thereof.

In an embodiment, the commands may be recorded for future use and improved machine learning performance as well as human neural performance/recall as reinforcement learning.

In an embodiment, the bio-signal that the PCB can read includes at least one of EEG (Electroencephalography), ECG (Electrocardiography), EMG (Electromyography), EOG (Electrooculography), visually evoked potentials, steady state visually evoked potentials, steady state audio evoked potentials, and motion evoked potentials.

Referring to FIG. 9, a device **900** comprises a printed circuit board **902**, a first area **904**, a second area **906**, a third area **908**, an analog front end **910**, processing, analyzing and mapping **912** logic, a biofeedback **914**, a sensor header **916**, an EEG analog to digital **918**, a haptic controller **920**, an audio driver/amplifier **922**, an OLED **924**, a micro sd card **926**, a USB/TTL bridge **928**, a Bluetooth low energy module **930**, a microprocessor **932**, and power management module **934**.

The printed circuit board **902** comprises three areas, the first area **904** (analog front end **910**), the second area **906** (processing, analyzing and mapping **912**) and the third area **908** (biofeedback **914**).

The first area **904** is the analog front end **910** that includes sensor header **916**, EEG analog to digital **918** converter and the like. The first area of the printed circuit board receives the bio-signal and converts it to a digital signal. The second area **906** includes Bluetooth low energy module **930**, OLED **924**, micro sd card **926**, microprocessor **932**, power management module **934**, and the like. The second area of the printed circuit board processes and analyzes the bio-signal using the microprocessor **932** and maps the bio-signal into an output on the augmented reality glasses. The output may include audio and visual output or a haptic output. The power management module may control power to the various components and modules, including the Bluetooth low energy module **930**. The third area **908** provides a biofeed-

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back **914** using a USB/TTL bridge **928**, an audio driver/amplifier **922**, or a haptic controller **920**.

FIG. 10 illustrates a BCI+AR system **1000** in accordance with one embodiment of the disclosure. A sensor **1002** receives signals from a user **1006**. These signals trigger an event in the operating system **1004**. The signals are then mapped to an output using the hardware **1008**. The output may include audio and video or may be a haptic output including haptic vibration patterns.

FIG. 11 illustrates an embodiment of a BCI+AR environment **1100**. The BCI+AR environment **1100** comprises a sensor **1104**, an EEG analog to digital converter **1106**, an Audio/Video/Haptic Output **1108**, a processing **1110**, a strap **1114**, an augmented reality glasses **1112**, a human user **1102**, and a BCI **1116**. A human user **1102** is wearing BCI **1116**, which is part of a headset. When the human user **1102** interacts with the environment, the sensor **1104**, located within the BCI **1116**, reads the intentions and triggers the operating system. The EEG analog to digital converter **1106** receives the sensor **1104** output (e.g., intention). EEG analog to digital converter **1106** transforms the sensor output into a digital signal which is sent to processing **1110**. The signal is then processed, analyzed and mapped to an Audio/Video/Haptic Output **1108** and displayed on the augmented reality glasses **1112**.

In an embodiment, strap **1114** is a head strap for securing the AR+BCI to the human head. In some embodiments, such as an implantable BCI, and AR system, the strap may not be used. The strapless system may use smart glasses or contact lenses. There may be multiple sensors, but no less than one sensor, in different embodiments. After seeing the output, the user may have different bio-signals from the brain, and as such this is a closed-loop biofeedback system. As the user focuses more on the SSVEP stimuli, the audio may feedback by frequency, power (volume), and selected cue audio to assist the human in reinforcing their focus on the stimuli. This may also occur with the vibration type and intensity of the haptics, as well additional peripheral visual cues in the display. These feedbacks are independent to the audio and haptics that may play back through the AR headset via a smartphone. It is even possible to remotely add to the sensory mix that of olfactory (smell) feedback that actually travels through entirely different parts of the brain that has been shown to be one of the strongest bio-feedback reinforcements in human cognitive training.

As a non-limiting example, when someone uses the BCI for the first time, they are considered a "Naïve" user, or one who's brain has never been trained with this kind of user interface. As a user continues to use it, their brain becomes less naïve and more capable and trained. They may become quicker and quicker at doing it. This is reinforcement learning—the BCI enables someone to align their intention and attention to an object and click it.

In an embodiment, to enrich the user interface experience, multiple feedback modalities (auditory, visual, haptic, and olfactory) may be available for choosing the most advantageous feedback modality for the individual or for the type of training. For example, when an appropriate brain wave frequency is generated by the user, real-time feedback about the strength of this signal may be represented by adjusting the intensity and frequency of the audio or haptic feedback. In addition, the possibility of using multimodal feedback means that multiple sensory brain regions are stimulated simultaneously, which enhances the neural signal and representation of feedback, thereby accelerating learning and neural plasticity.

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An advantage of using odors as reinforcers may be due to the direct link between the brain areas that sense smell (olfactory cortex) and those that form memories (hippocampus) and produce emotions (amygdala). Odors may strengthen memory encoding, consolidation, and trigger recall.

FIG. 12 illustrates components of an exemplary augmented reality device logic 1200. The augmented reality device logic 1200 comprises a graphics engine 1220, a camera 1222, processing units 1202, including one or more CPU 1204 and/or GPU 1206, a WiFi 1208 wireless interface, a Bluetooth 1210 wireless interface, speakers 1212, microphones 1214, one or more memory 1216, logic 1218, a visual display 1224, and vibration/haptic driver 1226.

The processing units 1202 may in some cases comprise programmable devices such as bespoke processing units optimized for a particular function, such as AR related functions. The augmented reality device logic 1200 may comprise other components that are not shown, such as dedicated depth sensors, additional interfaces, etc.

Some or all of the components in FIG. 12 may be housed in an AR headset. In some embodiments, some of these components may be housed in a separate housing connected or in wireless communication with the components of the AR headset. For example, a separate housing for some components may be designed to be worn or a belt or to fit in the wearer's pocket, or one or more of the components may be housed in a separate computer device (smartphone, tablet, laptop or desktop computer etc.) which communicates wirelessly with the display and camera apparatus in the AR headset, whereby the headset and separate device constitute the full augmented reality device logic 1200. A user may also communicate with the AR headset via a Bluetooth keyboard 1230. Additionally, the AR headset may communicate with the cloud 1228 via WiFi 1208.

The memory 1216 comprises logic 1218 to be applied to the processing units 1202 to execute. In some cases, different parts of the logic 1218 may be executed by different components of the processing units 1202. The logic 1218 typically comprises code of an operating system, as well as code of one or more applications configured to run on the operating system to carry out aspects of the processes disclosed herein.

FIG. 13 is a block diagram of nonverbal multi-input and feedback device 1300 of a nonverbal multi-input and feedback device such as herein. It may be a block diagram of a portion of the device such as a processing portion of the device. FIG. 13 may be a high-level system architecture block diagram that helps explain that the major building blocks. Block diagram of nonverbal multi-input and feedback device 1300 can be applied to the overall system (e.g., multiple devices used as inputs), into a common universal application interface that enables the application 1302 to synchronize data coming from multiple devices and process signals with meta data, plus vocabulary and output logic to a plurality of output methods. FIG. 14 takes this to a finer level of detail.

In the center of block diagram of nonverbal multi-input and feedback device 1300 is the application 1302 or main processing block. To the left is the multimodal input and intent detection 1304 block which receives and processes user inputs from sensors (e.g., based on user input received by the sensors) such as touch 1312; bio-signals 1314; keyboard 1316; facial tracking 1318; eye and pupil tracking 1320; and alternative inputs 1322. This multimodal input and intent detection 1304 block feeds the processing from these inputs to the application 1302.

