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(54) **PHYSIOLOGICAL PARAMETER MEASUREMENT AND FEEDBACK SYSTEM**

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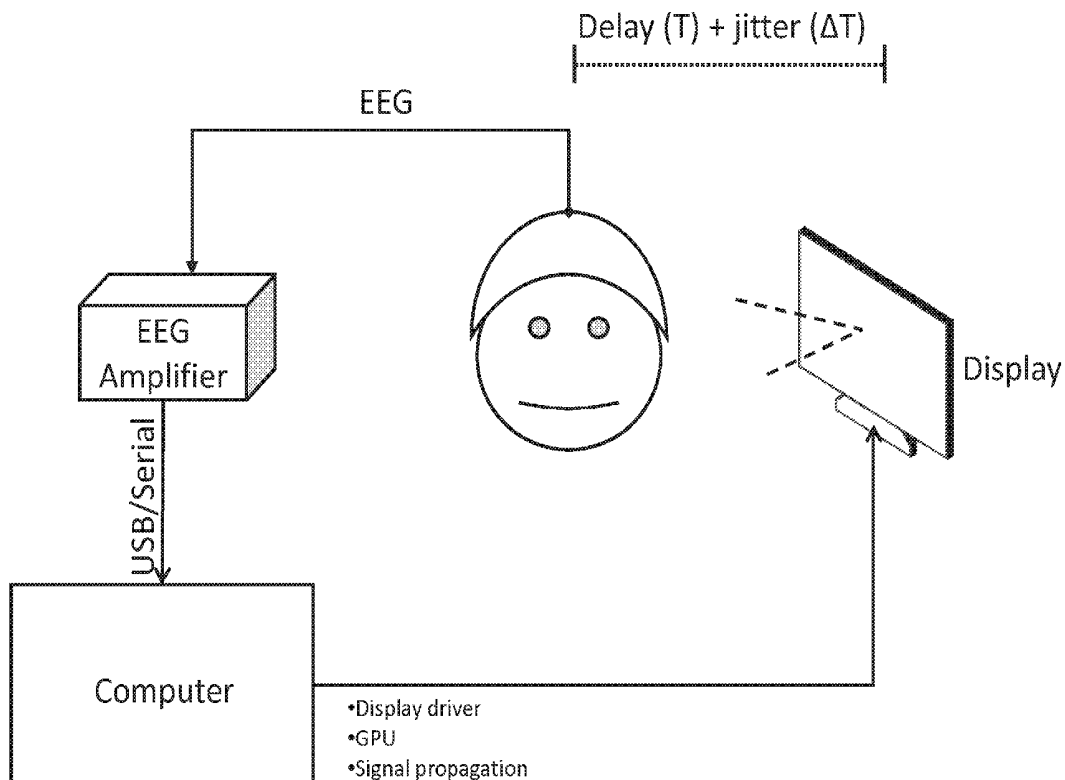
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(57) **ABSTRACT**

A physiological parameter measurement and motion tracking system including a control system, a sensing system, and a stimulation system is disclosed. The sensing system includes one or more physiological sensors including at least brain electrical activity sensors. The stimulation system includes one or more stimulation devices including at least a visual stimulation system. The control system includes an acquisition module configured to receive sensor signals from the sensing system, and a control module configured to process the signals from the acquisition module and control the generation of stimulation signals to one or more devices of the stimulation system. The control system further includes a clock module and the control system is configured to receive content code signals from the stimulation system and to time stamp the content code signals and the sensor signals with a clock signal from the clock module.



