(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 November 2016 (17.11.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/182947 A1

(51) International Patent Classification:
A61N 1/36 (2006.01) *A61N 1/08* (2006.01)

(21) International Application Number:
PCT/US2016/031321

(22) International Filing Date:
6 May 2016 (06.05.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/159,151 8 May 2015 (08.05.2015) US
15/066,813 10 March 2016 (10.03.2016) US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

WO 2016/182947 A1

(54) **Title**: MONTAGE DESIGN FOR CLOSED LOOP SENSING AND NEUROSTIMULATION OF THE DORSAL LATERAL PREFRONTAL CORTEX AND/OR MOTOR CORTEX

(57) **Abstract**: Described is a system for automatic adjustment of neurostimulation. The system controls stimulation of specific neural regions through a neural device positioned on a human subject, while simultaneously performing recordings from the neural device using a targeted arrangement of stimulating electrodes and distinct types of recording electrodes of the neural device. Stimulation of the specific neural regions is adjusted in real-time based on the recordings from the neural device.

[0001] MONTAGE DESIGN FOR CLOSED LOOP SENSING AND NEUROSTIMULATION OF THE DORSAL LATERAL PREFRONTAL CORTEX AND/OR MOTOR CORTEX

[0002] CROSS-REFERENCE TO RELATED APPLICATIONS

[0003] This is a Continuation-in-Part Application of U.S. Application No. 15/066,813, filed in the United States on March 10, 2016, entitled, "System and Method for Training and Assessment," the entirety of which are incorporated herein by reference.

[0004] This is also a Non-Provisional Application of U.S. Provisional Patent Application No. 62/159,151 filed May 8, 2015, entitled, "Montage Design for Closed Loop Sensing and Neurostimulation of the Dorsal Lateral Prefrontal Cortex and/or Motor Cortex," the entirety of which is incorporated herein by reference.

[0005] BACKGROUND OF INVENTION

[0006] (1) Field of Invention

[0007] The present invention relates to a system for adjusting neurostimulation and, more particularly, to a system for adjusting neurostimulation based on real-time sensing of brain states.

[0008] (2) Description of Related Art

[0009] Neurostimulation is a therapeutic activation of part of the nervous system using electrodes. Current techniques use a combination of electroencephalogram (EEG)/transcranial direct-current stimulation (tDCS) or functional near-infrared spectroscopy (fNIRS)/tDCS to target a variety of regions. Current state-of-the-art montages only provide either temporal (EEG) or spatial (fNIRS) information and do not provide all possible information about the current state of the brain, leading to possible misalignment and settings for neurostimulation.

[00010] Currently, brain imaging and planning of new stimulation occurs after the stimulation has been completed, such as described by Datta et al. in "Validation of finite element model of transcranial electrical stimulation using scalp potentials: Implications for clinical dose," *J Neural Engineering* 2013;10(3), which is hereby incorporated by reference as though fully set forth herein. While operable for imaging after stimulation, such existing methods do not allow for simultaneous stimulation and recording or imaging. Thus, a continuing need exists for a system for adapting neurostimulation based on simultaneous recordings of the brain.

[00011] SUMMARY OF THE INVENTION

[00012] The present invention relates to a system for adjusting neurostimulation and, more particularly, to a system for adjusting neurostimulation based on real-time sensing of brain states. The system comprises one or more processors and a memory having instructions such that when the instructions are executed, the one or more processors perform multiple operations. The system stimulates specific neural regions through a neural device, while simultaneously performing recordings from the neural device using a targeted arrangement of stimulating electrodes and distinct types of recording electrodes of the neural device. Stimulation of the specific neural regions is adjusted in real-time based on the recordings from the neural device.

[00013] In another aspect, the system sets stimulation parameters to optimize any neural changes recorded by the recording electrodes to match a desired neural activity.

[00014] In another aspect, the system provides feedback of both temporal neural changes and region specific neural changes via electroencephalogram (EEG) electrodes and functional near-infrared spectroscopy (fNIRS) electrodes, respectively.

[00015] In another aspect, preferred positions of stimulating electrodes on the neural device are provided that will focus effects of the stimulation on the specific neural regions while still allowing concentrated recordings of the specific neural regions.

[00016] In another aspect, stimulation is applied to a specific brain region, wherein the stimulation to be applied is determined by stimulation parameters determined based on prior recordings.

[00017] In another aspect, the stimulation is adjusted to decrease stimulation in one brain region and increase stimulation in another brain region.

[00018] In another aspect, the present invention comprises a method for automatic adjustment of neurostimulation. A targeted arrangement of stimulating electrodes and distinct types of recording electrodes is created for individualized stimulation. Stimulation of specific neural regions through a neural device, while simultaneously performing recordings from the neural device using the targeted arrangement of stimulating electrodes and distinct types of recording electrodes. Stimulation of the specific neural regions is adjusted in real-time based on the recordings from the neural device.

[00019] In another aspect, the neural device is a neural cap.

[00020] In another aspect, the present invention also comprises a method for causing a processor to perform the operations described herein.

[00021] Finally, in yet another aspect, the present invention also comprises a computer program product comprising computer-readable instructions stored on a non-transitory computer-readable medium that are executable by a computer having a processor for causing the processor to perform the operations described herein.

[00022] BRIEF DESCRIPTION OF THE DRAWINGS

[00023] The objects, features and advantages of the present invention will be apparent from the following detailed descriptions of the various aspects of the invention in conjunction with reference to the following drawings, where:

[00024] FIG. 1 is a block diagram depicting the components of a system for adjusting neurostimulation according to embodiments of the present disclosure;

[00025] FIG. 2 is an illustration of a computer program product according to embodiments of the present disclosure;

[00026] FIG. 3 is an illustration of an example arrangement of functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), and transcranial direct-current stimulation (tDCS) electrodes according to embodiments of the present disclosure;

[00027] FIG. 4A is an illustration of a control condition according to embodiments of the present disclosure;

[00028] FIG. 4B is an illustration of a stimulation condition according to embodiments of the present disclosure;

[00029] FIG. 4C is an illustration of topographic maps of wavelet-transformed data according to embodiments of the present disclosure;

[00030] FIG. 5 is an illustration of a closed loop system for adjusting neurostimulation parameters according to various embodiments of the present disclosure;

[00031] FIG. 6 illustrates a human subject receiving neurostimulation via a neural device according to some embodiments of the present disclosure; and

[00032] FIG. 7 illustrates a neural cap worn by a human subject for sensing and neurostimulation according to embodiments of the present disclosure.

[00033] DETAILED DESCRIPTION

[00034] The present invention relates to a system for adjusting neurostimulation and, more particularly, to a system for adjusting neurostimulation based on real-time sensing of brain states. The following description is presented to enable one of ordinary skill in the art to make and use the invention and to incorporate it in the context of particular applications. Various modifications, as well as a variety of uses in different applications will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to a wide range of aspects. Thus, the present invention is not intended to be limited to the aspects presented, but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[00035] In the following detailed description, numerous specific details are set forth in order to provide a more thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced without necessarily being limited to these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

[00036] The reader's attention is directed to all papers and documents which are filed concurrently with this specification and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference. All the features disclosed in this specification, (including any accompanying claims, abstract, and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[00037] Furthermore, any element in a claim that does not explicitly state "means for" performing a specified function, or "step for" performing a specific function, is not to be interpreted as a "means" or "step" clause as specified in 35 U.S.C. Section 112, Paragraph 6. In particular, the use of "step of" or "act of" in the claims herein is not intended to invoke the provisions of 35 U.S.C. 112, Paragraph 6.