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Above is a context awareness 1306 block which receives and processes metadata inputs from sensors such as biometrics 1324; environment 1326; object recognition 1328; facial recognition 1330; voice recognition 1332; date and time 1334; history 1336; location 1338; proximity 1340; and other metadata 1342 inputs. This context awareness 1306 block feeds the processing from these inputs to the application 1302.

To the right is an output and action 1310 block which sends outputs to displays, computing devices, controllers, speakers and network communication devices such as flat screen flat screen display 1344; augmented/virtual reality 1346; virtual AI assistant 1348; synthesized voice 1350; prosthetic device 1352; social media and messaging 1354; media consumption 1356; and other output 1358. The outputs may include control commands and communication sent to other computing devices, they may include text, graphics, emoji, and/or audio. Other output 1358 may include Robots, Drones, Swarms and other semi-autonomous systems; Mobility Systems & Vehicle controls such as wheelchairs, automobiles and aircraft; and Environmental connected systems such as smart buildings, spacecraft or submersibles.

Below is a vocabulary 1308 block that provides a lexicon or vocabulary in the selected language to the application. FIG. 13 may also be applied to a single sensory device unto itself. This may be a "BIG IDEA" in so far as the architecture can scale from a single closed-loop system (such as in FIGS. 13-17, plus 19) as well as combinations of sensory I/O devices (FIGS. 12, 18, 20). It may be a system of systems that scale up, down and play together.

The system in block diagram of nonverbal multi-input and feedback device 1300 comprises one (or more) sensory input, one intent detection API, one application, one (or more) meta data, one (or more) vocabulary, one (or more) output and action method, and one (or more) output/actuation system or device. It may be thought of as a universal "augmented intelligence" engine that takes inputs, enriches them with extra meaning, and directs the output based on instructions for the enriched information. The storyboard in FIG. 16 illustrates the power of this.

In a simple embodiment of diagram 1010, a user sees a symbol or button that means "help", and presses it, and the device says "help". In a more complicated embodiment of block diagram of nonverbal multi-input and feedback device 1300, a user sees a symbol or button that means "help", and press it. Here, rather than the device saying "help", it learns that the user is connected to a caregiver with logic to send urgent matters to that person via text or instant message when away from home. The device may geolocation data that indicates the user is away from home; tag the communication with appended contextual information; and its output and action logic tell the system to send a text message to the caregiver with the user's location in a human-understandable grammatically correct phrase "Help, I'm in Oak Park" including the user's Sender ID/Profile and coordinates pinned on a map.

FIG. 14 is a block diagram of a single framework of a nonverbal multi-input and feedback device 1400 such as herein. The block diagram of a single framework of a nonverbal multi-input and feedback device 1400 may be of a single framework for translating diverse sensor inputs into a variety of understandable communication and command outputs for a nonverbal multi-input and feedback device such as herein. The single framework of a nonverbal multi-input and feedback device comprises sensors 1402a-1402f, input gestures 1404, context awareness 1406, machine learn-

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ing **1408**, output expressions **1410**, and destinations **1412**. Input gestures **1404** may include touch **1414**, movement **1416**, mental **1418**, glances **1420**, audible **1422**, and breath **1424**. Context awareness **1406** may include time synchronization **1426**, configure data sources **1428**, configure data processing parameters **1430**, configure timing **1432**, and metadata tagging **1434**. Machine learning **1408** may include an acquire analog data streams **1436**, convert to digital data streams **1438**, analyze data streams **1440**, and execute digital operations for actuation **1442**. Output expressions **1410** may include text **1444**, symbol **1446**, color **1448**, an image **1450**, sound **1452**, and vibration **1454**. Destinations **1412** may include a mobile **1456**, a wearable **1** **1458**, a wearable **2** **1460**, an implant **1** **1462**, an implant **2** **1464**, and a prosthetic **1** **1466**.

FIG. **14** may describe in more detail what kind of processing is happening within and across the blocks of FIG. **13**. Specifically, the left intention signals being combined with context awareness metadata to enrich the data in order to determine the logic of the output and action. FIG. **14** may include the description of the Vocabulary **1308** and application **1302** boxes of FIG. **13**, though not shown. It may be a block diagram of a portion of the device such as a processing portion of the device. In the framework, input from the sensors **1402a-1402f** (e.g., due to input received by the sensors) are received by or as an input gesture **1404**. In the framework, context awareness **1406** awareness is used to interpret or determine the user gesture or intent from the inputs received. In the framework machine learning **1408** is used to interpret or determine the user gesture or intent from the inputs received. In the framework, output expression **1410** is used to determine the outputs, such as control commands and communication sent to other computing devices that include text, graphics, emoji, and/or audio. In the framework, destination **1412** is used to determine where the outputs are sent, such as to what other computing devices the command and/or communications are to be sent (such as by the network). The user's Primary and Secondary language preferences are accessed during the processing of intention data which is stored in the vocabulary **1308** subsystem such as shown in FIG. **13**, and may be accessed in the context awareness **1406**, machine learning **1408** and output and action **1310** systems and methods in FIG. **13** and FIG. **14**.

FIG. **15** illustrates a block diagram of nonverbal multi-input and feedback device **1500** in one embodiment. The block diagram of nonverbal multi-input and feedback device **1500** shows a system comprising analog input **1502**, sensors **1504**, processing **1506**, digital output **1508**, and output methods **1510** that may be performed with the digital output **1508**.

The system illustrated may include an application programming interface (API) that is interoperable with multiple types of analog input **1502** from the sensors **1504**. The system illustrated may also comprise a real-time clock for tracking, synchronizing, and metadata **1520** tagging of data streams and analog inputs **1502**. The system further comprises a subsystem for data storage and management, for historical data **1512** in some embodiments. The system may comprise a subsystem for personalization settings **1518**, as well as a subsystem for sourcing and integrating metadata **1520** into the application **1522** and data stream. The system may further comprise a software application **1522**. In some embodiments, the system may include a GUI for the software application for the user. In other embodiments, the system may include a GUI for the software application for others who are connected to a system user.

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A subsystem of the system may include processing for visual **1526**, audible **1528**, and written **1530** languages. This language subsystem may differentiate between the user's primary and secondary languages **1524**. The language subsystem may set the secondary language manually or automatically. Attributes processed by visual **1526**, audible **1528**, and written **1530** language subsystems may include but not be limited to color, image, graphics, audible tones, phonemes, dialects, jargon, semantics, tonality, and written characters.

The system may include a subsystem of digital outputs **1508** and output methods **1510**, that can be configured either manually or automatically. The variety of output methods **1510** may include a network **1516** interface connection. The system may comprise a subsystem for managing data transfer over the network **1516**.

The system in some embodiments may comprise a historical data **1512** subsystem for closed-loop machine learning of the system and subsystems and the sensory devices being used with the system. In some embodiments, improved models, algorithms and software may be pushed from the learning system **1514** to update and be used within the system and subsystems and the sensory devices being used with the system.

In one embodiment, the system and subsystems may operate entirely on a sensory device. In one embodiment, the system and subsystems may operate partially on a sensory device and partially distributed to other devices or the cloud. In one embodiment, the system and subsystems may operate entirely distributed on other devices or the cloud.

The system of FIG. **15** may be one embodiment of a fully self-contained brain computer interface (BCI) in a wireless headset, comprising an augmented reality display as part of the digital output **1508**, at least two sensors **1504** for reading a bio-signal from a user as analog input **1502**, at least one processing **1506** module for the augmented reality display, at least one biofeedback device that produces at least one of a visual, audible, and tactile effect in communication with the processing module to provide feedback to the user, a wireless network interface that transmits and receives data to and from other devices over the processing **1506**, wherein the data is at least one of stored, passed through, and processed on the fully self-contained BCI, as part of the output methods **1510**, a battery, wherein the battery provides power to one or more of the augmented reality display, the at least two sensors, the processing module, and the at least one biofeedback device, at least one of onboard storage or remote storage with enough memory to store, process and retrieve the data, and a printed circuit board, such as the printed circuit board **902** introduced in FIG. **9**.