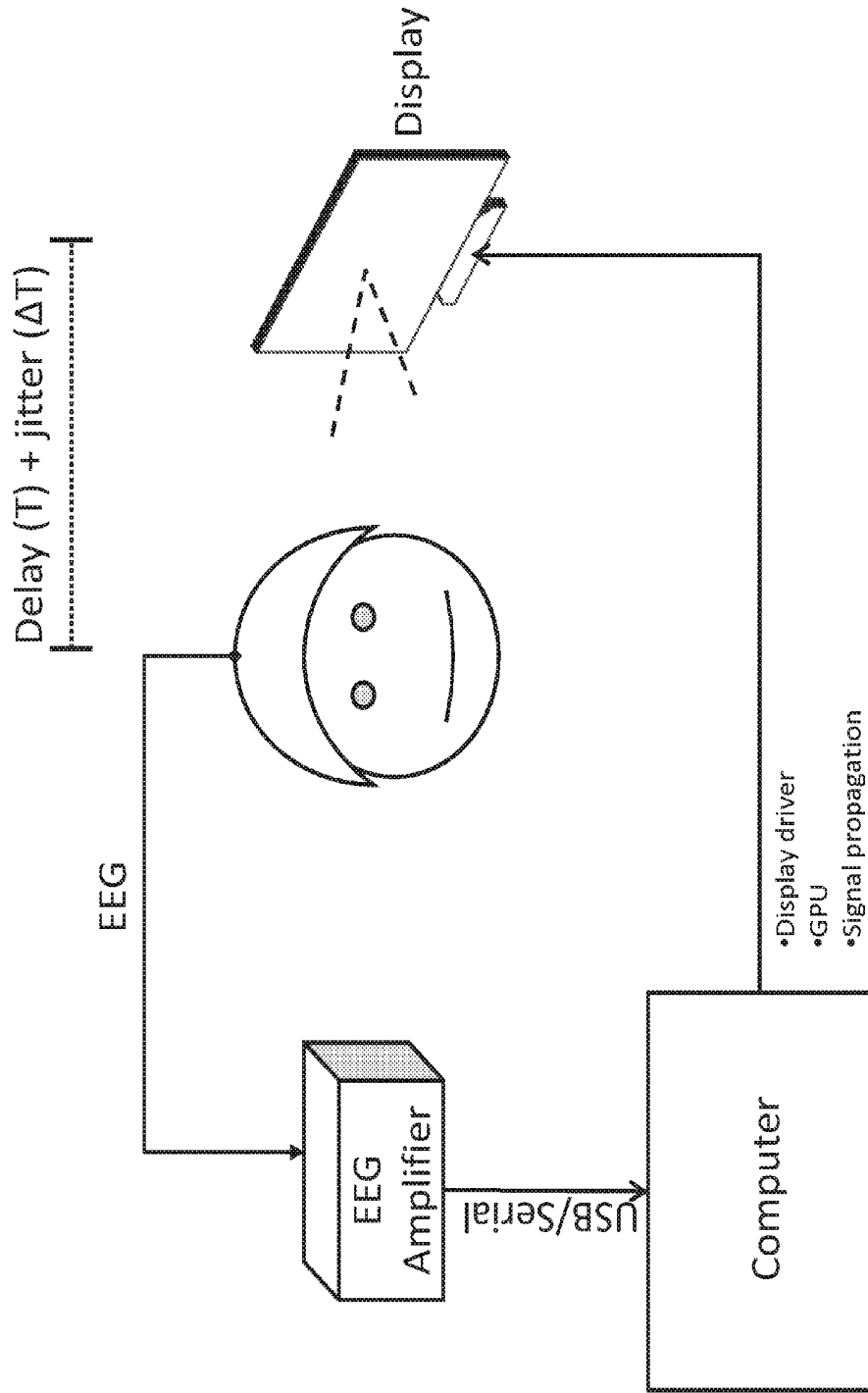


Fig. 1a

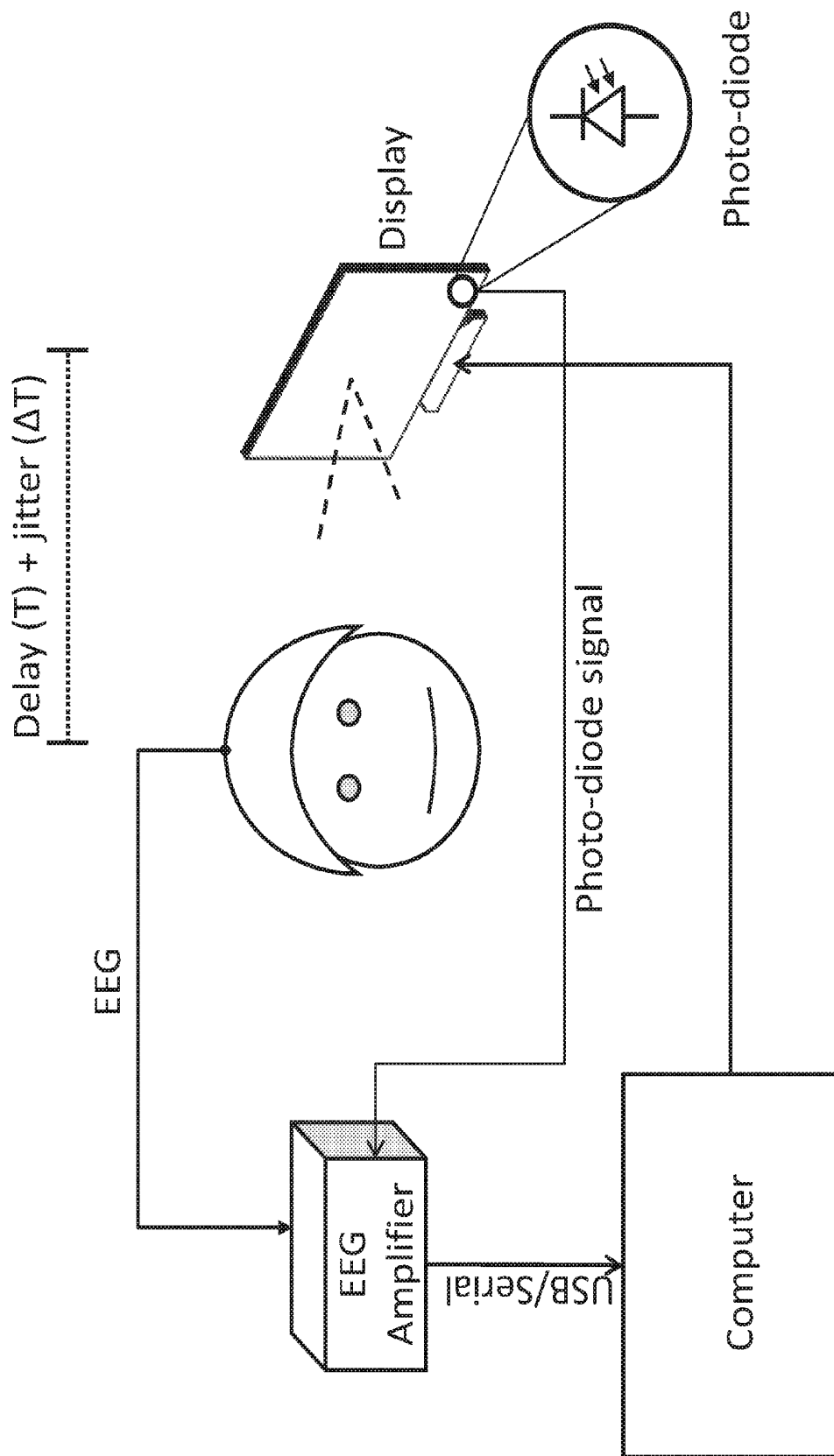


Fig. 1b

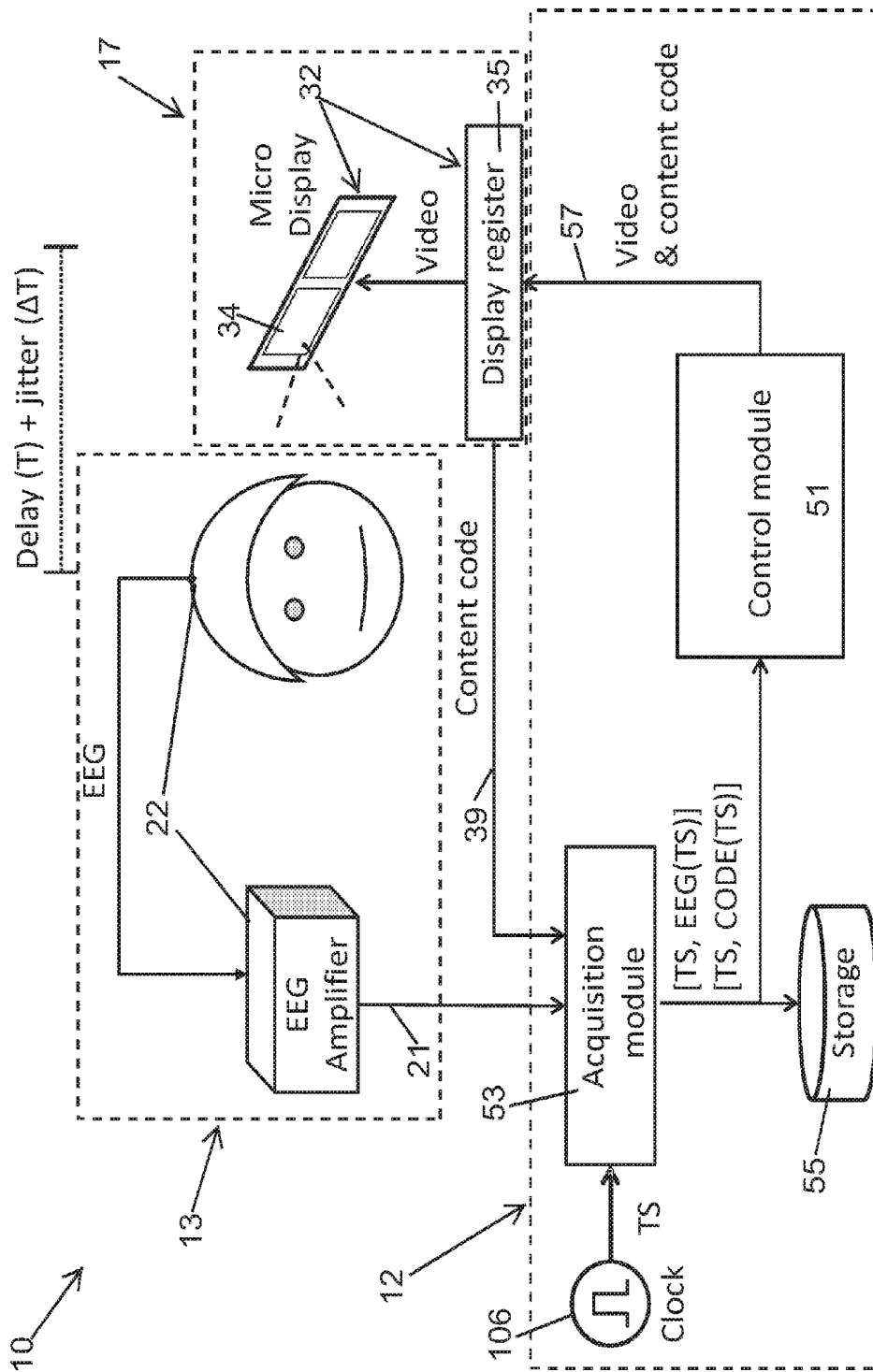


Fig. 2a

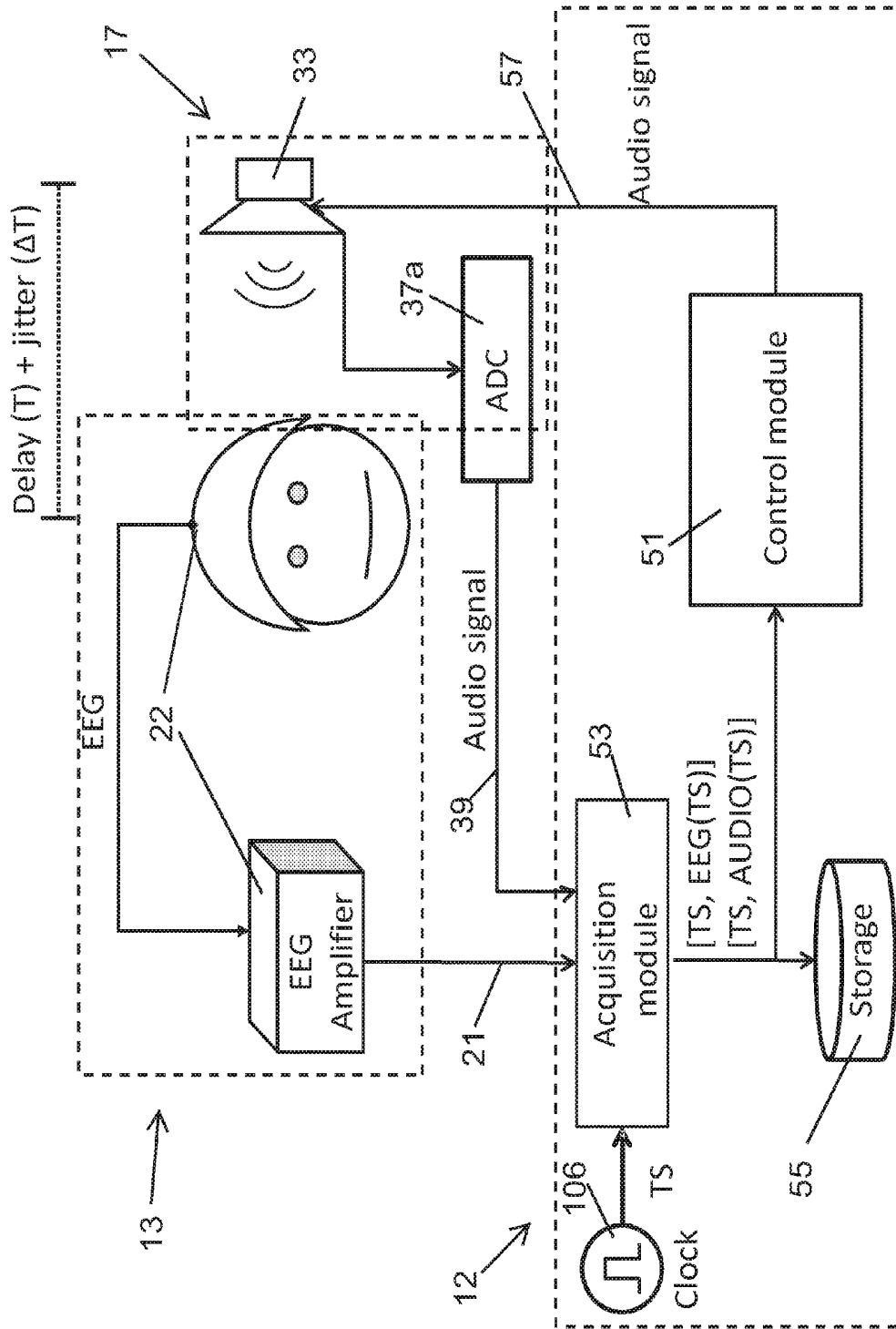