[00038] Please note, if used, the labels left, right, front, back, top, bottom, forward, reverse, clockwise and counter-clockwise have been used for convenience purposes only and are not intended to imply any particular fixed direction. Instead, they are used to reflect relative locations and/or directions between

various portions of an object. As such, as the present invention is changed, the above labels may change their orientation.

[00039] (1) Principal Aspects

[00040] Various embodiments of the invention include three "principal" aspects. The first is a system for adjusting neurostimulation. The system is typically in the form of a computer system operating software or in the form of a "hard-coded" instruction set. This system may be incorporated into a wide variety of devices that provide different functionalities. The second principal aspect is a method, typically in the form of software, operated using a data processing system (computer). The third principal aspect is a computer program product. The computer program product generally represents computer-readable instructions stored on a non-transitory computer-readable medium such as an optical storage device, e.g., a compact disc (CD) or digital versatile disc (DVD), or a magnetic storage device such as a floppy disk or magnetic tape. Other, non-limiting examples of computer-readable media include hard disks, read-only memory (ROM), and flash-type memories. These aspects will be described in more detail below.

[00041] A block diagram depicting an example of a system (i.e., computer system 100) of the present invention is provided in FIG. 1. The computer system 100 is configured to perform calculations, processes, operations, and/or functions associated with a program or algorithm. In one aspect, certain processes and steps discussed herein are realized as a series of instructions (e.g., software program) that reside within computer readable memory units and are executed by one or more processors of the computer system 100. When executed, the instructions cause the computer system 100 to perform specific actions and exhibit specific behavior, such as described herein.

[00042] The computer system 100 may include an address/data bus 102 that is configured to communicate information. Additionally, one or more data processing units, such as a processor 104 (or processors), are coupled with the address/data bus 102. The processor 104 is configured to process information and instructions. In an aspect, the processor 104 is a microprocessor. Alternatively, the processor 104 may be a different type of processor such as a parallel processor, application-specific integrated circuit (ASIC), programmable logic array (PLA), complex programmable logic device (CPLD), or a field programmable gate array (FPGA).

[00043] The computer system 100 is configured to utilize one or more data storage units. The computer system 100 may include a volatile memory unit 106 (e.g., random access memory ("RAM"), static RAM, dynamic RAM, etc.) coupled with the address/data bus 102, wherein a volatile memory unit 106 is configured to store information and instructions for the processor 104. The computer system 100 further may include a non-volatile memory unit 108 (e.g., read-only memory ("ROM"), programmable ROM ("PROM"), erasable programmable ROM ("EPROM"), electrically erasable programmable ROM "EEPROM"), flash memory, etc.) coupled with the address/data bus 102, wherein the non-volatile memory unit 108 is configured to store static information and instructions for the processor 104. Alternatively, the computer system 100 may execute instructions retrieved from an online data storage unit such as in "Cloud" computing. In an aspect, the computer system 100 also may include one or more interfaces, such as an interface 110, coupled with the address/data bus 102. The one or more interfaces are configured to enable the computer system 100 to interface with other electronic devices and computer systems. The communication interfaces implemented by the one or more interfaces may include wireline (e.g., serial cables, modems, network adaptors, etc.) and/or

wireless (e.g., wireless modems, wireless network adaptors, etc.) communication technology.

[00044] In one aspect, the computer system 100 may include an input device 112 coupled with the address/data bus 102, wherein the input device 112 is configured to communicate information and command selections to the processor 100. In accordance with one aspect, the input device 112 is an alphanumeric input device, such as a keyboard, that may include alphanumeric and/or function keys. Alternatively, the input device 112 may be an input device other than an alphanumeric input device. In an aspect, the computer system 100 may include a cursor control device 114 coupled with the address/data bus 102, wherein the cursor control device 114 is configured to communicate user input information and/or command selections to the processor 100. In an aspect, the cursor control device 114 is implemented using a device such as a mouse, a track-ball, a track-pad, an optical tracking device, or a touch screen. The foregoing notwithstanding, in an aspect, the cursor control device 114 is directed and/or activated via input from the input device 112, such as in response to the use of special keys and key sequence commands associated with the input device 112. In an alternative aspect, the cursor control device 114 is configured to be directed or guided by voice commands.

[00045] In an aspect, the computer system 100 further may include one or more optional computer usable data storage devices, such as a storage device 116, coupled with the address/data bus 102. The storage device 116 is configured to store information and/or computer executable instructions. In one aspect, the storage device 116 is a storage device such as a magnetic or optical disk drive (e.g., hard disk drive ("HDD"), floppy diskette, compact disk read only memory ("CD-ROM"), digital versatile disk ("DVD")). Pursuant to one aspect, a display device 118 is coupled with the address/data bus 102, wherein the display device

118 is configured to display video and/or graphics. In an aspect, the display device 118 may include a cathode ray tube ("CRT"), liquid crystal display ("LCD"), field emission display ("FED"), plasma display, or any other display device suitable for displaying video and/or graphic images and alphanumeric characters recognizable to a user.

[00046] The computer system 100 presented herein is an example computing environment in accordance with an aspect. However, the non-limiting example of the computer system 100 is not strictly limited to being a computer system. For example, an aspect provides that the computer system 100 represents a type of data processing analysis that may be used in accordance with various aspects described herein. Moreover, other computing systems may also be implemented. Indeed, the spirit and scope of the present technology is not limited to any single data processing environment. Thus, in an aspect, one or more operations of various aspects of the present technology are controlled or implemented using computer-executable instructions, such as program modules, being executed by a computer. In one implementation, such program modules include routines, programs, objects, components and/or data structures that are configured to perform particular tasks or implement particular abstract data types. In addition, an aspect provides that one or more aspects of the present technology are implemented by utilizing one or more distributed computing environments, such as where tasks are performed by remote processing devices that are linked through a communications network, or such as where various program modules are located in both local and remote computer-storage media including memory-storage devices.

[00047] An illustrative diagram of a computer program product (i.e., storage device) embodying the present invention is depicted in FIG. 2. The computer program product is depicted as floppy disk 200 or an optical disk 202 such as a CD or

DVD. However, as mentioned previously, the computer program product generally represents computer-readable instructions stored on any compatible non-transitory computer-readable medium. The term "instructions" as used with respect to this invention generally indicates a set of operations to be performed on a computer, and may represent pieces of a whole program or individual, separable, software modules. Non-limiting examples of "instruction" include computer program code (source or object code) and "hard-coded" electronics (i.e. computer operations coded into a computer chip). The "instruction" is stored on any non-transitory computer-readable medium, such as in the memory of a computer or on a floppy disk, a CD-ROM, and a flash drive. In either event, the instructions are encoded on a non-transitory computer-readable medium.