Bio-signals from the user may comprise at least one of EEG (Electroencephalography), ECG (Electrocardiography), functional near infrared spectroscopy (fNIRS), Magnetoencephalography (MEG), EMG (Electromyography), EOG (Electrooculography), and Time-Domain variants (TD-) of these bio-signal processing methods. Bio-signals may also comprise a visually evoked potential, an audio evoked potential, a haptic evoked potential, and a motion evoked potential, and other bio-signals from multiple sources attached to other body parts other than a user's head.

The at least one processing module for the augmented reality display may include a processor that renders a stimulation effect. This stimulation effect may be at least one of a timed visual stimulation on the augmented reality display, a timed audio stimulation, and a haptic stimulation on the fully self-contained BCI configured to evoke a measurable response in a user's brain. The processing mod-

ule may include a processor that analyzes and maps the bio-signal into a digital command. This digital command may include least one of instructions for a visual output configured for displaying on the augmented reality display and instructions for triggering a visual effect. The processing module may be embodied as the processing units **1202** introduced in FIG. **12**.

The printed circuit board may include at least one of the at least two sensors, the processing module, the at least one biofeedback device, the battery, and combinations thereof. The printed circuit board may be configured to emulate a Bluetooth keyboard and send output data to at least one of a mobile device, a computer, and the augmented reality display. The output data may include at least one of a letter, a character, a number, and combinations thereof.

Processing performed by the processing module may include the visually evoked potential, the audio evoked potential, and the haptic evoked potential. The bio-signal is processed and analyzed in real-time. The processing module may have different modes, including raw, simmer, and cooked modes, a human interface device-keyboard mode, and combinations thereof. The system may also have a strapless mode, wherein the fully self-contained BCI uses smart glasses or smart contact lenses, an implantable brain computer interface, and an AR system.

The raw mode may stream a full EEG sensor stream of data for further processing locally on device or remotely in a cloud via a mobile or desktop internet connected device that may filter, recognize, or interact with the full EEG sensor stream of data. The cooked mode may comprise a fully processed custom digital command generated by a local recognizer and classifier. The fully processed custom digital command may be sent to a destination system over the network **1516**, per the "send it" output method **1510**, and executed on the destination system, with no raw data passed to the user. The recognizer and classifier may be embodied as the recognizer **2024** and classifier **2026** introduced in FIG. **20**. The simmer mode may be a hybrid combination between the raw mode and the cooked mode, and the at least one processing module may intersperse a raw data stream with cooked metadata **1520** appended to bio-signal data.

Time domain data may be appended to raw data, cooked data, and simmer data in order for the system to process bio-signal data streams from multiple bio-signal data sources and ensure all bio-signal data streams are synchronized. Metadata from other sensors and data sources may be appended to the raw data, the cooked data, and the simmer data in order for a classifier to alter the command that is sent to execute on a destination system. This classifier may be embodied as the classifier **2026** introduced in FIG. **20**. Visual, audible, and tactile sensory frequency stimulators may be appended with metadata from other sensors **1504** and data sources wherein the visual, audible, and tactile sensory frequency stimulators are altered to produce a unique pattern which includes metadata that is decodable by the recognizer and classifier.

The fully self-contained BCI may be electrically detached from the augmented reality display, and may be configured to transfer data wirelessly or via a wired connection to an external augmented reality display. The fully self-contained BCI in the wireless headset may be an accessory apparatus that is configured to be temporarily mechanically integrated with another wearable device, and configured to transfer data wirelessly or via a wired connection to the other wearable device. The fully self-contained BCI may in another embodiment be permanently mechanically inte-

grated with another wearable device and may transfer data wirelessly or via a wired connection to the other wearable device.

A charging port may be connected to a charging bridge, wherein the charging bridge includes internal circuitry and data management connected to the fully self-contained BCI and the augmented reality display. The internal circuitry may include charging circuitry, thereby allowing charging of both the fully self-contained BCI and the augmented reality display with the charging circuitry. These functions may in some embodiments be carried out by the USB/TTL bridge **928** and power management module **934** introduced in FIG. **9**.

The fully self-contained BCI may be configured to generate visual, auditory, or haptic stimulations to a user's visual cortex, a user's auditory cortex, and a user's somatosensory cortex, thereby resulting in detectable brain wave frequency potentials that are at least one of stimulated, event-related, and volitionally evoked. The BCI may process the detectable brain wave frequencies, thereby facilitating mapping of bio-signals to digital commands. Stimulation effects and digital commands may be altered with metadata from other sensors or data sources.

The BCI may synchronize bio-signal processing from multiple sensors with a real-time clock such as the real-time clock **2022** introduced in FIG. **20**. Digital commands may be associated to a device. The device may be operated according to the digital commands. The BCI may stimulate the user's visual cortex, wherein stimulating includes biofeedback to the user's visual cortex and biofeedback confirmation of the operating of the device. The BCI may stimulate the user's somatosensory cortex, wherein stimulating includes the biofeedback confirmation of the operating of the device. The BCI may stimulate the user's auditory cortex, wherein the stimulating includes biofeedback confirmation of the operating of the device.

The fully self-contained BCI may be configured to utilize AI machine learning for pattern recognition, classification, and personalization that operates while the fully self-contained BCI is not connected to a network **1516**. The AI machine learning may be embodied as the machine learning **1408** introduced in FIG. **14**. It may be included in the learning system **1514** of this figure. It may also be supported by the machine learning capture and modeling **1910** and machine learning parameters **1924** introduced in FIG. **19**. The AI machine learning may act as one or more of an auto-tuning dynamic noise reducer, a feature extractor, and a recognizer-categorizer-classifier. AI machine learning training may be applied when the fully self-contained BCI is connected to the network **1516** to create an individualized recognizer-categorizer-classifier. Derived outputs of the AI machine learning training may be stored in an expert system knowledge base in cloud storage or on a mobile computing device having at least one of a wireless connection and a wired connection to the wireless headset and being at least one of mounted on the wireless headset and within wireless network range of the wireless headset. Synthesized insights derived from the AI machine learning and the expert system knowledge base may be stored in cloud storage or on the mobile computing device and may be used to generate an individualized executable recognizer-categorizer-classifier downloadable onto the at least one processing **1506** module of the fully self-contained BCI or the mobile computing device via at least one of a wireless connection and a wired connection between the network and a BCI storage device for offline usage without network dependencies. The system may be configured to interface with resource constrained

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devices including wearable devices, implantable devices, and internet of things (IoT) devices. At least one biofeedback device may be configured to stimulate at least one of a user's central nervous system and peripheral nervous system.

FIG. 16 illustrates a logical diagram of one use case of a user wearing an augmented reality headset that includes a display, speakers and vibration haptic motors and an accelerometer/gyroscope and magnetometer. FIG. 16 shows the flow of activity from head motion analog input 1602 as captured by a headset with head motion detection sensors 1604, through how a user selects options through head motion 1606 and the application creates output based on the user's selected options 1608. On the condition that system detects the user is away from home 1610, FIG. 16 shows that the system may send output to a caregiver via text message 1612.

The user may calibrate the headset based on the most comfortable and stable neck and head position which establishes the X/Y/Z position of 0/0/0. Based on this central ideal position, the user interface is adjusted to conform to the user's individual range of motion, with an emphasis of reducing the amount of effort and distance needed to move a virtual pointer in augmented reality from the 0/0/0 position to outer limits of their field of view and range of motion. The system may be personalized with various ergonomic settings to offset and enhance the users ease of use and comfort using the system. A head motion analog input 1602 may be processed as analog streaming data and acquired by the headset with head motion detection sensors 1604 in real-time, and digitally processed, either directly on the sensory device or via a remotely connected subsystem. The system may include embedded software on the sensory device that handles the pre-processing of the analog signal. The system may include embedded software that handles the digitization and post-processing of the signals. Post-processing may include but not be limited to various models of compression, feature analysis, classification, metadata tagging, categorization. The system may handle preprocessing, digital conversion, and post-processing using a variety of methods, ranging from statistical to machine learning. As the data is digitally post-processed, system settings and metadata may be referred to determine how certain logic rules in the application are to operate, which may include mapping certain signal features to certain actions. Based on these mappings, the system operates by executing commands and may include saving data locally on the sensory device or another storage device, streaming data to other subsystems or networks.