Fig. 2b

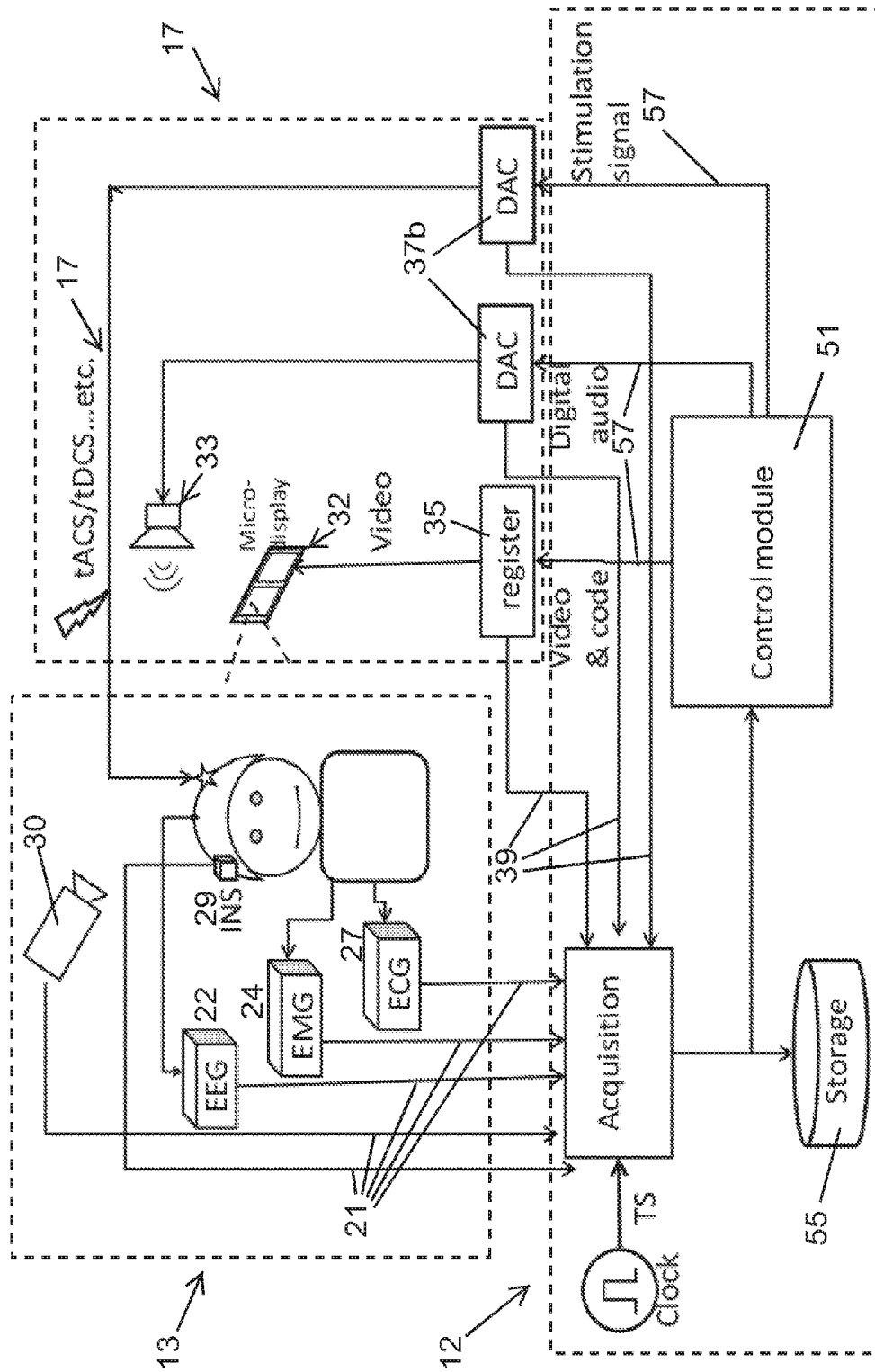
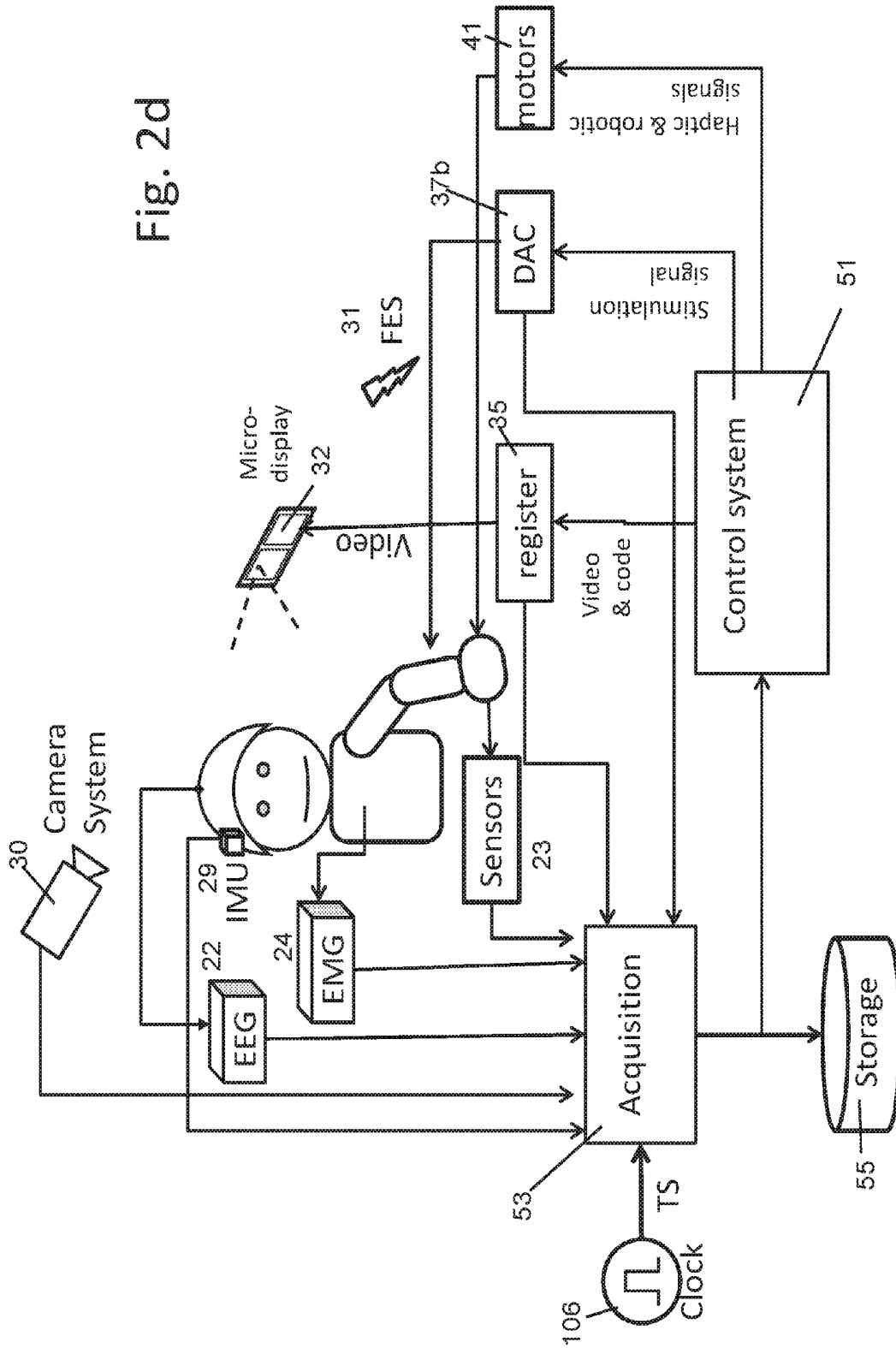
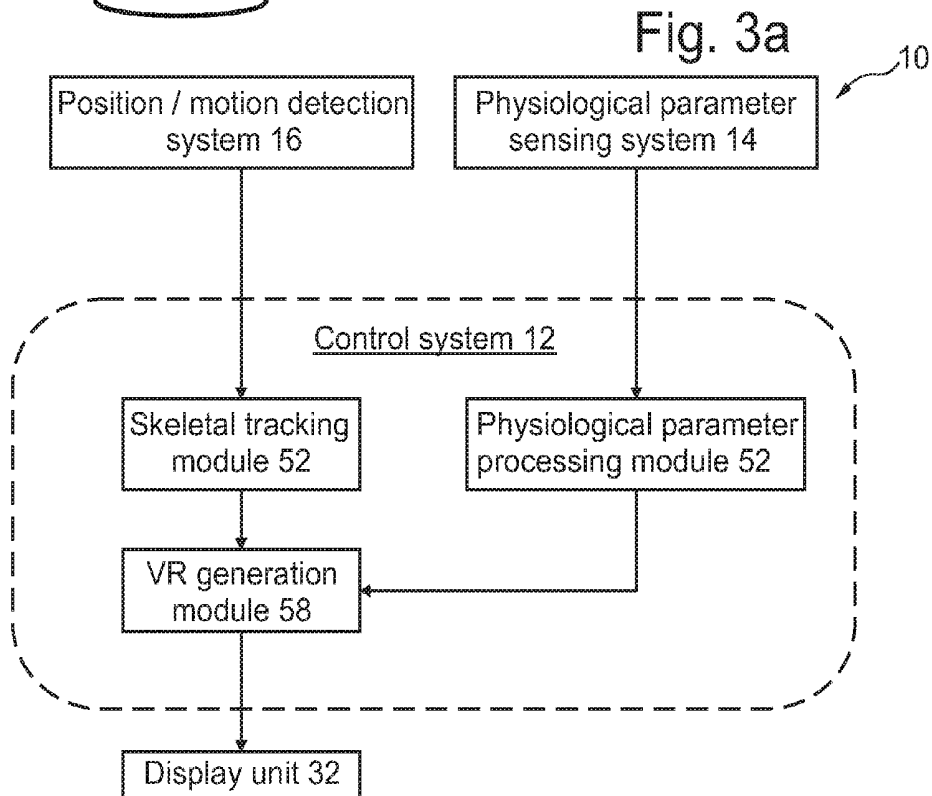
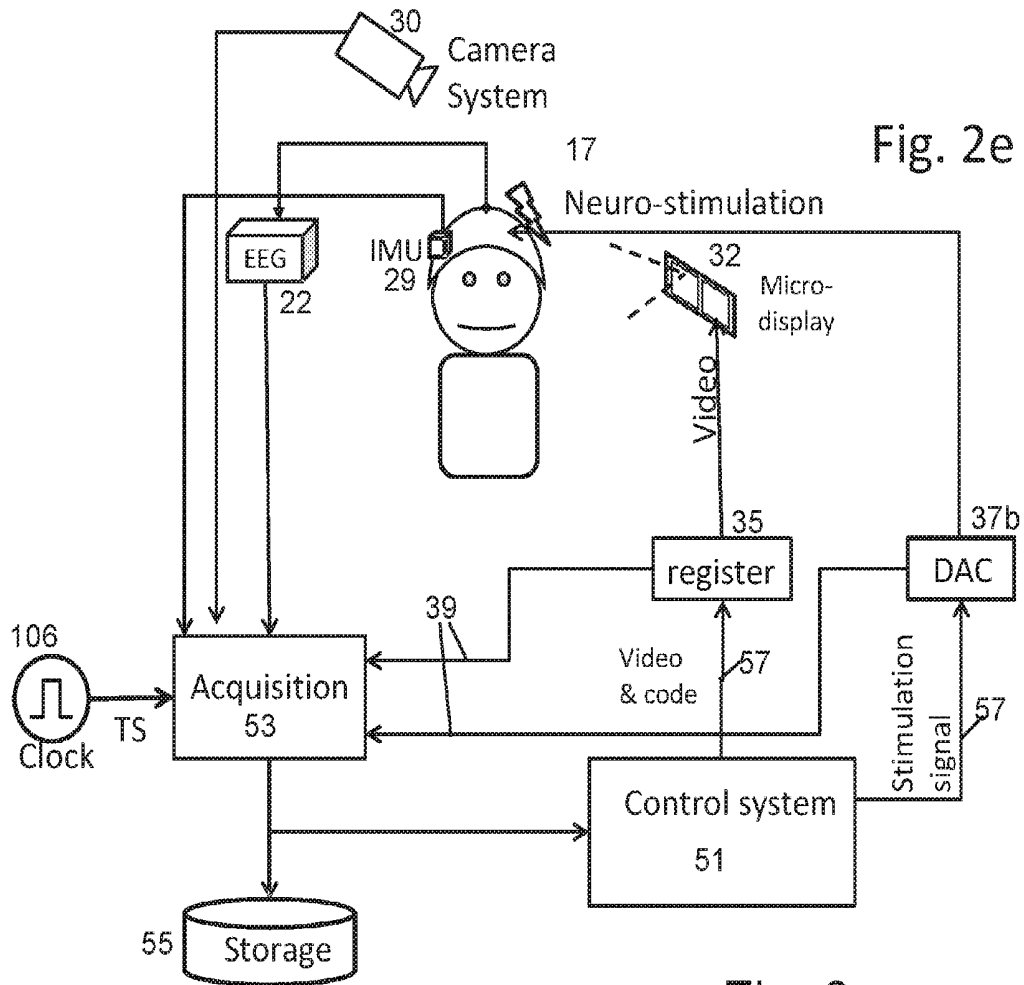