[00048] (2) Specific Details of Various Embodiments

[00049] Described is a method for using non-invasive transcranial direct current stimulation (tDCS) of neurons in specific regions of the brain (e.g., motor cortex and/or dorsal lateral prefrontal cortex (dlPFC)) while simultaneously recording neural activity via electroencephalography (EEG) from the entire brain and functional near-infrared spectroscopy (fNIRS) from specific regions of the brain (e.g., motor cortex and dlPFC). The specific placement of each electrode for stimulating and recording allows for a novel focality in stimulation to the desired regions (based on an average adult male's head) while also allowing for full coverage from the recording electrodes. The ability to monitor the brain activity of, for instance, the dlPFC and motor cortex in real-time allows for a closed-loop system that will alter the stimulation settings to match desired dlPFC and motor cortex neural activity.

[00050] The system according to embodiments of the present disclosure provides a unique approach to stimulating and recording from specific brain regions such that the different modalities cause minimal interference with each other while

maintaining full coverage of the regions of interest. While each of the electrode modalities (e.g., EEG, fNIRS, tDCS) has been used individually to target the motor cortex and dlPFC, the system according to various embodiments of the present disclosure uses all three modalities simultaneously.

[00051] By using this "montage" of electrodes, there is an unprecedented level of coverage to monitor the effects of neural stimulation to the motor cortex and/or the dlPFC in real-time. This will improve the ability to accurately set the levels of stimulation to optimize any neural changes to match the desired activity. By using EEG and fNIRS, the present invention will provide feedback of both temporal brain changes (via EEG) and region specific changes (via fNIRS).

[00052] The ability to monitor brain states in real-time during stimulation will allow adjustments to be made to the stimulation setting based off of the changes to the activation pattern caused by the neurostimulation. Currently, brain imaging and planning of new stimulation occurs after the stimulation has been completed. By having localized brain imaging of the regions being stimulated, the system described herein has the unique ability to monitor and adapt stimulation settings to reach a desired change in neural activity.

[00053] FIG. 3 depicts the placement of stimulating electrodes, fNIRS electrodes, and EEG electrodes on a head of a subject. The electrodes are represented by small circles. E represents EEG electrodes, S represents source electrodes, and D represents detector electrodes. Stimulation sites are represented by bold dashed circles. Bold lines connecting electrodes represent data channels of interest. The present invention functions by placing the stimulating electrodes (represented by bold dashed circles) at locations that will focus the effects of the stimulation on the brain region desired (e.g., motor cortex and/or dlPFC) while still allowing very concentrated recordings of the spatial areas of the regions by

the functional near infrared spectroscopy (fNIRS) electrodes (i.e., electrodes with "S" or "D").

[00054] Additionally, the EEG electrodes are not interfered with and provide detailed coverage over the entire head allowing for maximal information received. This information can then be analyzed and used to reset the stimulation parameters based on the accurate recordings made from the stimulation. FIGs. 4A, 4B and 4C show results of the montage depicted in FIG. 3, providing evidence of the ability of both EEG and fNIRS to record changes that occur during stimulation with this montage. A sham stimulation (FIG. 4A) (i.e., control condition) indicates a stimulation protocol that conveys the perception of being stimulated to the subject, but does not deliver the current to the brain. FIG. 4B depicts the actual stimulation condition in which the current is delivered to the dlPFC as depicted. Without a montage such as the one illustrated in FIG. 3, these changes would not be able to be analyzed and understood.

[00055] Specifically, FIGs. 4A and 4B depict simultaneous recording of fNIRS with tDCS showing the difference in location activities caused by tDCS. FIG. 4C depicts simultaneous recording of EEG with tDCS showing the difference in timing activities caused by tDCS. FIG. 4C illustrates topographic maps of wavelet-transformed data. The smaller arrows point to significant changes in the midline frontal theta spectral power across days, which corresponds to skill acquisition. The large arrow depicts the progression of the subjects over the training regime of 4 days.

[00056] Closed loop stimulation adaptation is unique to the present invention. FIG. 5 illustrates the architecture for a closed stimulation adaptation that measures behavioral output (e.g., piloting improvements) via behavioral sensing 500 and multi-modal sensing 502 to adapts the stimulation (HD-tDCS neurostimulation

504) to a pattern that is fitting for the current level of expertise of the user and a training task 506 at hand. Behavioral sensing is performed by, for example, custom software written to read flight-recorder-like data from the simulation, which was then used to compare the behavioral performance within subjects an also across subject conditions. Behavioral sensing are specific to the skill being trained. For example, the sensing may be based on quantitative metrics of pilot skill, such as G-force at landing). Multi-modal sensing 502 is performed by, for instance, fNIRS and EEG 508, which record neural activity in the brain 510 of the user. In combination with an operator performance system 512, the measurements from the multi-modal sensing 502 are used to automatically adjust stimulation parameters for HD-tDCS neurostimulation 504 of areas of the user's brain 510 in order to reach a desired cognitive state to improve the user's performance of the training task 506.

[00057] For example, the system according to various embodiments can be used to assist a complete novice being introduced to a task in which they must fly a plane through high turbulence. Using the present invention, the user will receive a computed stimulation (HD-tDCS neurostimulation 504) in a specific area, such as the motor cortex. The stimulation (HD-tDCS neurostimulation 504) is computed based on recordings from expert pilots and other novice pilots as well as a comparison of their fNIRS and EEG measurements and behaviors to the current novice pilot. It is critical to determine the typical variance of various novice pilots to optimize learning and stimulation parameters. In addition, individual phenotypes of behavior can be used to personalize stimulation montage for optimum learning. However, as the current novice pilot's performance improves, the model adapts the stimulation to decrease stimulation in the motor cortex, but increase the decision making aspect of the pilot's brain and target the dlPFC. This adjustment is performed as an evolving system that adapts stimulation based on the current recorded expert pilots and the novice

pilot's improvements. The goal is to improve the performance of the novice 514 pilot to the level of the advanced 516 pilot.

[00058] FIG. 6 illustrates a human subject 600 receiving neurostimulation according to some embodiments of the present disclosure. A neural device 602 able to generate an electrical current delivers neurostimulation by applying a current through one electrode 604 (e.g., anode), and it flows through the brain to another electrode 606 (e.g., cathode). The neural device 602 is depicted as a patch that adheres to a portion of the patient's head. Any suitable neural device 602 can be used (such as the neural cap described below) provided that it can control stimulation of specific neural regions while performing recordings from the neural device 602 using a targeted arrangement of stimulating electrodes and recording electrodes of the neural device 602.

[00059] FIG. 7 illustrates a neural device worn by a human subject for sensing and neurostimulation according to embodiments of the present disclosure. As depicted in FIG. 7, the neural device is a neural cap 700. As shown, the neural cap 700 may have configurable harness locations for stimulators and sensors. Additionally, the sensor/stimulator may contain a spring-loaded system 702 to maintain skin contact. Compression fitting of the neural cap 700 achieves sensor/stimulator consistency. Furthermore, the neural cap 700 can be connected to portable data input/output (I/O) package 704.