In the case illustrated in FIG. 16, the user is looking at a display that may include characters, symbols, pictures, colors, videos, live camera footage or other visual, oral or interactive content. In this example, the user is looking at a set of "radial menus" or collection of boxes or circles with data in each one that may be a symbol, character, letter, word or entire phrase. The user has been presented a set of words that surround a central phrase starter word in the middle like a hub and spoke to choose from based on typical functional communication with suggested fringe words and access to predictive keyboard, structured and unstructured language. The user selects options through head motion 1606, and may rapidly compose a phrase by selecting the next desired word presented in the radial menus, or adding a new word manually via another input method. The user traverses the interface using head movement gestures, similar to 3-dimensional swipe movements, to compose communication. The user progressively chooses the next word until they're

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satisfied with the phrase they've composed and can determine how to actuate the phrase. Algorithms may be used to predict the next character, word, or phrase, and may rearrange or alter the expression depending on its intended output including but not limited to appending emoji, symbols, colors, sounds or rearranging to correct for spelling or grammar errors. The user may desire for the phrase to be spoken aloud to a person nearby, thus selecting a "play button" or simply allowing the sentence to time out to be executed automatically. The application creates output based on the user's selected options 1608. If they compose a phrase that is a control command like "turn off the lights", they can select a "send button" or may based on semantic natural language processing and understanding, automatically send the phrase to a third party virtual assistant system to execute the command, and turn off the lights. The potential use of metadata, in this example, could simply be geolocation data sourced from other systems such as GIS or GPS data or WIFI data, or manually personalized geofencing in the application personalization settings, where the system would know if the user is "at home" or "away from home". On condition that system detects the user is away from home 1610, for example, the metadata may play a role in adapting the language being output to reflect the context of the user. For instance, the system could be configured to speak aloud when at home but send output to a caregiver via text message 1612 and append GPS coordinates when away from home. The system may support collecting and processing historical data from the sensory device, system, subsystems, and output actions to improve the performance and personalization of the system, subsystems, and sensory devices.

FIG. 17 illustrates a logical diagram of one use case in which user wears an EEG-based brain-computer interface headset 1702 containing electrodes that are contacting the scalp 1704. FIG. 17 shows that streaming analog data can be acquired from the brainwave activity 1706. In this manner, the user may be presented a set of words to choose from 1708, compose a phrase, and select what action the system takes using the phrase they've composed 1710.

A user wears an EEG-based brain-computer interface headset 1702 containing electrodes that are contacting the scalp 1704. The electrodes are connected to an amplifier and analog-to-digital processing pipeline. The sensory device (BCI) acquires streaming electrical current data measured in microvolts (mV). The more electrodes connected to the scalp and to the BCI, the more streaming analog data can be acquired from the brainwave activity 1706. The analog streaming data is acquired by the electrodes, pre-processed through amplification, and digitally processed, either directly on the sensory device or via a remotely connected subsystem. The system may include embedded software on the sensory device that handles the pre-processing of the analog signal. The system may include embedded software that handles the digitization and post-processing of the signals. Post-processing may include but not be limited to various models of compression, feature analysis, classification, metadata tagging, categorization. The system may handle preprocessing, digital conversion, and post-processing using a variety of methods, ranging from statistical to machine learning. As the data is digitally post-processed, system settings and metadata may be referred to determine how certain logic rules in the application are to operate, which may include mapping certain signal features to certain actions. Based on these mappings, the system operates by executing commands and may include saving data locally on

the sensory device or another storage device, streaming data to other subsystems or networks.

In the case illustrated in FIG. 17, the user is looking at a display that may include characters, symbols, pictures, colors, videos, live camera footage or other visual, oral or interactive content. In this example, the user is looking at a group of concentric circles, arranged in a radial layout, with characters on each circle. The user has been presented a set of words to choose from **1708** based on typical functional communication with suggested fringe words and access to predictive keyboard and can rapidly compose a phrase by selecting the next desired word presented in the outer ring of circles, or adding a new word manually. The user progressively chooses the next word until they're satisfied with the phrase they've composed **1710** and can determine how to actuate the phrase. Algorithms may be used to predict the next character, word, or phrase, and may rearrange or alter the expression depending on its intended output including but not limited to appending emoji, symbols, colors, sounds or rearranging to correct for spelling or grammar errors. The user may desire for the phrase to be spoken aloud to a person nearby, thus selecting a "play button" or simply allowing the sentence to time out to be executed automatically. If they compose a phrase that is a control command like "turn off the lights", they can select a "send button" or may based on semantic natural language processing and understanding, automatically send the phrase to a third party virtual assistant system to execute the command, and turn off the lights. The potential use of metadata, in this example, could simply be geolocation data sourced from other systems such as GIS or GPS data or WIFI data, or manually personalized geofencing in the application personalization settings, where the system would know if the user is "at home" or "away from home". In this case, the metadata may play a role in adapting the language being output to reflect the context of the user. For instance, the system could be configured to speak aloud when at home but send to a caregiver via text message and append GPS coordinates when away from home. The system may support collecting and processing historical data from the sensory device, system, subsystems, and output actions to improve the performance and personalization of the system, subsystems, and sensory devices.

FIG. 18 illustrates a use case in which a user wears an augmented reality headset combined with a brain computer interface **1802**, having the capabilities described with respect to FIG. 16 and FIG. 17. Both head motion analog input and brainwave activity **1804** may be detected and may allow a user to select from a set of words to choose from **1806**, as well as what to do with the phrase they've composed **1808** by selecting those words.

A user is wearing an augmented reality headset combined with a brain computer interface on their head. The headset contains numerous sensors as a combined sensory device including motion and orientation sensors and temporal bio-electric data generated from the brain detected via EEG electrodes contacting the scalp of the user, specifically in the regions where visual, auditory and sensory/touch is processed in the brain. The AR headset may produce visual, auditory or haptic stimulation that is detectible via the brain computer interface, and by processing brainwave data with motion data, the system may provide new kinds of multi-modal capabilities for a user to control the system. The analog streaming data is acquired by the Accelerometer, Gyroscope, Magnetometer and EEG analog-to-digital processor, and digitally processed, either directly on the sensory device or via a remotely connected subsystem. The system may include embedded software on the sensory device that

handles the pre-processing of the analog signal. The system may include embedded software that handles the digitization and post-processing of the signals. Post-processing may include but not be limited to various models of compression, feature analysis, classification, metadata tagging, categorization. The system may handle preprocessing, digital conversion, and post-processing using a variety of methods, ranging from statistical to machine learning. As the data is digitally post-processed, system settings and metadata may be referred to determine how certain logic rules in the application are to operate, which may include mapping certain signal features to certain actions. Based on these mappings, the system operates by executing commands and may include saving data locally on the sensory device or another storage device, streaming data to other subsystems or networks.