Fig. 2c





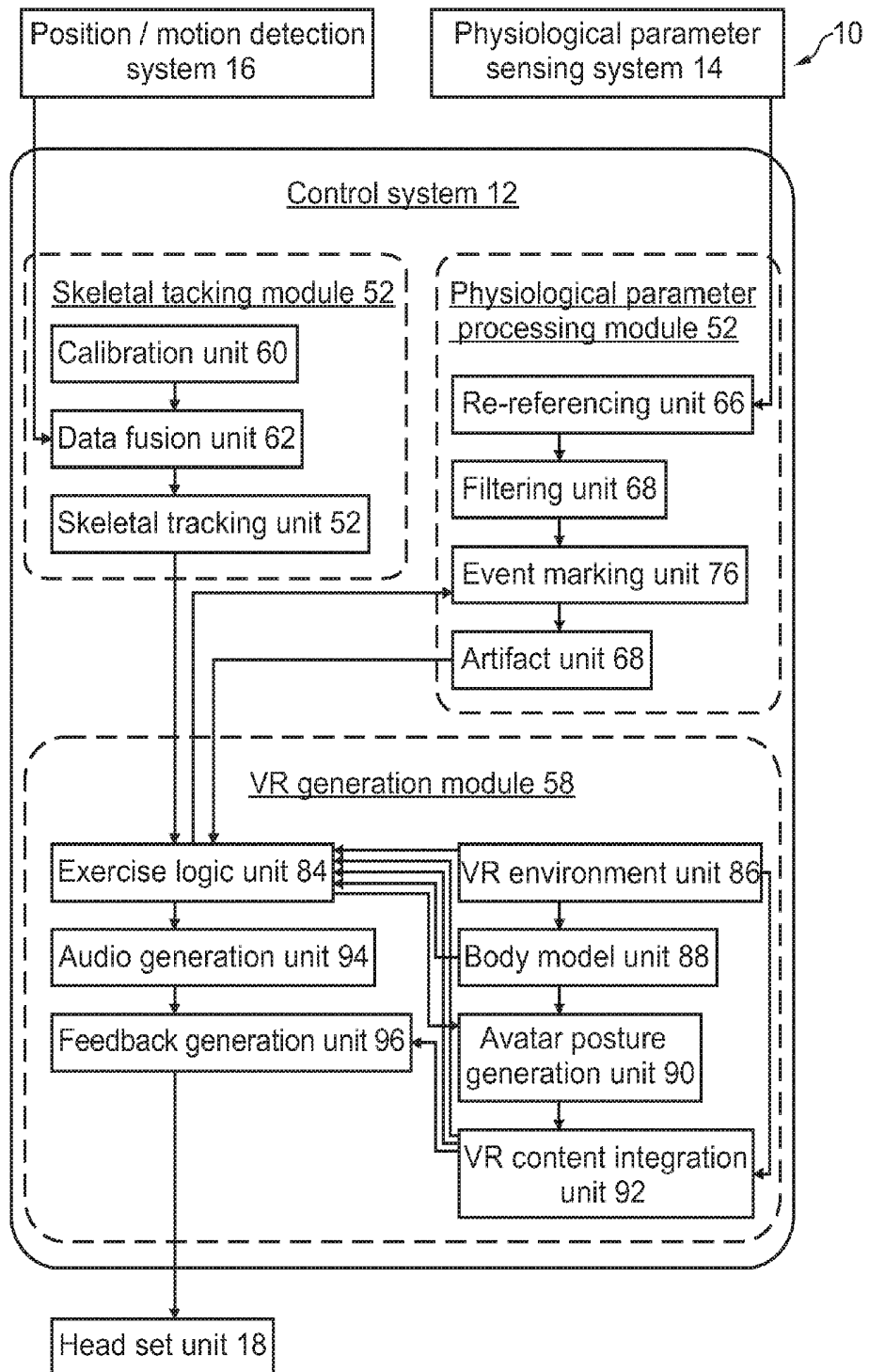


Fig. 3b

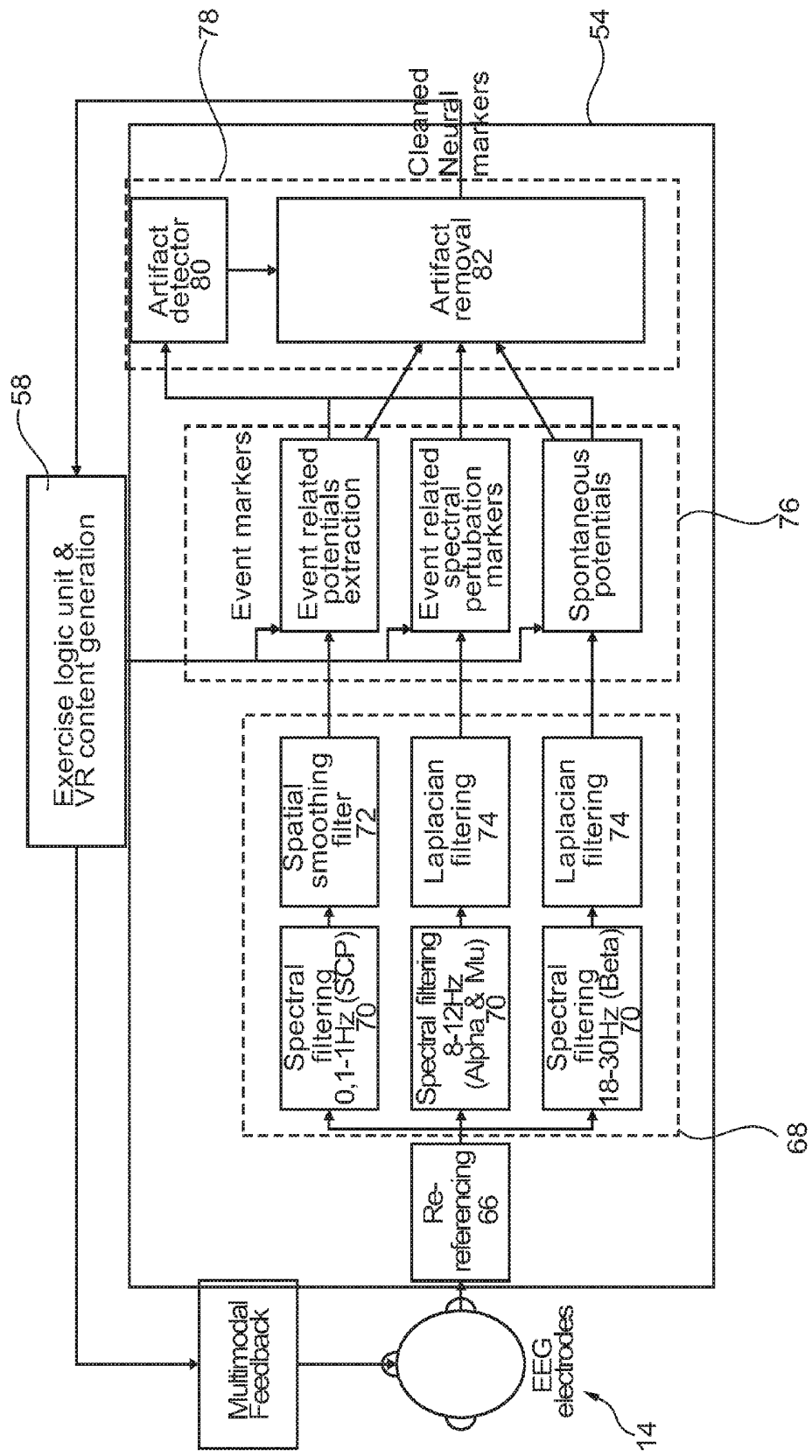
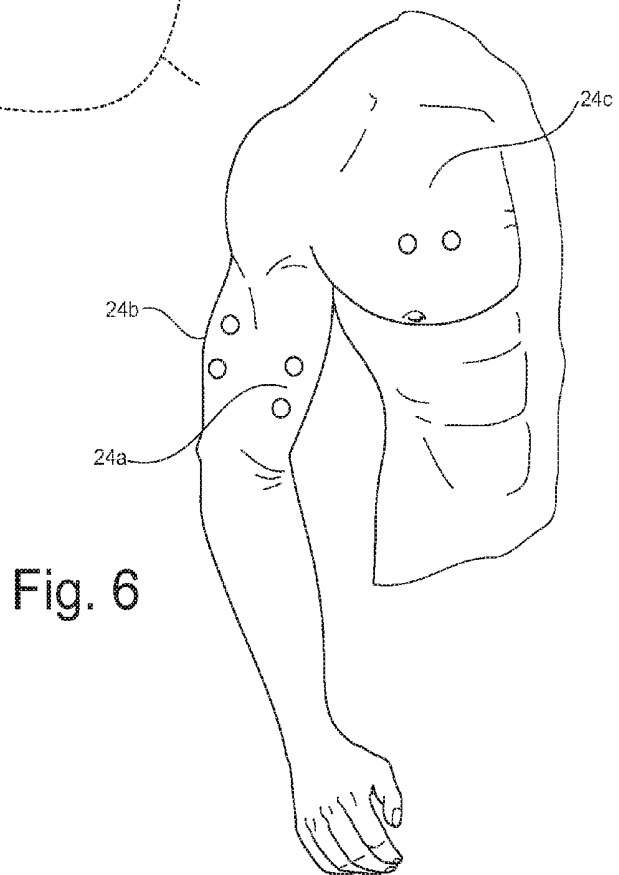
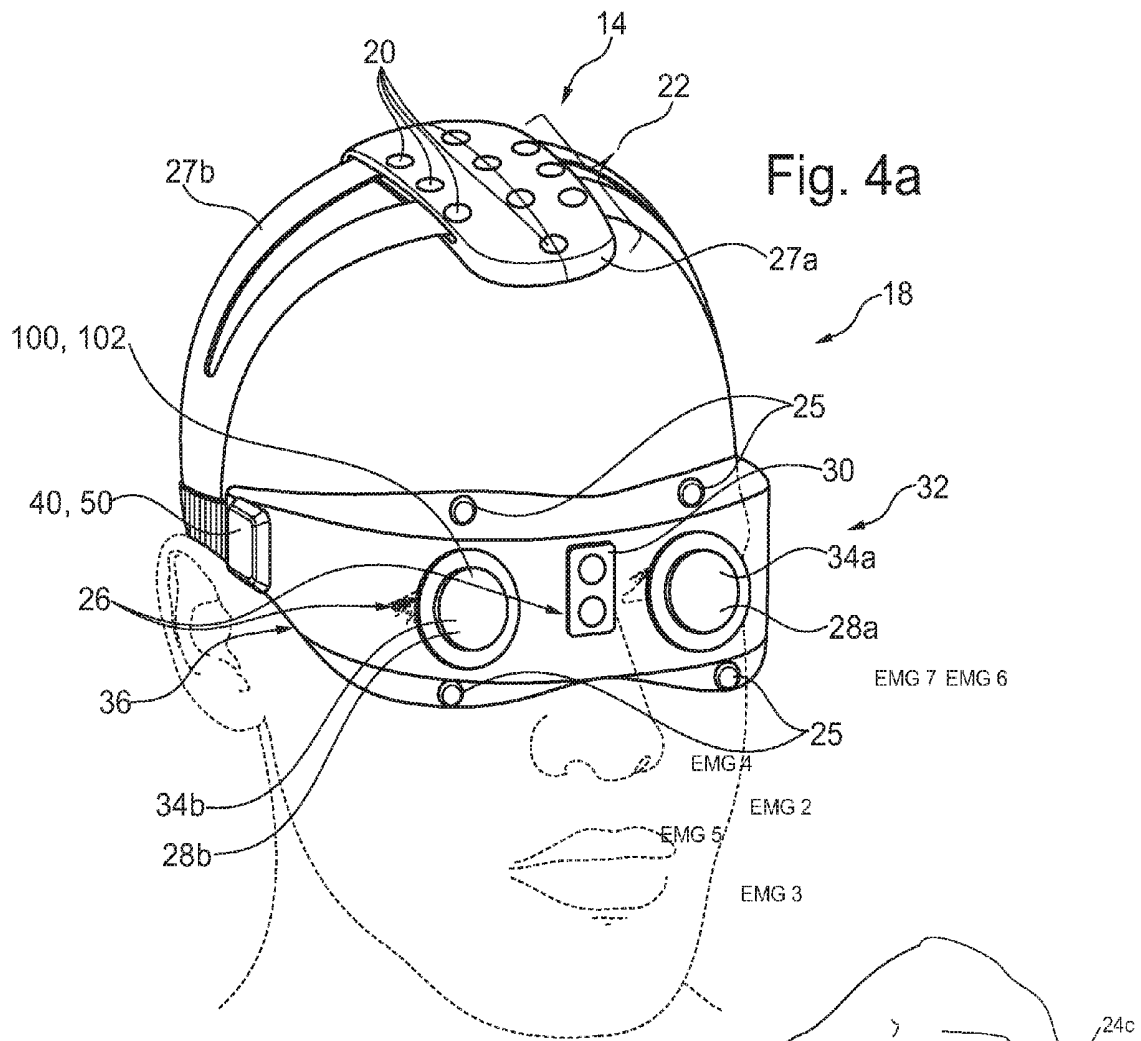
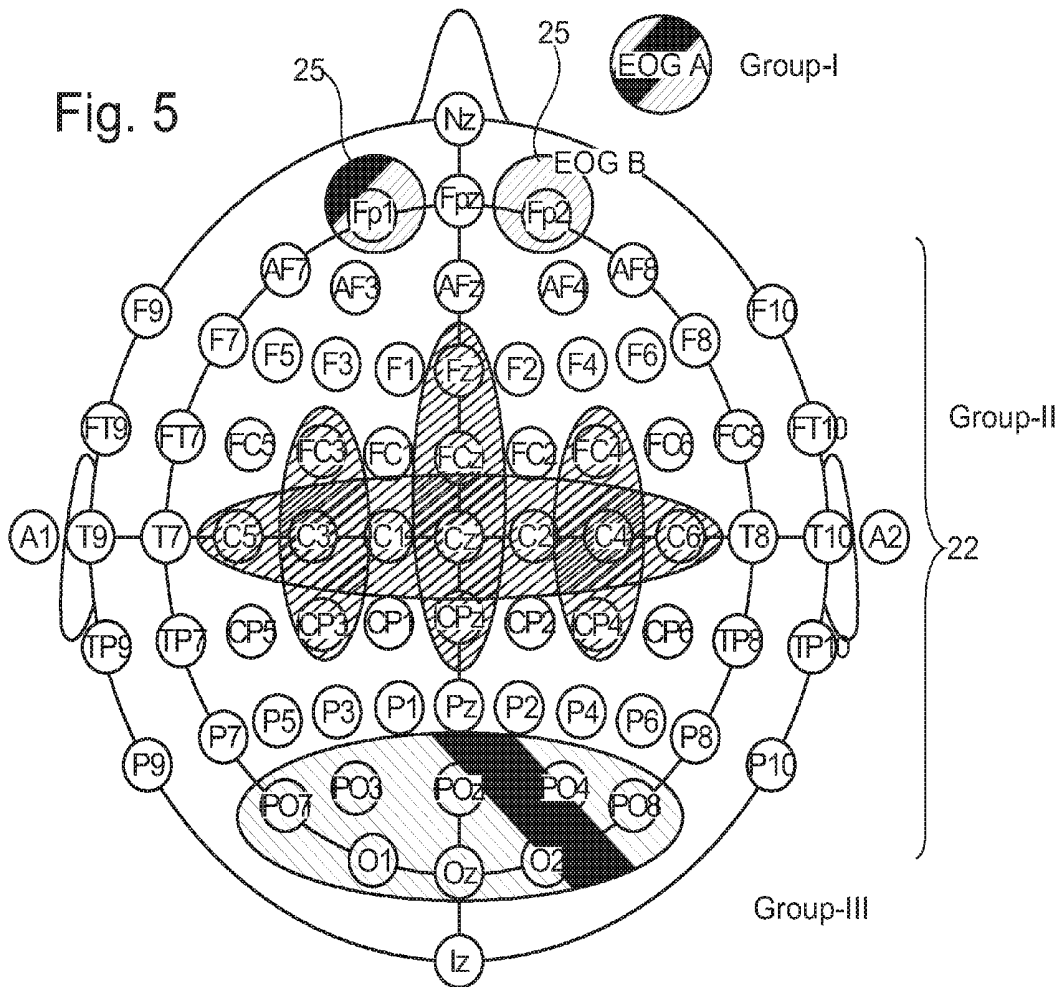
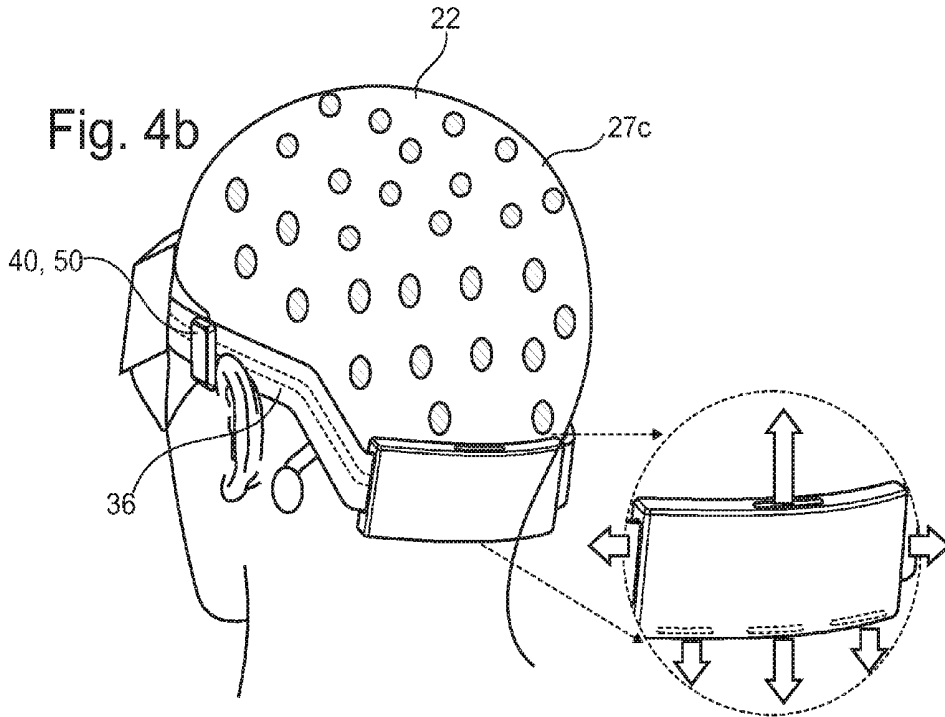