[00060] Finally, while this invention has been described in terms of several embodiments, one of ordinary skill in the art will readily recognize that the invention may have other applications in other environments. It should be noted that many embodiments and implementations are possible. Further, the following claims are in no way intended to limit the scope of the present invention to the specific embodiments described above. In addition, any

recitation of "means for" is intended to evoke a means-plus-function reading of an element and a claim, whereas, any elements that do not specifically use the recitation "means for", are not intended to be read as means-plus-function elements, even if the claim otherwise includes the word "means". Further, while particular method steps have been recited in a particular order, the method steps may occur in any desired order and fall within the scope of the present invention.

CLAIMS

What is claimed is:

1. A system for automatic adjustment of neurostimulation, the system comprising:
   one or more processors and a non-transitory memory having instructions encoded thereon such that when the instructions are executed, the one or more processors perform operations of:
   controlling stimulation of specific neural regions through a neural device, while simultaneously performing recordings from the neural device using a targeted arrangement of stimulating electrodes and distinct types of recording electrodes of the neural device; and
   adjusting stimulation of the specific neural regions in real-time based on the recordings from the neural device.

2. The system as set forth in Claim 1, wherein the one or more processors further perform an operation of setting stimulation parameters to optimize any neural changes recorded by the recording electrodes to match a desired neural activity.

3. The system as set forth in Claim 1, wherein the one or more processors further perform an operation of providing feedback of both temporal neural changes and region specific neural changes via electroencephalogram (EEG) electrodes and functional near-infrared spectroscopy (fNIRS) electrodes, respectively.

4. The system as set forth in Claim 1, wherein the one or more processors further perform an operation of providing preferred positions of stimulating electrodes on the neural device that will focus effects of the stimulation on the specific neural regions while still allowing concentrated recordings of the specific neural regions.

5. The system as set forth in Claim 1, wherein the one or more processors further perform an operation of applying stimulation to a specific brain region, wherein the stimulation to be applied is determined by stimulation parameters determined based on prior recordings.

6. The system as set forth in Claim 5, wherein the one or more processors further perform an operation of adjusting the stimulation to decrease stimulation in one brain region and increase stimulation in another brain region.

7. A computer-implemented method for automatic adjustment of neurostimulation, comprising:

an act of causing one or more processors to execute instructions stored on a non-transitory memory such that upon execution, the one or more processors perform operations of:

controlling stimulation of specific neural regions through a neural device, while simultaneously performing recordings from the neural device using a targeted arrangement of stimulating electrodes and distinct types of recording electrodes of the neural device; and

adjusting stimulation of the specific neural regions in real-time based on the recordings from the neural device.

8. The method as set forth in Claim 7, wherein the one or more processors further perform an operation of setting stimulation parameters to optimize any neural changes recorded by the recording electrodes to match a desired neural activity.

9. The method as set forth in Claim 7, wherein the one or more processors further perform an operation of providing feedback of both temporal neural changes and region specific neural changes via electroencephalogram (EEG) electrodes and functional near-infrared spectroscopy (fNIRS) electrodes, respectively.

10. The method as set forth in Claim 7, wherein the one or more processors further perform an operation of providing preferred positions of stimulating electrodes on the neural device that will focus effects of the stimulation on the specific neural regions while still allowing concentrated recordings of the specific neural regions.

11. The method as set forth in Claim 7, wherein the one or more processors further perform an operation of applying stimulation to a specific brain region, wherein the stimulation to be applied is determined by stimulation parameters determined based on prior recordings.

12. The method as set forth in Claim 11, wherein the one or more processors further perform an operation of adjusting the stimulation to decrease stimulation in one brain region and increase stimulation in another brain region.

13. A computer program product for automatic adjustment of neurostimulation, the computer program product comprising:

computer-readable instructions stored on a non-transitory computer-readable medium that are executable by a computer having one or more processors for causing the processor to perform operations of:

controlling stimulation of specific neural regions through a neural device, while simultaneously performing recordings from the neural device using a targeted arrangement of stimulating electrodes and distinct types of recording electrodes of the neural device; and

adjusting stimulation of the specific neural regions in real-time based on the recordings from the neural device.

14. The computer program product as set forth in Claim 13, further comprising instructions for causing the one or more processors to further perform an operation

of setting stimulation parameters to optimize any neural changes recorded by the recording electrodes to match a desired neural activity.

15. The computer program product as set forth in Claim 13, further comprising instructions for causing the one or more processors to further perform an operation of providing feedback of both temporal neural changes and region specific neural changes via electroencephalogram (EEG) electrodes and functional near-infared spectroscopy (fNIRS) electrodes, respectively.

16. The computer program product as set forth in Claim 13, further comprising instructions for causing the one or more processors to further perform an operation of providing preferred positions of stimulating electrodes on the neural device that will focus effects of the stimulation on the specific neural regions while still allowing concentrated recordings of the specific neural regions.

17. The computer program product as set forth in Claim 13, further comprising instructions for causing the one or more processors to further perform an operation of applying stimulation to a specific brain region, wherein the stimulation to be applied is determined by stimulation parameters determined based on prior recordings.

18. The computer program product as set forth in Claim 17, further comprising instructions for causing the one or more processors to further perform an operation of adjusting the stimulation to decrease stimulation in one brain region and increase stimulation in another brain region.

19. A method for automatic adjustment of neurostimulation, comprising acts of:

creating a targeted arrangement of stimulating electrodes and distinct types of recording electrodes for individualized stimulation through a neural device;

controlling stimulation of specific neural regions through the neural device, while simultaneously performing recordings from the neural device using the targeted arrangement of stimulating electrodes and distinct types of recording electrodes of the neural device; and

adjusting stimulation of the specific neural regions in real-time based on the recordings from the neural device.