In the case illustrated in FIG. 18, the user is looking at a display that may include characters, symbols, pictures, colors, videos, live camera footage or other visual, oral or interactive content. In this example, the user is looking at a visual menu system in AR with certain hard to reach elements flickering at different frequencies. The user has been presented a set of items to choose from based on typical functional communication with suggested fringe words and access to predictive keyboard and can rapidly compose a phrase by selecting the next desired word presented in the AR head mounted display, or adding a new word manually. Enabling the user affordances of extra-sensory reach of visible objects out of reach within the comfortable range of motion of neck movement. The user progressively chooses the next word until they're satisfied with the phrase they've composed and can determine how to actuate the phrase. Algorithms may be used to predict the next character, word, or phrase, and may rearrange or alter the expression depending on its intended output including but not limited to appending emoji, symbols, colors, sounds or rearranging to correct for spelling or grammar errors. The user may desire for the phrase to be spoken aloud to a person nearby, thus selecting a "play button" or simply allowing the sentence to time out to be executed automatically. If they compose a phrase that is a control command like "turn off the lights", they can select a "send button" or may based on semantic natural language processing and understanding, automatically send the phrase to a third party virtual assistant system to execute the command, and turn off the lights. The potential use of metadata, in this example, could simply be geolocation data sourced from other systems such as GIS or GPS data or WIFI data, or manually personalized geofencing in the application personalization settings, where the system would know if the user is "at home" or "away from home". In this case, the metadata may play a role in adapting the language being output to reflect the context of the user. For instance, the system could be configured to speak aloud when at home but send to a caregiver via text message and append GPS coordinates when away from home. The system may support collecting and processing historical data from the sensory device, system, subsystems, and output actions to improve the performance and personalization of the system, subsystems, and sensory devices.

FIG. 19 is a flow diagram **1900** showing a closed loop bio-signal data flow for a nonverbal multi-input and feedback device such as herein. It may be performed by inputs or a computer of the device. The flow diagram **1900** comprises a human user **1902**, electrode sensors **1904**, a brain computer interface headset and firmware **1906**, an augmented reality mobile application **1908**, machine learning capture and modeling **1910** that may be performed in an



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edge, peer, or cloud device, and an augmented reality headset **1912**. The electrode sensors **1904** may **1904** may capture **1914** data that is sent for analog-to-digital **1916** conversion. The digital signal may be used for intent detection **1918** resulting in an action trigger **1920** to a user interface **1922**. The digital data may further be sent to raw data capture **1926**, and may be used as training data **1932** for training and data analysis **1934**. Training and data analysis **1934** may **1934** may yield machine learning parameters **1924** which may be fed back for use in intent detection **1918**. The user interface **1922** may determine stimulus placement and timing **1928**, which may be used in the augmented reality environment **1930** created by the augmented reality mobile application **1908**. The stimulus placement and timing **1936** resulting in the augmented reality headset **1912** and may evoke potential stimulus **1938** in the human user **1902**. The user interface **1922** may also generate an output and action **1940**.

The flow diagram **1900** includes computer stimulates visual, auditory and somatosensory cortex with evoked potentials; signal processing of real time streaming brain response; human controls computer based on mental fixation of stimulation frequencies; and system can determine different output or actions on behalf of the user for input data received via one or more sensors of the device. Flow diagram **1900** may apply to a user wearing any of the nonverbal multi-input and feedback devices and/or sensors herein. As a result of this being closed-loop biofeedback and sensory communication and control system that stimulates the brains senses of sight, sound, and touch and reads specific stimulation time-based frequencies, and tags them with metadata in real-time as the analog data is digitized, the user can rapidly learn how to navigate and interact with the system using their brain directly. This method of reinforcement learning is known in the rapid development process of the brain's pattern recognition abilities and the creation of neural plasticity to develop new neural connections based on stimulation and entrainment. This further enables the system to become a dynamic neural prosthetic extension of their physical and cognitive abilities. The merging of context awareness metadata, vocabulary, and output and action logic into the central application in addition to a universal interface for signal acquisition and data processing is what makes this system extremely special. Essentially, this system helps reduce the time latency between detecting cognitive intention and achieving the associated desired outcome, whether that be pushing a button, saying a word or controlling robots, prosthetics, smart home devices or other digital systems.

FIG. **20** is a flow diagram **2000** showing multimodal, multi-sensory system for communication and control **2002** for a nonverbal multi-input and feedback device such as herein. It may be performed by inputs or a computer of the device. The flow diagram **2000** comprises multimodal, multi-sensory systems for communication and control **2002** that includes wireless neck and head tracking **2004** and wireless brain tracking **2006**. The multimodal, multi-sensory system for communication and control **2002** may further comprise central sensors **2008** for EEG, peripheral sensors **2010** such as EMG, EOG, ECG, and others, an analog to digital signal processor **2012** processing data from the central sensors **2008**, and an analog to digital signal processor **2014** processing data from the peripheral sensors **2010**. The analog to digital subsystem **2016** and sensor service subsystem **2018** manage output from the analog to digital signal processor **2012** and the analog to digital signal

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processor **2014**, respectively. Output from the analog to digital subsystem **2016** may be sent to a storage subsystem **2060**.

Outputs from the analog to digital subsystem **2016** and sensor service subsystem **2018** go to a collector subsystem **2020**, which also receives a real-time clock **2022**. The collector subsystem **2020** communicates with a recognizer **2024** for EEG data and a classifier **2026** for EMG, EOG, and ECG data, and data from other sensing. The collector subsystem **2020** further communicates to a wireless streamer **2028** and a serial streamer **2030** to interface with a miniaturized mobile computing system **2036** and a traditional workstation **2032**, respectively. The traditional workstation **2032** and miniaturized mobile computing system **2036** may be communicated with a cloud **2034** for storage or processing. The miniaturized mobile computing system **2036** may assist in wireless muscle tracking **2038** (e.g., EMG data) and wireless eye pupil tracking **2040**.

A controller subsystem **2042** accepts input from a command queue **2044** which accepts input from a BT write callback **2050**. The BT write callback **2050** may send commands **2046** to a serial read **2048**. The controller subsystem **2042** may send output to the controller subsystem **2042** and a peripherals subsystem **2052**. The peripherals subsystem **2052** generates audio feedback **2054**, haptic feedback **2056**, and OLED visual feedback **2058** for the user.

The flow diagram **2000** includes synchronizing signals from multiple biosensors including brain, body, eye and movement; processing multiple models concurrently for multi-sensory input; and directing and processing biofeedback through peripheral subsystems. Flow diagram **2000** may apply to a user wearing any of the nonverbal multi-input and feedback devices and/or sensors herein.

FIG. **21** is a block diagram **2100** showing an example of cloud processing for a nonverbal multi-input and feedback device such as herein. The block diagram **2100** comprises data authentication **2102**, a sensory device and mobile system **2104**, a cloud system **2106**, and a database **2122**. The data authentication **2102** module may be configured to authenticate data and communicate with the sensory device and mobile system **2104** and cloud system **2106**. The sensory device and mobile system **2104** may include companion application **2108** and data collection, firmware **2110** and data collection, and data analysis **2112** or raw and processed data. The cloud system **2106** may comprise SQS message queuing **2114**, server computing **2116** to analyze raw and process data, elastic computing **2118** to build, train, and test machine learning models, and object storage **2120** for persistent storage of biodata, machine learning, and metadata. The database **2122** stores associations and metadata and is in communication with the cloud system **2106**.

Block diagram **2100** has the cloud system, the nonverbal multi-input device and an authorization system. Block diagram **2100** includes: machine learning processing signal data on device; metadata enrichment; push raw and processed data to cloud; cloud application building new models for devices; system updates devices remotely and wirelessly; secure and privacy compliant. This configuration is quite powerful but unassumingly simple in this block diagram.

FIG. **22** is a block diagram **2200** showing an example of a system architecture for integrated virtual AI assistant and web services **2202** for a nonverbal multi-input and feedback device such as herein. The block diagram **2200** comprises integrated virtual AI assistant and web services **2202** which may include an audio input processor **2204**, an AI communication library **2206**, a virtual assistant **2208** such as Alexa,

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an AI directive sequencer library **2210**, a capability agent **2212**, and an active focus manager library **2214**. A gesture **2216** from a user may be detected by a sensor **2218**. An application user interface **2220** may process sensor data, and may send data to the audio input processor **2204**. The capability agent **2212** may send data back to the application user interface **2220**. The application user interface **2220** may signal an actuation subsystem **2222** to provide visual feedback **2224**, audible feedback **2226**, and haptic feedback **2228**.