Fig. 3c





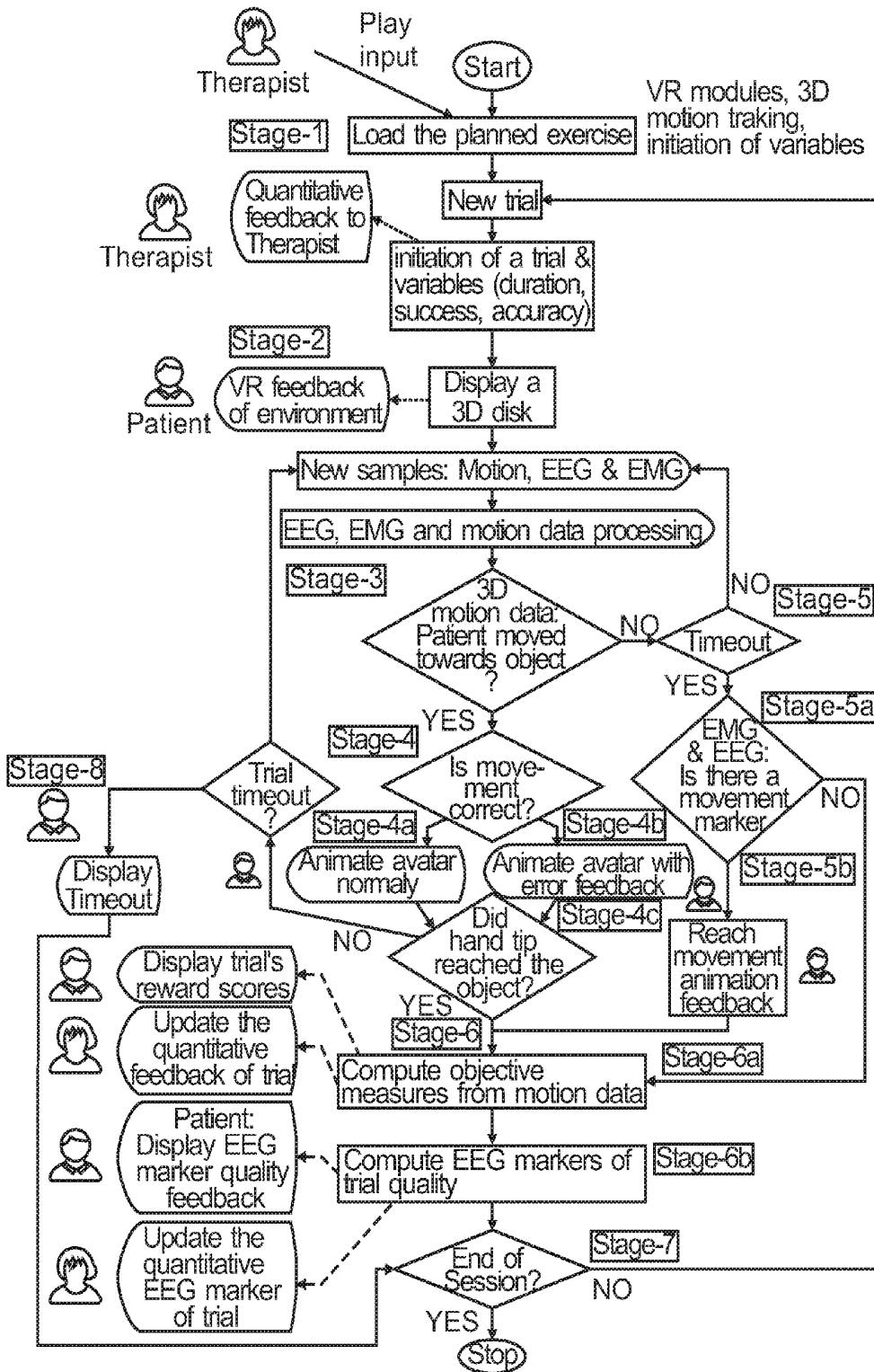
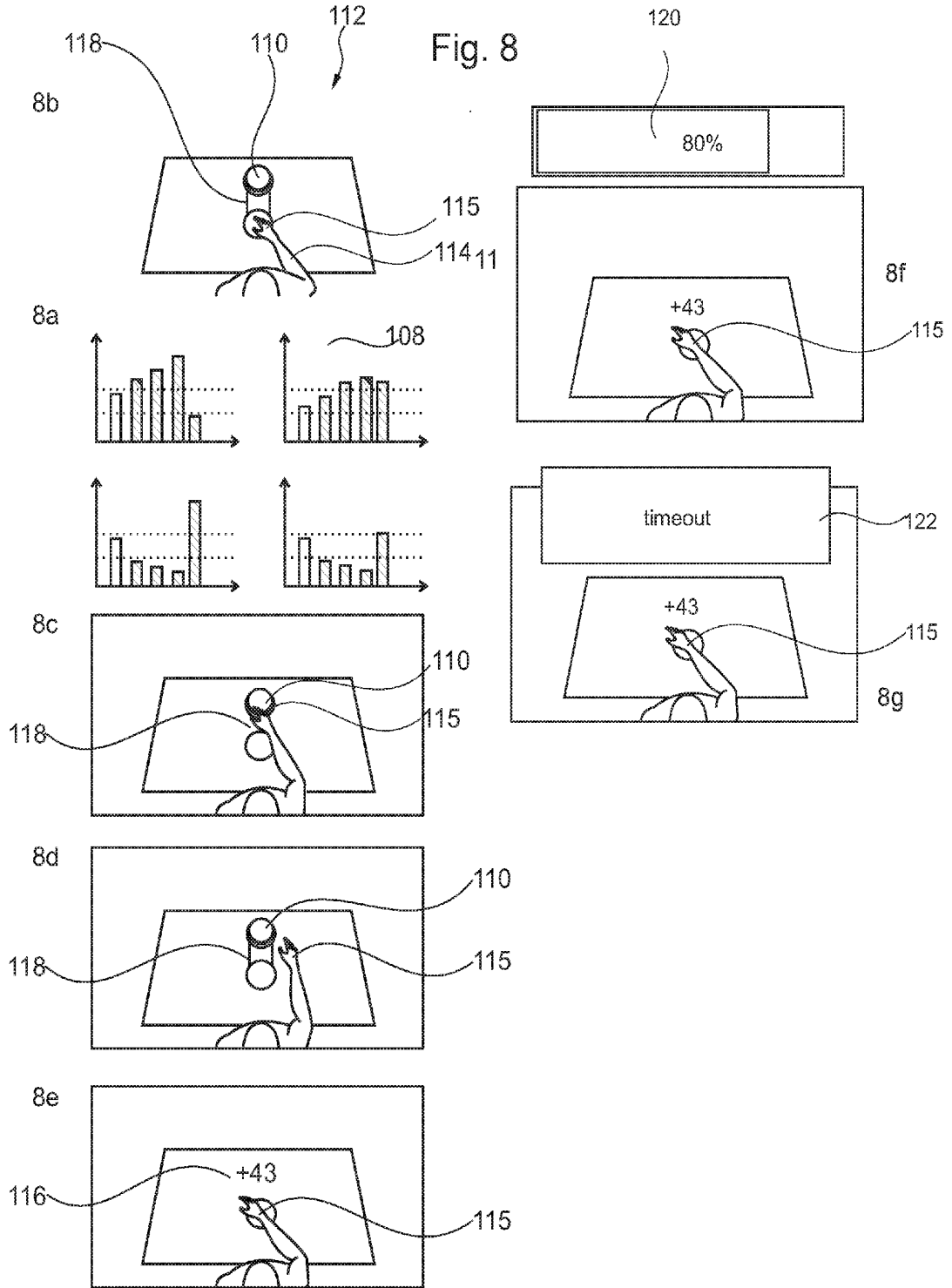