20. The system as set forth in Claim 1, wherein the neural device is a neural cap.

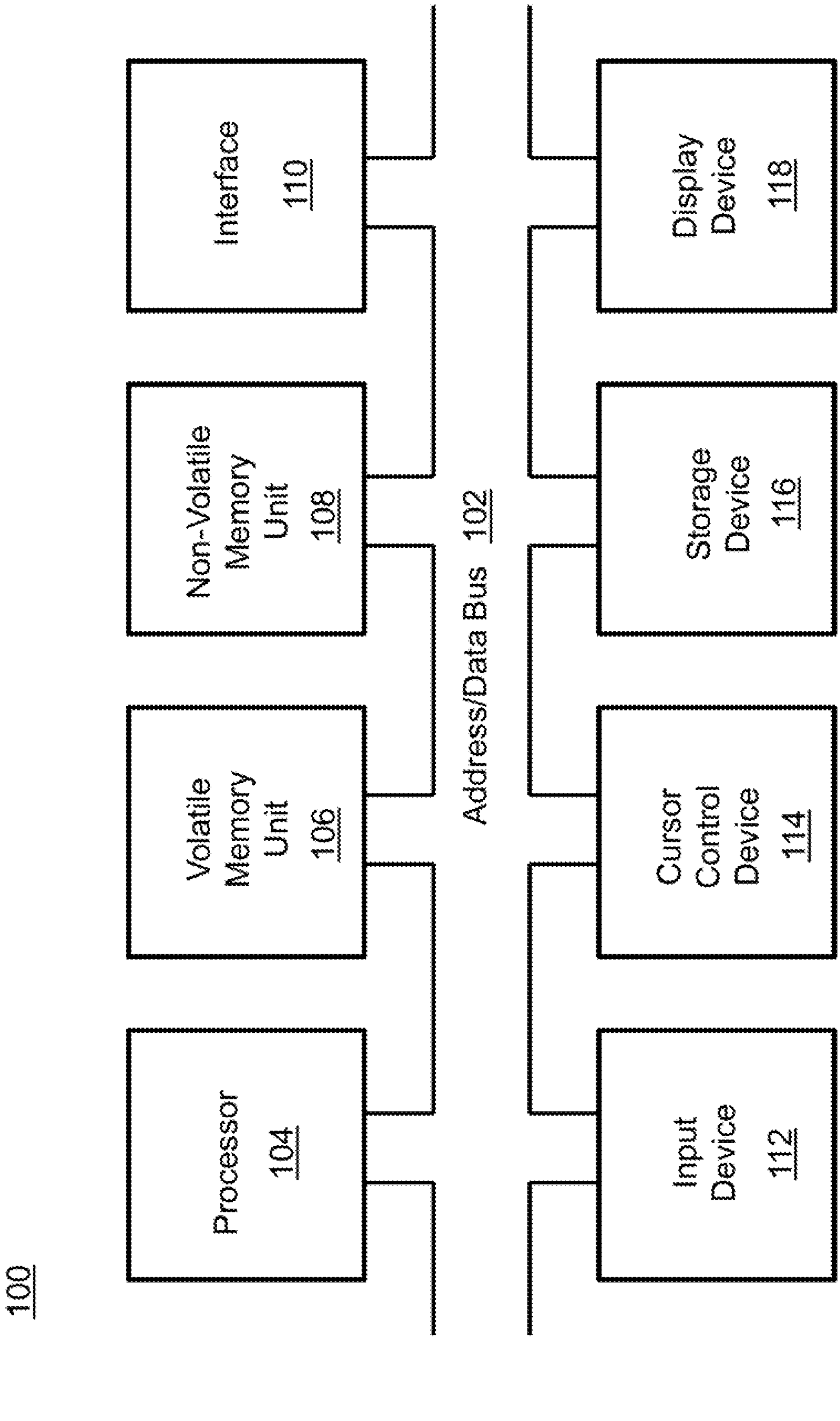
100
Processor
104
Volatile Memory Unit
106
Non-Volatile Memory Unit
108
Interface
110
Address/Data Bus 102
Input Device
112
Cursor Control Device
114
Storage Device
116
Display Device
118

FIG. 1

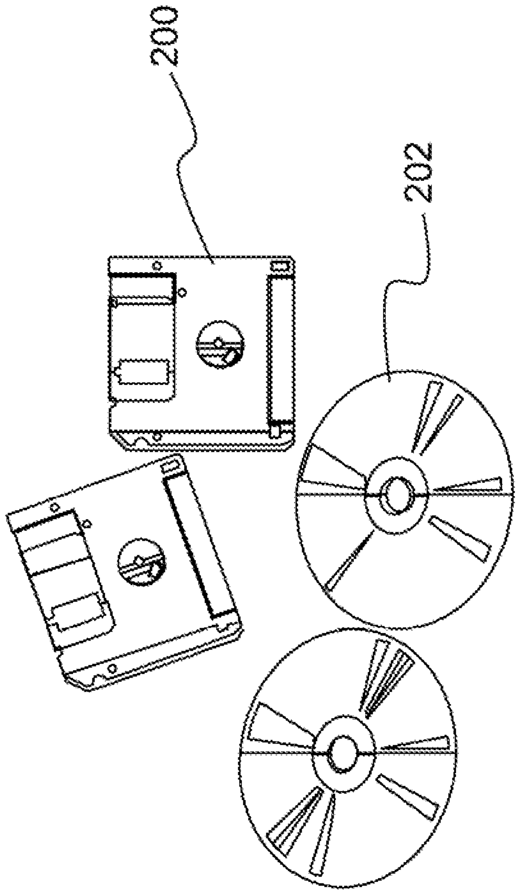

FIG. 2

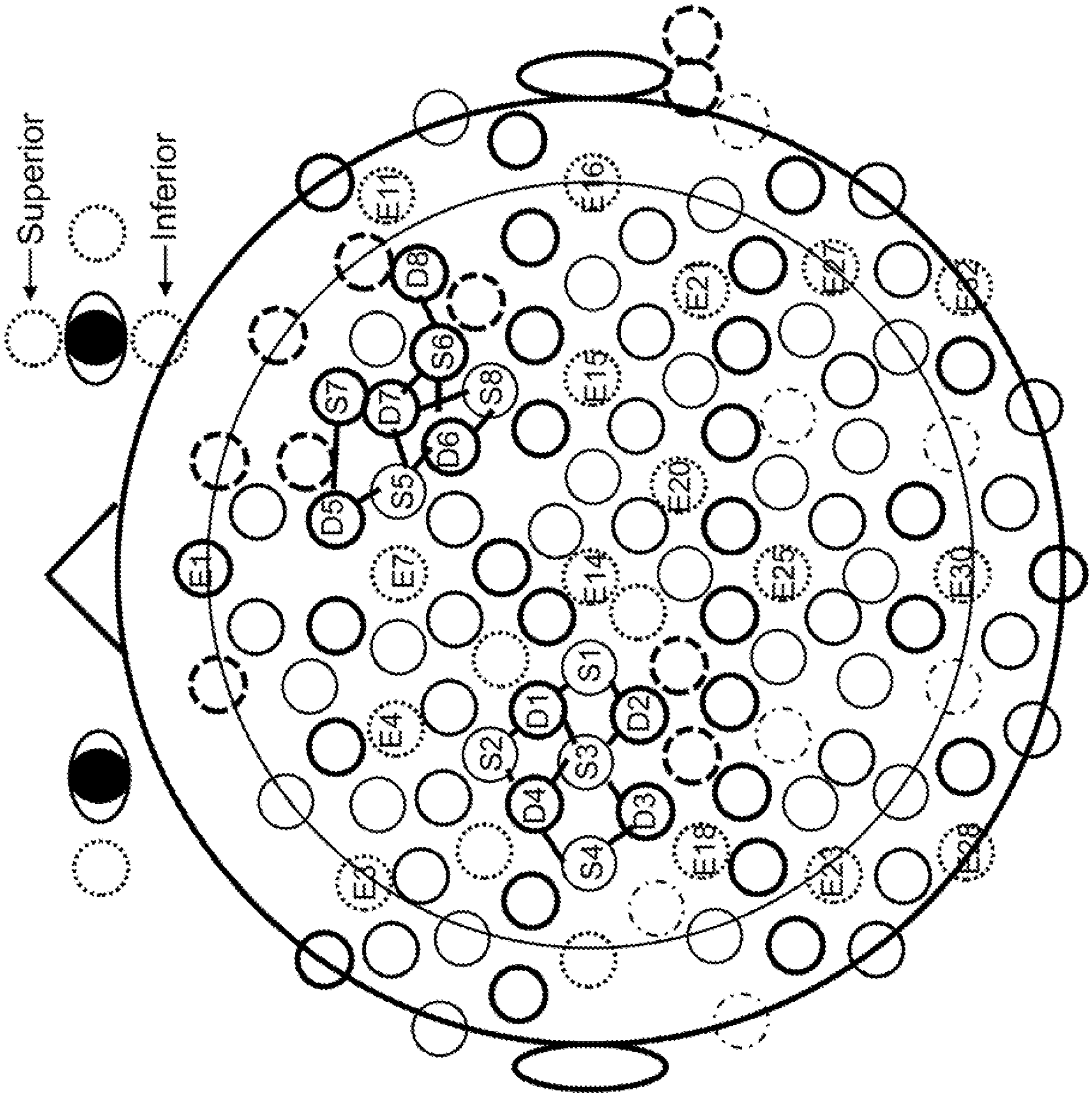
Superior
Inferior
E1
E4
E5
E7
E11
E14
E15
E16
E18
E20
E21
E23
E25
E27
E28
E30
E32
S1
S2
S3
S4
S5
S6
S7
S8
D1
D2
D3
D4
D5
D6
D7
D8