The block diagram **2200** includes: system manages intention signal acquisition, processing, language composition, and output; in the event where a user wants to send their intention to a virtual assistant (like Alexa, Siri). The blocks outside of the dashed border run on the sensory device, and currently, the blocks inside the dashed line are running in the cloud (e.g., represent a custom configuration for how to use the Alexa service in a cloud architecture.) It could also be possible that all of what's described here as in the cloud could run locally in the sensory device.

FIG. **23** is a block diagram **2300** showing an example of system operations for a nonverbal multi-input and feedback device such as herein. The block diagram **2300** comprises an AI virtual assistant **2302**, such as Alexa, a content management system **2304**, cloud data logs **2306**, authentication **2308**, speech generation **2310**, a runtime environment **2312**, a serverless cloud **2314**, an API gateway **2316**, an application **2318**, a TTS voice engine **2320**, an email client **2322**, account analytics **2324**, marketing analytics **2326**, application analytics **2328**, a vocabulary **2330**, user events **2332**, a customer relations management **2334**, and an app store **2336**.

Block diagram **2300** includes: system operation blocks including authentication. This is an example of the complexity of a system operating in the cloud. Everything in this figure is in the cloud, except for the application that is running on the sensory device. The augment/virtual reality application **2318** for the nonverbal multi-input and feedback device may interface with an authentication **2308** module, an API gateway **2316**, a vocabulary **2330**, application analytics **2328**, AI virtual assistant **2302**, and marketing analytics **2326**. The AI virtual assistant **2302** may communicate back to the application **2318**. The application **2318** may also be in direct communication with a serverless cloud **2314**, or may communicate with the serverless cloud **2314** through the API gateway **2316**. Authentication **2308** may also be in communication with the serverless cloud **2314**. The API gateway **2316** further allows the application **2318** to communicate with the content management system **2304**, which may be used to store cloud data logs **2306**. The content management system **2304** may send data back to the application **2318** through the authentication **2308** module, which may act as a gateway to ensure security and content authorization. Finally, the content management system **2304** may provide data to an account analytics **2324** module. Account analytics **2324** may provide data to a user events **2332** module, which may in turn feed data to application analytics **2328**.

The serverless cloud **2314** may allow communication with the runtime environment **2312** and the customer relations management **2334** module. The customer relations management **2334** may provide data for marketing analytics **2326**. The runtime environment **2312** may interface with speech generation **2310**, a TTS voice engine **2320**, an email client **2322**, and account analytics **2324**. Speech generation **2310** may allow a user to access an app store **2336**.

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FIG. **24A** illustrates an isometric view of a BCI headset system **2400** in accordance with one embodiment. The BCI headset system **2400** comprises an augmented reality display lens **2402**, a top cover **2404**, an adjustable strap **2406**, a padding **2408**, a ground/reference electrode **2410**, a ground/reference electrode adjustment dial **2412**, a biosensor electrodes **2414**, a battery cell **2416**, a fit adjustment dial **2418**, and a control panel cover **2420**.

The augmented reality display lens **2402** may be removable from the top cover **2404** as illustrated in FIG. **24C**. The augmented reality display lens **2402** and top cover **2404** may have magnetic portions that facilitate removably securing the augmented reality display lens **2402** to the top cover **2404**. The augmented reality display lens **2402** may in one embodiment incorporate a frame around the lens material allowing the augmented reality display lens **2402** to be handled without depositing oils on the lens material.

The adjustable strap **2406** may secure the BCI headset system **2400** to a wearer's head. The adjustable strap **2406** may also provide a conduit for connections between the forward housing **2432** shown in FIG. **24C** and the components located along the adjustable strap **2406** and to the rear of the BCI headset system **2400**. Padding **2408** may be located at the front and rear of the BCI headset system **2400**, as well as along the sides of the adjustable strap **2406**, as illustrated. A fit adjustment dial **2418** at the rear of the BCI headset system **2400** may be used to tighten and loosen the fit of the BCI headset system **2400** by allowing adjustment to the adjustable strap **2406**.

A snug fit of the BCI headset system **2400** may facilitate accurate readings from the ground/reference electrodes **2410** at the sides of the BCI headset system **2400**, as illustrated here in FIG. **24A** as well as in FIG. **24C**. A snug fit may also facilitate accurate readings from the biosensor electrodes **2414** positioned at the back of the BCI headset system **2400**. Further adjustment to these sensors may be made using the ground/reference electrode adjustment dials **2412** shown, as well as the biosensor electrode adjustment dials **2424** illustrated in FIG. **24B**.

In addition to the padding **2408**, biosensor electrodes **2414**, and fit adjustment dial **2418** already described, the rear of the BCI headset system **2400** may incorporate a battery cell **2416**, such as a rechargeable lithium battery pack. A control panel cover **2420** may protect additional features when installed, those features being further discussed with respect to FIG. **24B**.

FIG. **24B** illustrates a rear view of a BCI headset system **2400** in accordance with one embodiment. The control panel cover **2420** introduced in FIG. **24B** is not shown in this figure, so that underlying elements may be illustrated. The BCI headset system **2400** further comprises a control panel **2422**, a biosensor electrode adjustment dials **2424**, an auxiliary electrode ports **2426**, and a power switch **2428**.

With the control panel cover **2420** removed, the wearer may access a control panel **2422** at the rear of the BCI headset system **2400**. The control panel **2422** may include biosensor electrode adjustment dials **2424**, which may be used to calibrate and adjust settings for the biosensor electrodes **2414** shown in FIG. **24A**.

The control panel **2422** may also include auxiliary electrode ports **2426**, such that additional electrodes may be connected to the BCI headset system **2400**. For example, a set of gloves containing electrodes may be configured to interface with the BCI headset system **2400**, and readings from the electrodes in the gloves may be sent to the BCI headset system **2400** wirelessly, or via a wired connection to the auxiliary electrode ports **2426**.

The control panel **2422** may comprise a power switch **2428**, allowing the wearer to power the unit on and off while the control panel cover **2420** is removed. Replacing the control panel cover **2420** may then protect the biosensor electrode adjustment dials **2424** and power switch **2428** from being accidentally contacted during use. In one embodiment, a power LED may be incorporated onto or near the power switch **2428** as an indicator of the status of unit power, e.g., on, off, battery low, etc.

FIG. **24C** illustrates an exploded view of a BCI headset system **2400** in accordance with one embodiment. The BCI headset system **2400** further comprises a USB port **2430** in the rear of the BCI headset system **2400** as well as a forward housing **2432** which may be capable of holding a smart phone **2434**. The USB port **2430** may in one embodiment be a port for a different signal and power connection type. The USB port **2430** may facilitate charging of the battery cell **2416**, and may allow data transfer through connection to additional devices and electrodes.

The top cover **2404** may be removed from the forward housing **2432** as shown to allow access to the forward housing **2432**, in order to seat and unseat a smart phone **2434**. The smart phone **2434** may act as all or part of the augmented reality display. In a BCI headset system **2400** incorporating a smart phone **2434** in this manner, the augmented reality display lens **2402** may provide a reflective surface such that a wearer is able to see at least one of the smart phone **2434** display and the wearer's surroundings within their field of vision.

The top cover **2404** may incorporate a magnetized portion securing it to the forward housing **2432**, as well as a magnetized lens reception area, such that the augmented reality display lens **2402** may through incorporation of a magnetized frame, be secured in the front of the top cover **2404**, and the augmented reality display lens **2402** may also be removable in order to facilitate secure storage or access to the forward housing **2432**.