Fig. 7



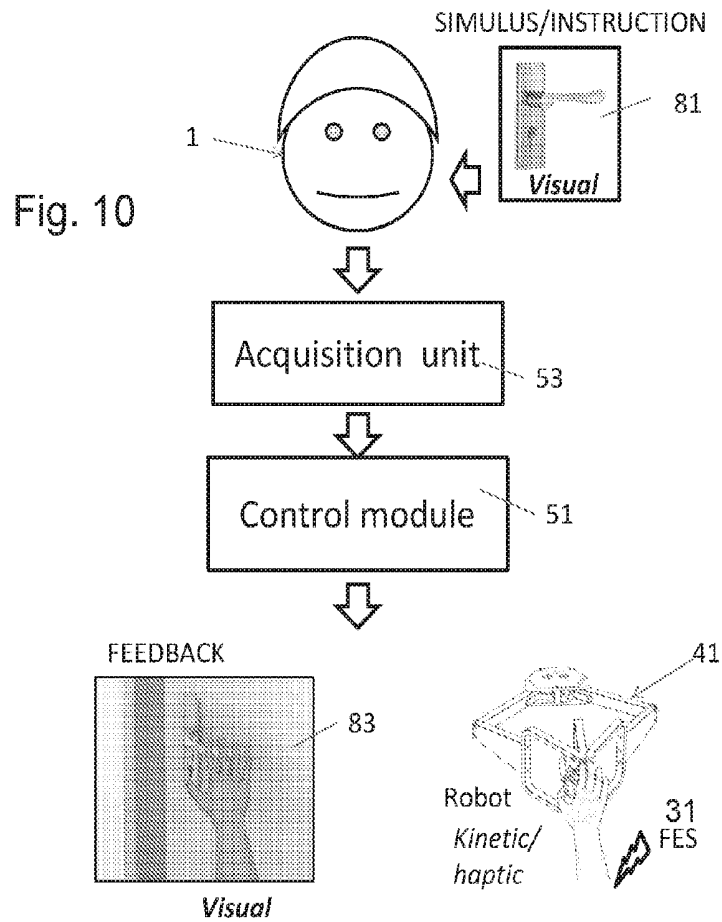
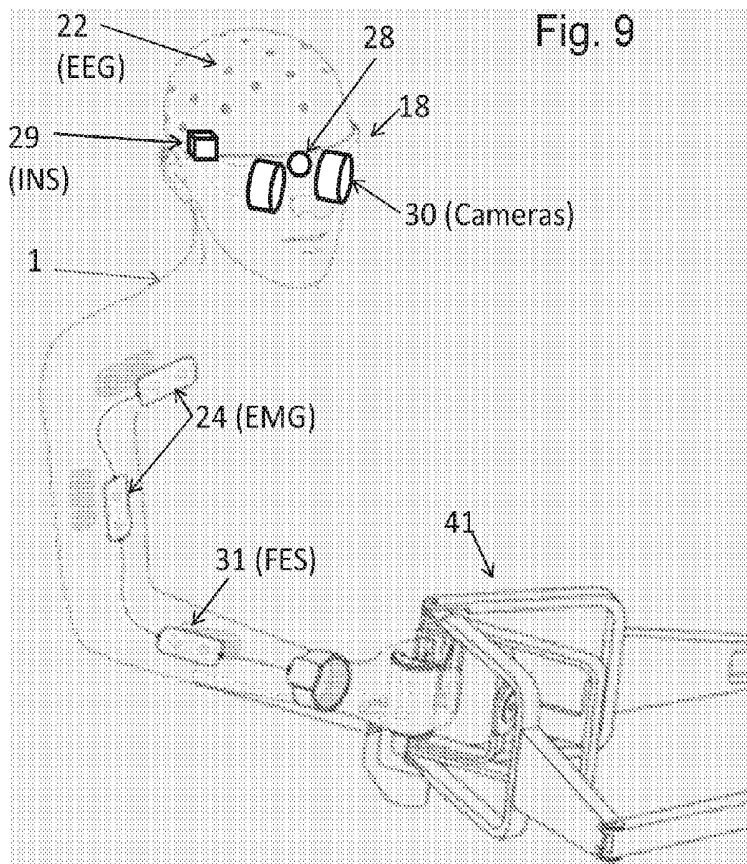
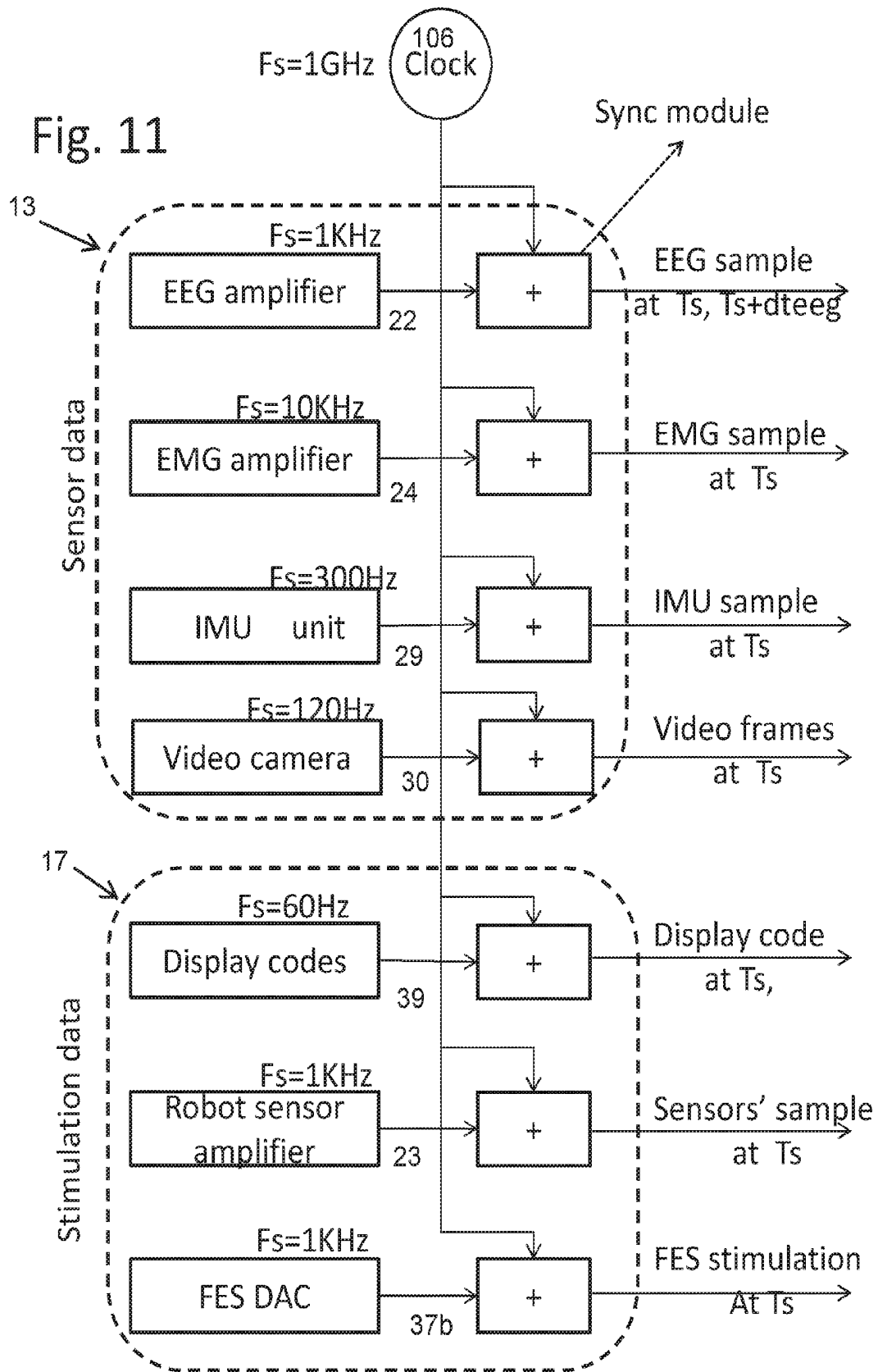