FIG. 3

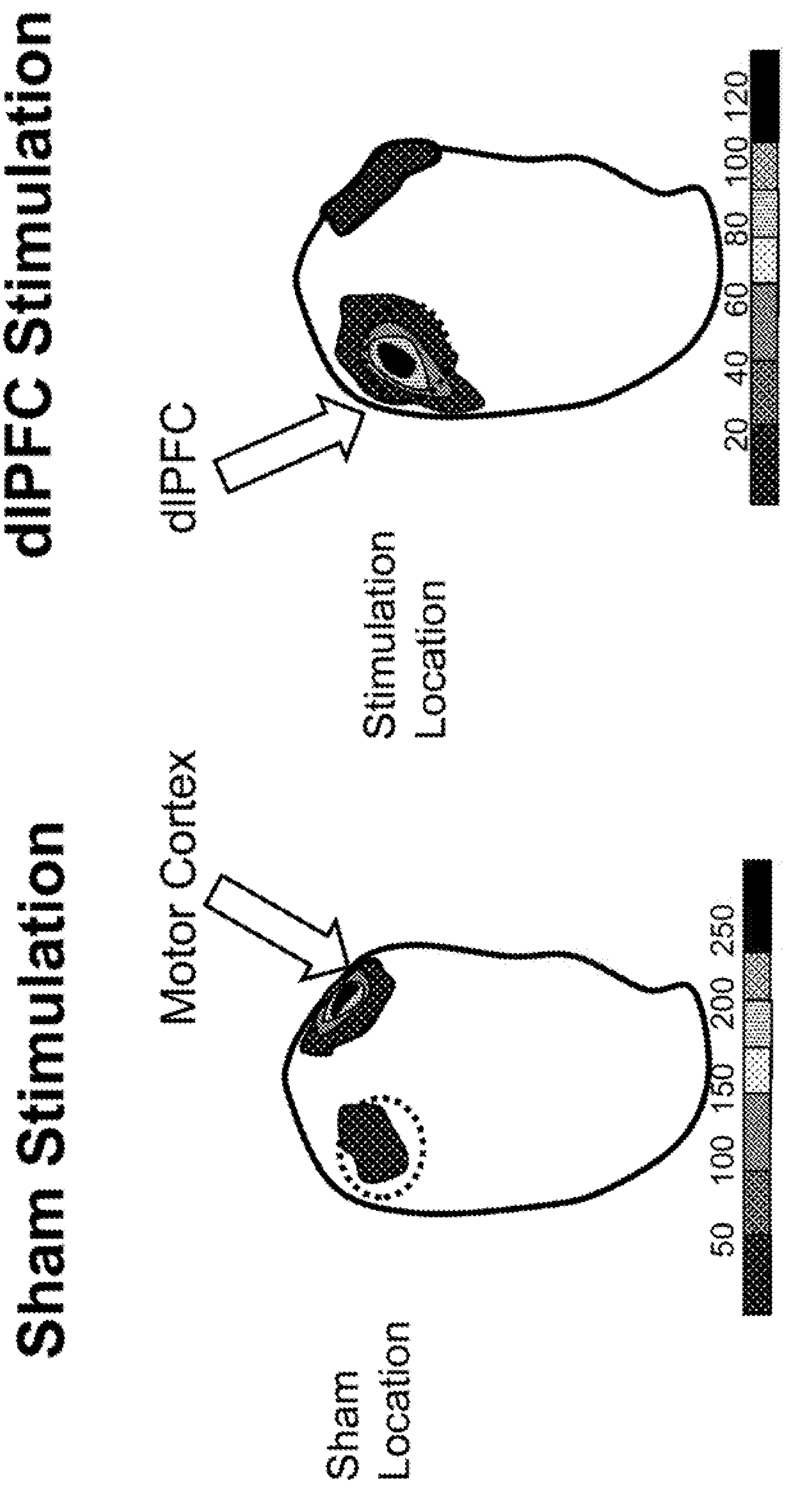
dlPFC Stimulation
dlPFC
Stimulation
Location
20 40 60 80 100 120
Sham Stimulation
Motor Cortex
Sham
Location
50 100 150 200 250