FIG. **24D** illustrates an exploded view of a BCI headset system **2400** in accordance with one embodiment. The BCI headset system **2400** further comprises a smart phone slot **2436** in the forward housing **2432**. When the augmented reality display lens **2402** and top cover **2404** are removed to expose the forward housing **2432** as shown, the smart phone slot **2436** may be accessed to allow a smart phone **2434** (not shown in this figure) to be inserted. In configurations where the BCI is an accessory that is bolted onto another AR/VR/Mix Reality system, the BCI headset system **2400** would not need one or more of the augmented reality display lens **2402**, the top cover **2404**, and the forward housing **2432**.

#### LISTING OF DRAWING ELEMENTS

**100** headset  
**102** PCB  
**104** strap  
**106** display  
**108** contoured sleeve  
**110** visual display source  
**200** disassembled BCI headset  
**202** pad  
**300** headset  
**302** cover  
**304** PCB  
**306** contoured sleeve  
**308** led  
**400** headset  
**402** sensor

**404** additional sensors  
**406** sensor  
**408** sensor  
**410** contoured sleeve  
**412** PCB  
**414** slit  
**416** clasp  
**500** cross section of headset  
**502** contoured sleeve  
**504** sensor  
**506** third area  
**600** cross section of headset  
**602** second area  
**604** sensor  
**606** third area  
**608** first area  
**610** contoured sleeve  
**612** channel  
**700** cross section view of headset  
**702** contoured sleeve  
**704** second area  
**706** first area  
**708** sensor  
**710** battery  
**712** sensor  
**714** third area  
**716** led  
**800** method  
**802** block  
**804** block  
**806** block  
**808** block  
**810** block  
**812** block  
**900** device  
**902** printed circuit board  
**904** first area  
**906** second area  
**908** third area  
**910** analog front end  
**912** processing, analyzing and mapping  
**914** biofeedback  
**916** sensor header  
**918** EEG analog to digital  
**920** haptic controller  
**922** audio driver/amplifier  
**924** OLED  
**926** micro sd card  
**928** USB/TTL bridge  
**930** Bluetooth low energy module  
**932** microprocessor  
**934** power management module  
**1000** BCI+AR system  
**1002** sensor  
**1004** operating system  
**1006** user  
**1008** hardware  
**1100** BCI+AR environment  
**1102** human user  
**1104** sensor  
**1106** EEG analog to digital converter  
**1108** Audio/Video/Haptic Output  
**1110** processing  
**1112** augmented reality glasses  
**1114** strap  
**1116** BCI  
**1200** augmented reality device logic

## 31

1202 processing units  
 1204 CPU  
 1206 GPU  
 1208 WiFi  
 1210 Bluetooth  
 1212 speakers  
 1214 microphones  
 1216 memory  
 1218 logic  
 1220 graphics engine  
 1222 camera  
 1224 visual display  
 1226 vibration/haptic driver  
 1228 cloud  
 1230 Bluetooth keyboard  
 1300 block diagram of nonverbal multi-input and feed-back device  
 1302 application  
 1304 multimodal input and intent detection  
 1306 context awareness  
 1308 vocabulary  
 1310 output and action  
 1312 touch  
 1314 bio-signals 1316 keyboard  
 1318 facial tracking  
 1320 eye and pupil tracking  
 1322 alternative inputs  
 1324 biometrics  
 1326 environment  
 1328 object recognition  
 1330 facial recognition  
 1332 voice recognition  
 1334 date and time  
 1336 history  
 1338 location  
 1340 proximity  
 1342 other metadata  
 1344 flat screen display  
 1346 augmented/virtual reality  
 1348 virtual AI assistant  
 1350 synthesized voice  
 1352 prosthetic device  
 1354 social media and messaging  
 1356 media consumption  
 1358 other output  
 1400 block diagram of a single framework of a nonverbal multi-input and feedback device  
 1402a sensor  
 1402b sensor  
 1402c sensor  
 1402d sensor  
 1402e sensor  
 1402f sensor  
 1404 input gesture  
 1406 context awareness  
 1408 machine learning  
 1410 output expression  
 1412 destination  
 1414 touch  
 1416 movement  
 1418 mental  
 1420 glances  
 1422 audible  
 1424 breath  
 1426 time synchronization  
 1428 configure data sources  
 1430 configure data processing parameters

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1432 configure timing  
 1434 metadata tagging  
 1436 acquire analog data streams  
 1438 convert to digital data streams  
 5 1440 analyze data streams  
 1442 execute digital operations for actuation  
 1444 text  
 1446 symbol  
 1448 color  
 10 1450 image  
 1452 sound  
 1454 vibration  
 1456 mobile  
 1458 wearable 1  
 1460 wearable 2  
 1462 implant 1  
 1464 implant 2  
 1466 prosthetic 1  
 1500 block diagram of nonverbal multi-input and feed-back device  
 20 1502 analog input  
 1504 sensors  
 1506 processing  
 1508 digital output  
 25 1510 output methods  
 1512 historical data  
 1514 learning system  
 1516 network  
 1518 personalization settings  
 30 1520 metadata  
 1522 application  
 1524 primary and secondary languages  
 1526 visual  
 1528 audible  
 35 1530 written  
 1602 head motion analog input  
 1604 headset with head motion detection sensors  
 1606 user selects options through head motion  
 1608 application creates output based on the user's selected options  
 40 1610 condition that system detects the user is away from home  
 1612 send output to a caregiver via text message  
 1702 user wears an EEG-based brain-computer interface headset  
 45 1704 electrodes that are contacting the scalp  
 1706 streaming analog data can be acquired from the brainwave activity  
 1708 set of words to choose from  
 50 1710 phrase they've composed  
 1802 augmented reality headset combined with a brain computer interface  
 1804 head motion analog input and brainwave activity  
 1806 set of words to choose from  
 55 1808 phrase they've composed  
 1900 flow diagram  
 1902 human user  
 1904 electrode sensors  
 1906 brain computer interface headset and firmware  
 60 1908 augmented reality mobile application  
 1910 machine learning capture and modeling  
 1912 augmented reality headset  
 1914 capture  
 1916 analog-to-digital  
 65 1918 intent detection  
 1920 action trigger  
 1922 user interface

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1924 machine learning parameters  
 1926 raw data capture  
 1928 stimulus placement and timing  
 1930 augmented reality environment  
 1932 training data  
 1934 training and data analysis  
 1936 stimulus placement and timing  
 1938 evoke potential stimulus  
 1940 output and action  
 2000 flow diagram  
 2002 multimodal, multi-sensory system for communication and control  
 2004 wireless neck and head tracking  
 2006 wireless brain tracking  
 2008 central sensors  
 2010 peripheral sensors  
 2012 analog to digital signal processor  
 2014 analog to digital signal processor  
 2016 analog to digital subsystem  
 2018 sensor service subsystem  
 2020 collector subsystem  
 2022 real-time clock  
 2024 recognizer  
 2026 classifier  
 2028 wireless streamer  
 2030 serial streamer  
 2032 traditional workstation  
 2034 cloud  
 2036 miniaturized mobile computing system  
 2038 wireless muscle tracking  
 2040 wireless eye pupil tracking  
 2042 controller subsystem  
 2044 command queue  
 2046 command  
 2048 serial read  
 2050 BT write callback  
 2052 peripherals subsystem  
 2054 audio feedback  
 2056 haptic feedback  
 2058 OLED visual feedback  
 2060 storage subsystem  
 2100 block diagram  
 2102 data authentication  
 2104 sensory device and mobile system  
 2106 cloud system  
 2108 companion application  
 2110 firmware  
 2112 data analysis  
 2114 SQS message queuing  
 2116 server computing  
 2118 elastic computing  
 2120 object storage  
 2122 database  
 2200 block diagram  
 2202 integrated virtual AI assistant and web services  
 2204 audio input processor  
 2206 AI communication library  
 2208 virtual assistant  
 2210 AI directive sequencer library  
 2212 capability agent  
 2214 active focus manager library  
 2216 gesture  
 2218 sensor  
 2220 application user interface  
 2222 actuation subsystem  
 2224 visual feedback  
 2226 audible feedback