Fig. 11



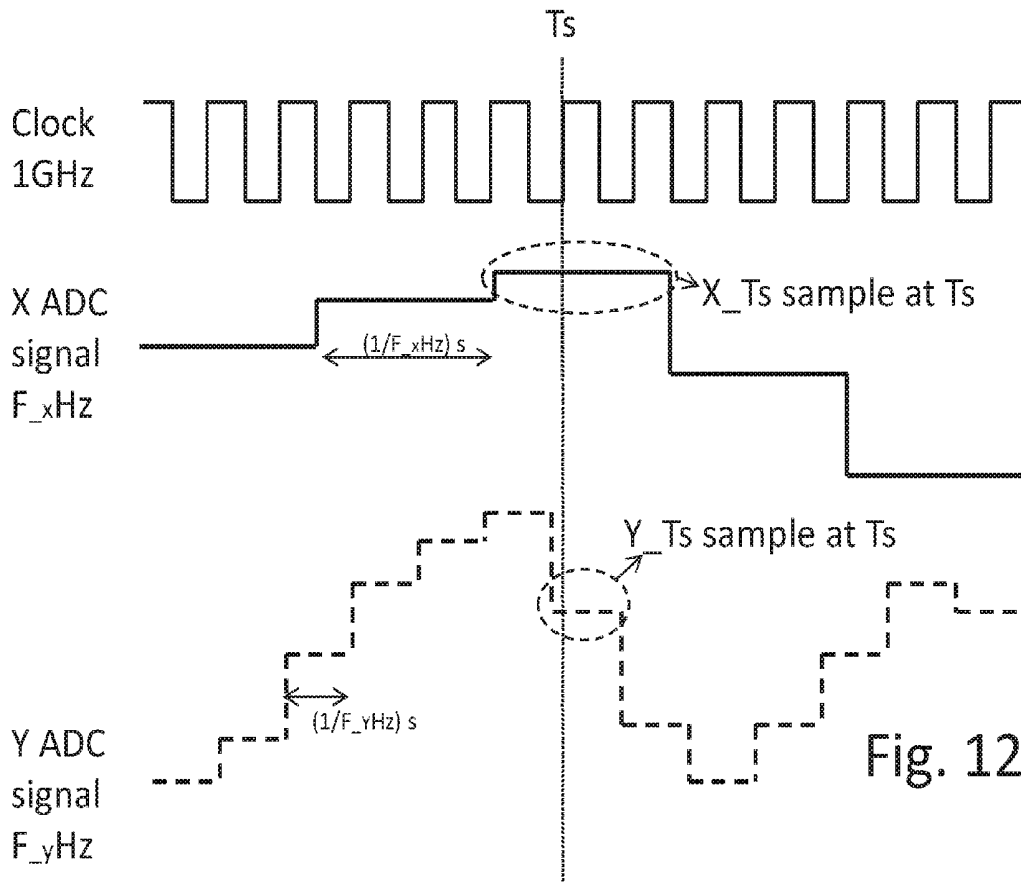


Fig. 12

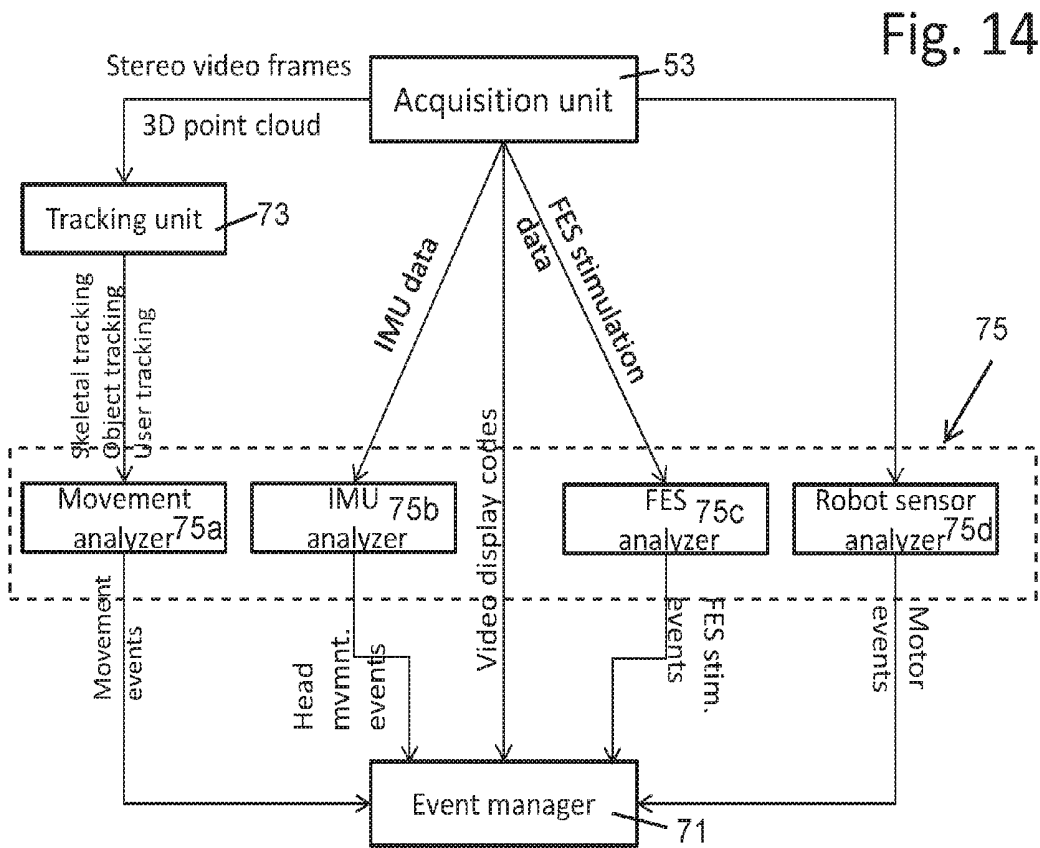


Fig. 14

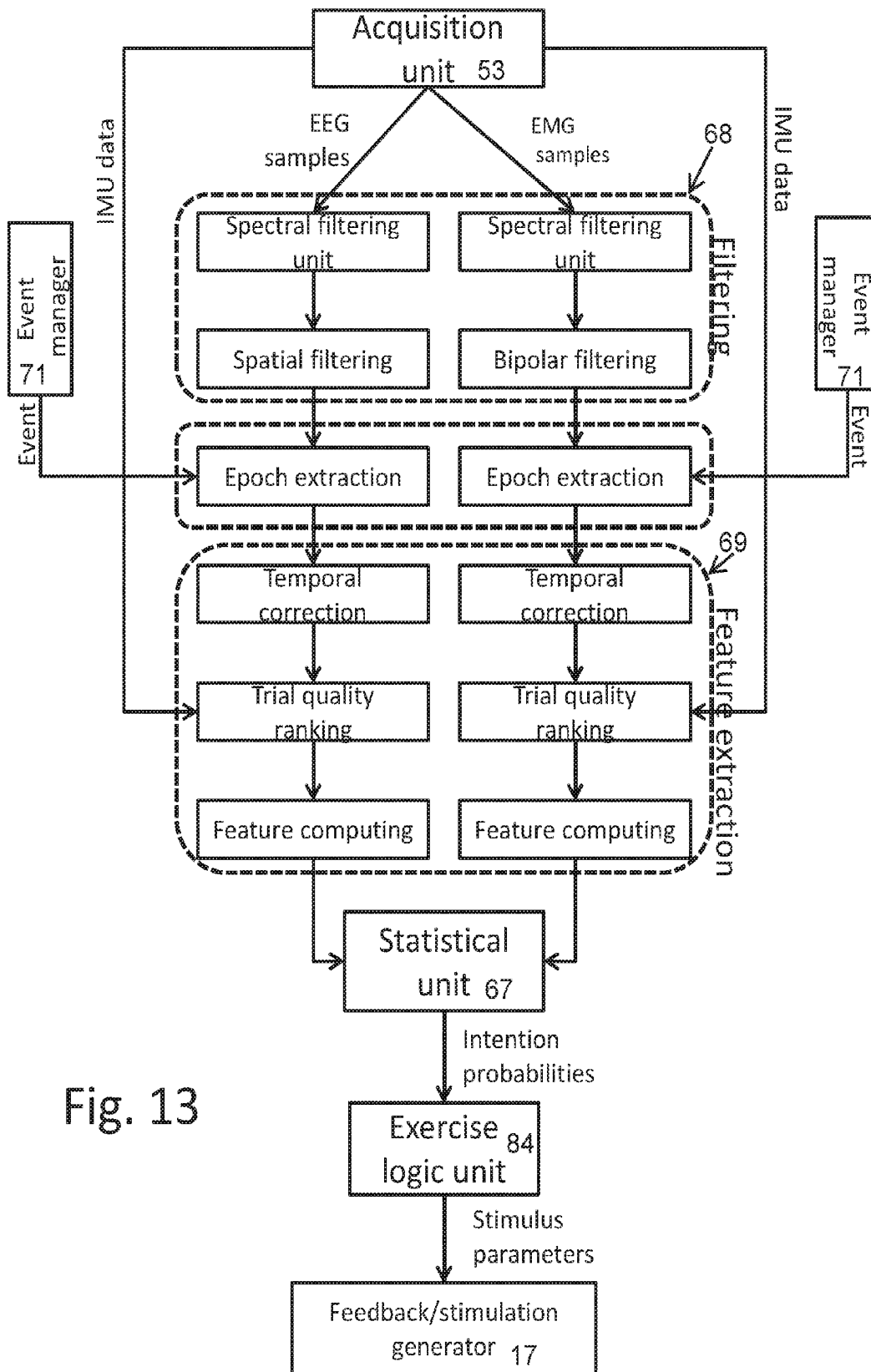


Fig. 13

PHYSIOLOGICAL PARAMETER MEASUREMENT AND FEEDBACK SYSTEM

TECHNICAL FIELD

[0001] The present invention relates generally to a system to measure a physiological parameter of a user in response to a stimulus, and to provide feedback to the user. One of the specific fields of the present invention relates to a system to measure a physiological parameter of a user to monitor cortical activity in response to a displayed movement of a body part, wherein the displayed movement is displayed to the user in a virtual or augmented reality. The system may be used to treat/aid recovery from neurological injury and/or neurological disease of the user after the user experiences a stroke. However, the system may be used in other applications such as gaming, or learning of motor skills that may be required for a sports related or other activity.

DESCRIPTION OF RELATED ART

[0002] Cerebrovascular diseases are conditions that develop due to problems with the blood vessels inside the brain and can result in a stroke. According to the World Health Organization around fifteen million people suffer stroke each year worldwide. Of these, around a third die and another third are permanently disabled. The neurological injury which follows a stroke often manifests as hemiparesis or other partial paralysis of the body.

[0003] Accordingly, the area of rehabilitation of stroke victims has been the subject of various research studies. Current rehabilitation procedures are often based on exercises performed by the impaired body part, the movement of which is tracked in real-time to provide feedback to the patient and/or a medical practitioner. Computer controlled mechanical actuation systems have been used to track a position of, and force applied by, a body part such an arm of a patient as a predetermined movement pattern is executed by the patient. To reduce patient fatigue such systems can support the patient, for example by actuators which can assist during execution of the movement. A disadvantage of such devices is that they can be complicated and expensive. Also, conventional systems are based on tracking actual movements and are therefore not adapted for diagnosis or treatment in the very early stages after an occurrence of stroke where movement is impaired or very limited. They may also present a risk to the patient if, for example, the body part is moved too quickly or if part of the heavy actuation equipment falls on the patient. They are also not particularly portable, which generally prohibits home use and use in a hospital environment, and can also be difficult to adapt to the rehabilitation requirements of a particular patient since the range of permitted movements is often confined by a mechanical system.