FIG. 4B

FIG. 4A

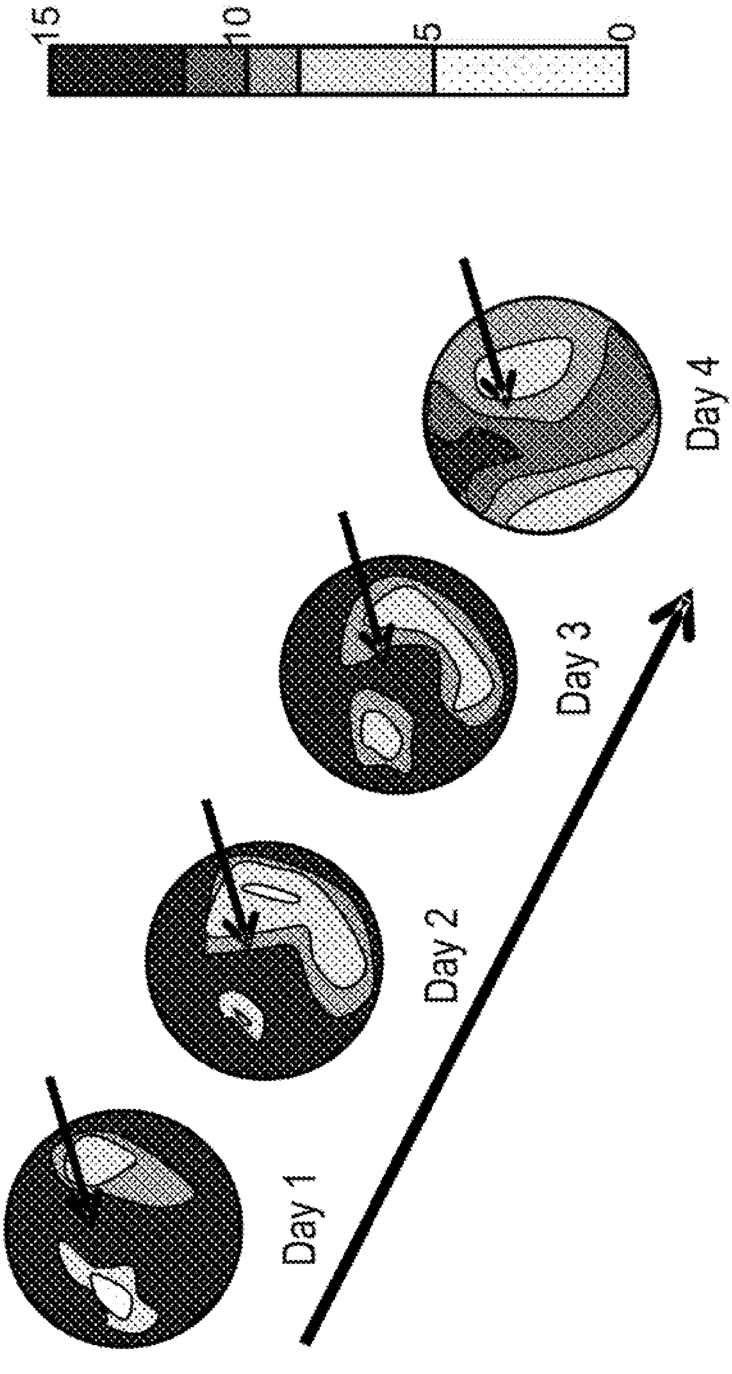

FIG. 4C

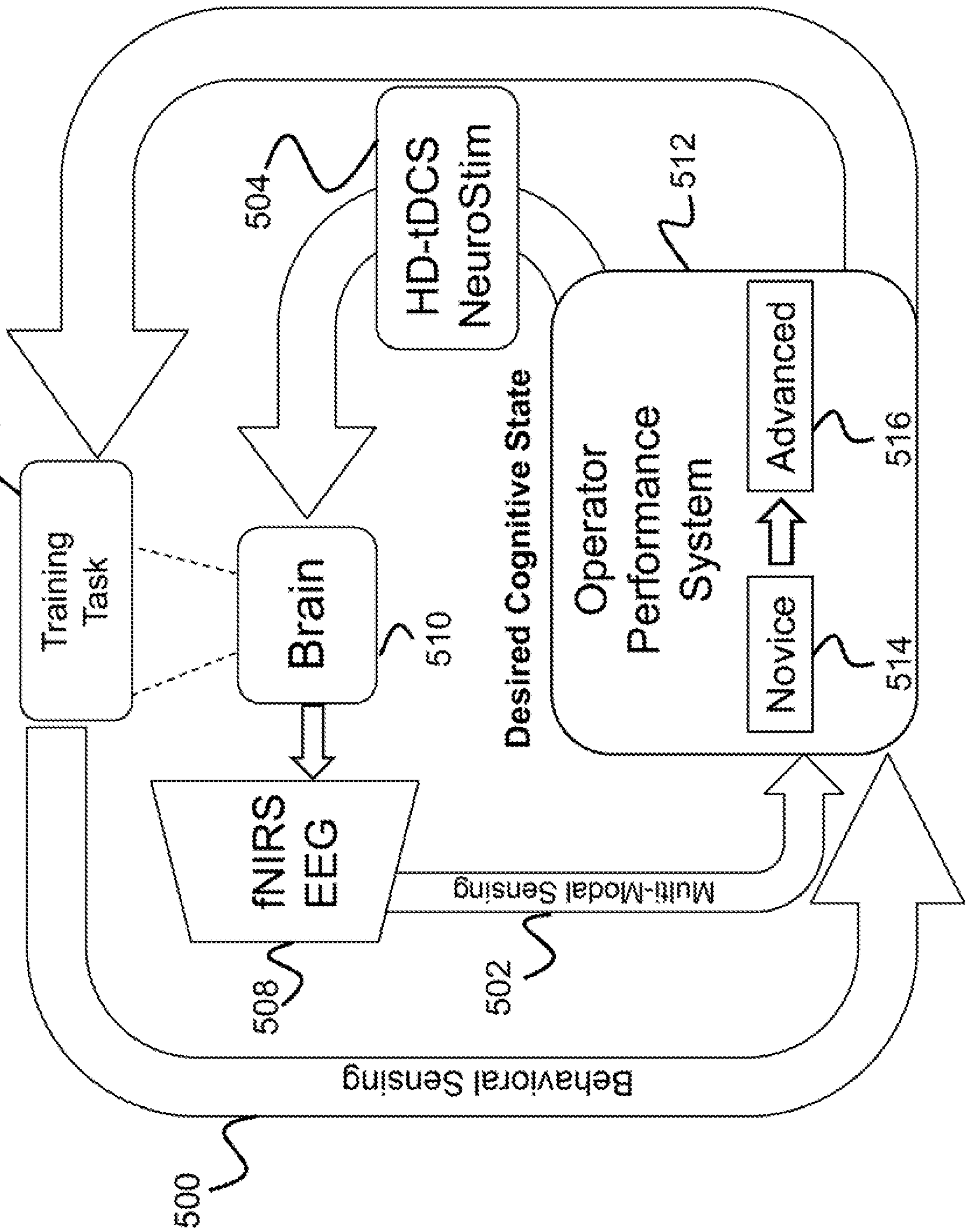
HD-tDCS
NeuroStim
504
506
Training
Task
Brain
510
Desired Cognitive State
Operator
Performance
System
512
Novice
514
Advanced
516
fNIRS
EEG
508
Multi-Modal Sensing
502
Behavioral Sensing
500