## 34

2228 haptic feedback  
 2300 block diagram  
 2302 AI virtual assistant  
 2304 content management system  
 2306 cloud data logs  
 2308 authentication  
 2310 speech generation  
 2312 runtime environment  
 2314 serverless cloud  
 2316 API gateway  
 2318 application  
 2320 TTS voice engine  
 2322 email client  
 2324 account analytics  
 2326 marketing analytics  
 2328 application analytics  
 2330 vocabulary  
 2332 user events  
 2334 customer relations management  
 2336 app store  
 2400 BCI headset system  
 2402 augmented reality display lens  
 2404 top cover  
 2406 adjustable strap  
 2408 padding  
 2410 ground/reference electrode  
 2412 ground/reference electrode adjustment dial  
 2414 biosensor electrodes  
 2416 battery cell  
 2418 fit adjustment dial  
 2420 control panel cover  
 2422 control panel  
 2424 biosensor electrode adjustment dials  
 2426 auxiliary electrode ports  
 2428 power switch  
 2430 USB port  
 2432 forward housing  
 2434 smart phone  
 2436 smart phone slot  
 Within this disclosure, different entities (which may variously be referred to as “units,” “circuits,” other components, etc.) may be described or claimed as “configured” to perform one or more tasks or operations. This formulation—[entity] configured to [perform one or more tasks]—is used herein to refer to structure (i.e., something physical, such as an electronic circuit). More specifically, this formulation is used to indicate that this structure is arranged to perform the one or more tasks during operation. A structure can be said to be “configured to” perform some task even if the structure is not currently being operated. A “credit distribution circuit configured to distribute credits to a plurality of processor cores” is intended to cover, for example, an integrated circuit that has circuitry that performs this function during operation, even if the integrated circuit in question is not currently being used (e.g., a power supply is not connected to it). Thus, an entity described or recited as “configured to” perform some task refers to something physical, such as a device, circuit, memory storing program instructions executable to implement the task, etc. This phrase is not used herein to refer to something intangible.  
 The term “configured to” is not intended to mean “configurable to.” An unprogrammed FPGA, for example, would not be considered to be “configured to” perform some specific function, although it may be “configurable to” perform that function after programming.  
 Reciting in the appended claims that a structure is “configured to” perform one or more tasks is expressly intended

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not to invoke 35 U.S.C. § 112(f) for that claim element. Accordingly, claims in this application that do not otherwise include the “means for” [performing a function] construct should not be interpreted under 35 U.S.C § 112(f).

As used herein, the term “based on” is used to describe one or more factors that affect a determination. This term does not foreclose the possibility that additional factors may affect the determination. That is, a determination may be solely based on specified factors or based on the specified factors as well as other, unspecified factors. Consider the phrase “determine A based on B.” This phrase specifies that B is a factor that is used to determine A or that affects the determination of A. This phrase does not foreclose that the determination of A may also be based on some other factor, such as C. This phrase is also intended to cover an embodiment in which A is determined based solely on B. As used herein, the phrase “based on” is synonymous with the phrase “based at least in part on.”

As used herein, the phrase “in response to” describes one or more factors that trigger an effect. This phrase does not foreclose the possibility that additional factors may affect or otherwise trigger the effect. That is, an effect may be solely in response to those factors, or may be in response to the specified factors as well as other, unspecified factors. Consider the phrase “perform A in response to B.” This phrase specifies that B is a factor that triggers the performance of A. This phrase does not foreclose that performing A may also be in response to some other factor, such as C. This phrase is also intended to cover an embodiment in which A is performed solely in response to B.

As used herein, the terms “first,” “second,” etc. are used as labels for nouns that they precede, and do not imply any type of ordering (e.g., spatial, temporal, logical, etc.), unless stated otherwise. For example, in a register file having eight registers, the terms “first register” and “second register” can be used to refer to any two of the eight registers, and not, for example, just logical registers 0 and 1.

When used in the claims, the term “or” is used as an inclusive or and not as an exclusive or. For example, the phrase “at least one of x, y, or z” means any one of x, y, and z, as well as any combination thereof.

The apparatuses, methods, and systems in this disclosure are described in the preceding on the basis of several preferred embodiments. Different aspects of different variants are considered to be described in combination with each other such that all combinations that upon reading by a skilled person in the field on the basis of this document may be regarded as being read within the concept of the disclosure. The preferred embodiments do not limit the extent of protection of this document.

Having thus described embodiments of the present disclosure of the present application in detail and by reference to illustrative embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the present disclosure.

What is claimed is:

1. A headband for a head-mountable device, comprising: a first end configured to attach to the head-mountable device;
- a second end configured to attach to the head-mountable device; and
- a sensor positioned between the first end and the second end, the sensor configured to:
  - detect brain activity of a user; and
  - generate a signal based on the detected brain activity,
 wherein:
  - the sensor is embedded in the headband; and

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the headband comprises an area that is transparent to the signal emitted by the sensor.

2. The headband of claim 1, wherein the headband is articulable relative to the head-mountable device.

3. The headband of claim 1, wherein the headband comprises an expandable surface area.

4. The headband of claim 1, wherein, the signal comprises a display command signal.

5. A wearable electronic device comprising:

a display;

a retention band attached to the display, the retention band having a first orientation and a second orientation;

a sensor connected to the retention band, the sensor configured to detect a brain activity of a user and produce a signal based on the brain activity; and

a processor configured to:

perform a first analysis of the signal in response to the retention band being in the first orientation; and

perform a second analysis of the signal in response to the retention band being in the second orientation.

6. The wearable electronic device of claim 5, wherein the wearable electronic device performs an action in response to the signal.

7. The wearable electronic device of claim 5, wherein:

the wearable electronic device comprises a head-mountable device; and

the retention band is adjustable.

8. The wearable electronic device of claim 5, wherein the sensor is configured to perform at least one of functional near-infrared spectroscopy or electroencephalography.

9. The wearable electronic device of claim 5, wherein the retention band is movable between the first orientation and the second orientation, the sensor directed toward a first brain region in the first orientation, and a second brain region in the second orientation when the wearable electronic device is worn by the user.

10. The wearable electronic device of claim 5, wherein the retention band produces at least one of visual, audio, or haptic feedback in response to the signal from the sensor.

11. The wearable electronic device of claim 5, wherein:

the sensor is a first sensor; and

further comprising a second sensor connected to the retention band, the second sensor configured to collect vital signs.

12. A head-mountable device comprising:

a housing;

a display positioned in the housing;

a retention band attached to the housing, the retention band having a first orientation and a second orientation;

a sensor connected to the retention band, the sensor configured to detect a brain activity of a user and produce a signal based on the brain activity; and

a processor positioned in the housing, configured to:

perform a first analysis of the signal in response to the retention band being in the first orientation; and

perform a second analysis of the signal in response to the retention band being in the second orientation.

13. The head-mountable device of claim 12, wherein:

the sensor further comprises a sensor array configured to detect brain activity, the sensor array positionable adjacent a back of a head.

14. The head-mountable device of claim 12, wherein:

the sensor transmits a signal to the processor, the signal based on the detected brain activity;

the processor analyzes the signal; and

the processor causes the head-mountable device to perform an action in response to the analysis of the signal.

15. The head-mountable device of claim 14, wherein the action comprises at least one of providing a visual feedback, providing an audio feedback, or providing a haptic feedback.

16. The head-mountable device of claim 12, wherein the retention band is removably attached to the housing. 5

17. The head-mountable device of claim 12, wherein the sensor is removably attached to the retention band.

18. The head-mountable device of claim 12, wherein the retention band is in electrical communication with the display. 10

19. The head-mountable device of claim 12, wherein the retention band is pivotably attached to the housing.

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