FIG. 5

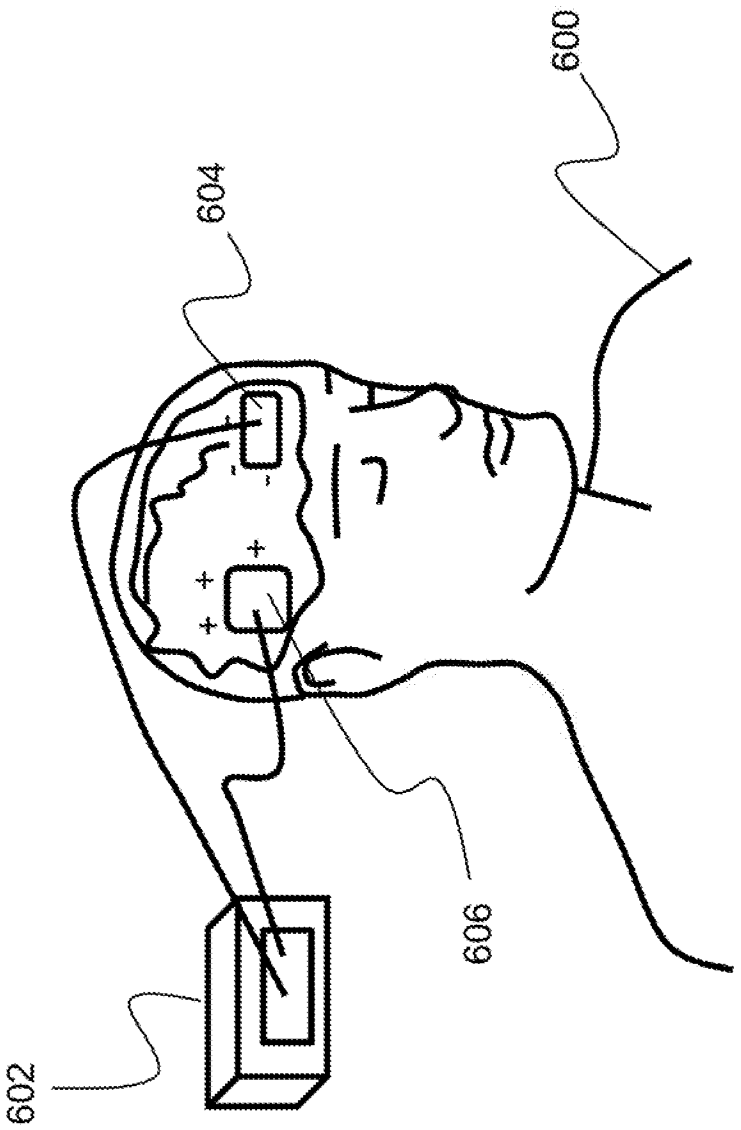

FIG. 6

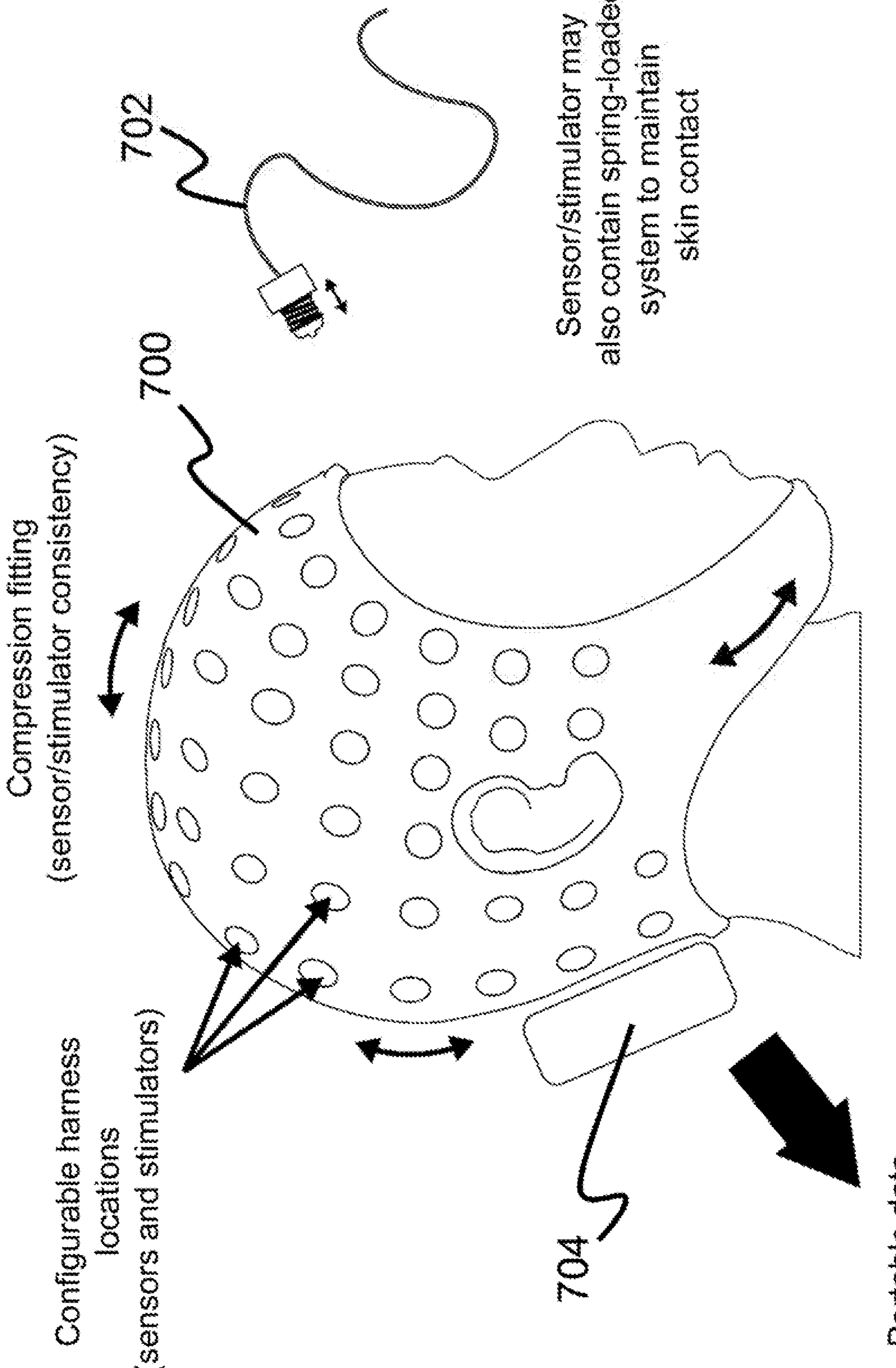
Compression fitting
(sensor/stimulator consistency)
700
702
Sensor/stimulator may
also contain spring-loaded
system to maintain
skin contact
Configurable harness
locations
(sensors and stimulators)
704
Portable data
I/O package

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/031321

A. CLASSIFICATION OF SUBJECT MATTER

A61N 1/36(2006.01)I, A61N 1/08(2006.01)I

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61N 1/36; A61B 5/04; A61B 5/048; A61B 5/0478; A61N 1/08; A61N 2/00; A61N 1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: montage, brain, neurostimulation, simultaneous, real-time, recording

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2013-192582 A1 (NEUROTREK, INC. et al.) 27 December 2013 See abstract; claims 1, 7, 11, 18; paragraph [0160].	1-18,20
A	US 2015-0005568 A1 (CALIFORNIA INSTITUTE OF TECHNOLOGY) 01 January 2015 See entire document.	1-18,20
A	US 8798707 B2 (CHOI, J. H. et al.) 05 August 2014 See entire document.	1-18,20
A	US 8831733 B2 (CALIFORNIA INSTITUTE OF TECHNOLOGY) 09 September 2014 See entire document.	1-18,20
A	WO 2005-092183 A1 (CYBERKINETICS, INC. et al.) 06 October 2005 See entire document.	1-18,20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 July 2016 (29.07.2016)	**16 August 2016 (16.08.2016)**

Name and mailing address of the ISA/KR
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/031321

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 19
because they relate to subject matter not required to be searched by this Authority, namely:
Claim 19 pertains to methods for treatment of the human body and thus relate to a subject-matter which this International Searching Authority is not required to search under PCT Article 17(2)(a)(i) and PCT Rule 39.1(iv).

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/031321

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2013-192582 A1	27/12/2013	EP 2863986 A1	29/04/2015
		US 2015-0174418 A1	25/06/2015
US 2015-0005568 A1	01/01/2015	None	
US 8798707 B2	05/08/2014	KR 10-1007558 B1	14/01/2011
		KR 10-2010-0039617 A	16/04/2010
		US 2011-0224528 A1	15/09/2011
		WO 2010-041794 A1	15/04/2010
US 8831733 B2	09/09/2014	US 2014-0018882 A1	16/01/2014
WO 2005-092183 A1	06/10/2005	EP 1734860 A1	27/12/2006
		US 2005-0203366 A1	15/09/2005