[0004] US 2011/0054870 discloses a VR based system for rehabilitation of a patient, wherein a position of a body part of a patient is tracked by a motion camera. Software is used to create a motion avatar, which is displayed to the patient on a monitor. In an example, if a patient moves only a right arm when movement of both arms are prescribed, then the avatar can also display motion of the left arm.

[0005] A similar system is disclosed in 'The design of a real-time, multimodal biofeedback system for stroke patient rehabilitation', Chen, Y et al., ACM International Conference on Multimedia, 23 Oct. 2006, wherein infra-red cameras are used to track a 3-dimensional position of markers on an arm

of a patient. Using a monitor, in VR a position of the arm of the patient is displayed as predefined movement patterns are completed, such as the grasping of a displayed image.

[0006] A drawback of certain VR based systems is that they only measure the response of the body part to an instructed task. Accordingly, they do not directly measure cortical activity in response to a displayed movement of a body part, only the way in which an area of the brain can control a body part. This may lead to areas of the brain being treated other than those which are damaged, or at least an inability to directly monitor a particular area of the brain. Moreover, the patient is not fully immersed in the VR environment since they look to a separate monitor screen to view the VR environment.

[0007] In WO 2011/123059 and US 2013/046206, VR based systems with brain monitoring and motion tracking are described, the main drawback of known systems being that they do not reliably nor accurately control synchronization between stimulation or action signals and brain activity signals, which may lead to incorrect or inaccurate processing and read out of brain response signals as a function of stimuli or actions.

[0008] In conventional systems, in order to synchronize multimodal data (including physiological, behavioral, environmental, multimedia and haptic, among others) with stimulation sources (e.g., display, audio, electrical or magnetic stimulation) several independent, dedicated (i.e. for each data source) units are connected in a decentralized fashion, meaning that each unit brings its inherent properties (module latencies and jitters) into the system. Additionally, these units may have different clocks, therefore acquiring heterogeneous data with different formats and at different speeds. In particular, there is no comprehensive system that comprises stereoscopic display of virtual and/or augmented reality information, where some content may be related to some extent to the physiological/behavioral activity of any related user and registered by the system, and/or any information coming from the environment. Not fulfilling the above-mentioned requirements may have negative consequences in various cases in different application fields, as briefly mentioned in the following non-exhaustive list of examples:

[0009] a) Analysis of neural responses to stimulus presentation is of importance in many applied neuro-science fields. Current solutions compromise the synchronization quality, especially in the amount of jitter between the measured neural signal (e.g., EEG) and the simulation signal (e.g., display of a cue). Due to this, not only the signal to noise ratio of acquired signals is lowered but also limit the analysis to lower frequencies (typically less than 30 Hz). A better synchronization ensuring least jitter would open up new possibilities of neural signals exploration in the higher frequencies as well as precise (sub millisecond) timing based stimulation (not only non-invasive stimulation, but also invasive stimulation directly at the neural cite and subcutaneous stimulation).

[0010] b) Virtual reality and body perception: If the synchronization between the capture of user's movements and their mapping onto a virtual character (avatar) that reproduces the movement in real time is not achieved, then, the delayed visual feedback of the performed movement via a screen or head-mounted display will give to the user the feeling that he/she is not the author of such movement. This may have important consequences in motor rehabilitation, where patients are trained to

recover mobility, as well as for training or execution of extremely dangerous operation as deactivating a bomb by manipulating a robot remotely.

[0011] c) Brain-computer interfaces: If the synchronization between motor intention (as registered by electroencephalographic data), muscle activity and the output towards a brain body-controlled neuroprosthesis fails, it is not possible to link motor actions with neural activation, preventing knowledge about the neural mechanisms underlying motor actions necessary to successfully control the neuroprosthesis.

[0012] d) Neurological examinations: The spectrum of electroencephalographic (EEG) data may reach up to 100 Hz for superficial, non-invasive recordings. In such a case, the time resolution is in the range of tens of milliseconds. If the synchronization between EEG and events evoking specific brain responses (e.g. P300 response for a determined action happening in virtual environments) fails, then it is not possible to relate the brain response to the particular event that elicited it.

[0013] (e) Functional re-innervation training to use a sophisticated neuroprosthetic device by an amputee patient: A hybrid brain computer interface (BCI) system coupled with FES and sub-cutaneous stimulation may be used in elaborating and optimizing functional re-innervation into residual muscles around stumps or other body parts of an amputees. For optimal results, it is important to have high quality synchronization between the sensor data and stimulation data for generating precise stimulation parameters.

SUMMARY OF THE INVENTION

[0014] An objective of the invention is to provide a physiological parameter measurement and motion tracking system that provides a user with a virtual or augmented reality environment that can be utilized to improve the response of the cognitive and sensory motor system, for instance in the treatment of brain damage or in the training of motor skills.

[0015] It would be advantageous to provide a physiological parameter measurement and motion tracking system (e.g., movements head and body) that ensures accurate real time integration of measurement and control of physiological stimuli and response signals.

[0016] It would be advantageous to provide a physiological parameter measurement and motion tracking system that can generate a plurality of stimuli signals of different sources (e.g. visual, auditive, touch sensory, electric, magnetic . . .) and/or that can measure a plurality of physiological response signals of different types (e.g. brain activity, body part movement, eye movement, galvanic skin response.).

[0017] It would be advantageous to reduce the number of cables of the system.

[0018] It would be advantageous to reduce electrical interference among the input modules (measurements) and output modules (stimuli) and system operation.

[0019] It would be advantageous to provide a system which is portable and simple to use such that it may be adapted for home use, for ambulatory applications, or for mobile applications.

[0020] It would be advantageous to easily adapt the system to various head and body sizes.

[0021] It would be advantageous to provide a system which is comfortable to wear, and which can be easily attached and removed from a user.

[0022] It would be advantageous to provide a system which is cost effective to manufacture.

[0023] It would be advantageous to provide a system which is reliable and safe to use.

[0024] It would be advantageous to provide a more immersive VR experience.

[0025] It would be advantageous to provide all input data and output data synchronized and used all in one functional operation and one storage.

[0026] It would be advantages to provide a system that is easily washable and sterilizable.

[0027] It would be advantages to provide a system that includes an optimized amount of brain activity sensors that provide sufficient brain activity yet save time for placement and operation. It would be advantageous to have different electrode configurations to easily adapt to target brain areas as required.

[0028] It would be advantageous to provide a system that allows removal of a headmounted display without disturbing brain activity and other physiological and motion tracking modules to allow a pause for patient.

[0029] It would be advantageous to switch between AR and VR for see-through effect whenever needed without removing the HMD.

[0030] It would be advantageous to have multiple user's physiological, behavioural, movement and their stimulus data synchronized for offline and real-time analysis.

[0031] Disclosed herein is a physiological parameter measurement and motion tracking system comprising a control system, a sensing system, and a stimulation system, the sensing system comprising one or more physiological sensors including at least brain electrical activity sensors, the stimulation system comprising one or more stimulation devices including at least a visual stimulation system, the control system comprising an acquisition module configured to receive sensor signals from the sensing system, and a control module configured to process the signals from the acquisition module and control the generation of stimulation signals to one or more devices of the stimulation system. The control system further comprises a clock module, wherein the control system is configured to receive signals from the stimulation system and to time stamp the stimulation system signals and the sensor signals with a clock signal from the clock module. The stimulation system signals may be content code signals transmitted from the stimulation system.

[0032] Brain activity sensors may include contact (EEG) or non contact sensors (MRI, PET), invasive (single and multi electrode arrays) and non invasive (EEG, MEG) sensors for brain monitoring.

[0033] The sensing system may further comprise physiological sensor including any one or more of an Electromyogram (EMG) sensor, an Electrooculography (EOG) sensor, an Electrocardiogram (ECG) sensor, an inertial sensor, a body temperature sensor, and a galvanic skin sensor, respiration sensor, pulse oximetry.

[0034] The sensing system may further comprise position and/or motion sensors to determine the position and/or the movement of a body part of the user.

[0035] In an embodiment, at least one said position/motion sensor comprises a camera and optionally a depth sensor.

[0036] The stimulation system may further comprise stimulation devices including any one or more of an audio

stimulation device (33), a Functional Electrical Stimulation (FES) device (31), robotic actuator and a haptic feedback device.

[0037] Also disclosed herein is a physiological parameter measurement and motion tracking system comprising: a display system to display information to a user; a physiological parameter sensing system comprising one or more sensing means configured to sense electrical activity in a brain of a user and to generate brain electrical activity information; a position/motion detection system configured to provide a body part position information corresponding to a position/motion of a body part of the user; a control system arranged to receive the brain electrical activity information from the physiological parameter sensing system and to receive the body part position information from the position/motion detection system, the control system being configured to provide a target location information to the display system comprising a target location for the body part, the display system being configured to display the target location information, the control system being further configured to provide body part position information to the display system providing the user with a view of the movement of the body part, or an intended movement of the body part. The physiological parameter measurement and motion tracking system further comprises a clock module, the clock module being operable to time stamp information transferred from the physiological parameter sensing system and the position/motion detection system, the system being operable to process the information to enable real-time operation.

[0038] In an embodiment, the control system may be configured to determine whether there is no or an amount of movement less than a predetermined amount sensed by the position/motion detection system and if no or an amount of movement less than the predetermined amount is determined, then to provide the body part position information to the display system based at least partially on the brain electrical activity information, such that the displayed motion of the body part is at least partially based on the brain electrical activity information.

[0039] In an embodiment, the physiological parameter sensing system comprises a plurality of sensors configured to measure different physiological parameters, selected from a group including EEG sensor, ECOG sensor, EMG sensor, GSR sensor, respiration sensor, ECG sensor, temperature sensor, respiration sensor and pulse-oximetry sensor.

[0040] In an embodiment, the position/motion detection system comprises one or more cameras operable to provide an image stream of a user.

[0041] In an embodiment, the position/motion detection system comprises one or more cameras operable to provide an image stream of one or more objects in the scene.

[0042] In an embodiment, the position/motion detection system comprises one or more cameras operable to provide an image stream of one or more persons in the scene.

[0043] In an embodiment, the cameras comprise one or more colour cameras and a depth sensing camera.

[0044] In an embodiment, the control system is operable to supply information to the physiological parameter sensing system cause a signal to be provided to stimulate movement or a state of a user.

[0045] In an embodiment, the system may further comprise a head set forming a single unit incorporating said display system operable to display a virtual or augmented reality image or video to the user; and said sensing means configured

to sense electrical activity in a brain, the sensing means comprising a plurality of sensors distributed over a sensory and motor region of the brain of the user.

[0046] In an embodiment, the brain activity sensors are arranged in groups to measure electrical activity in specific regions of the brain.

[0047] In an embodiment, the display unit is mounted to a display unit support configured to extend around the eyes of a user and at least partially around the back of the head of the user.

[0048] In an embodiment, sensors are connected to a flexible cranial sensor support that is configured to extend over a head of a user. The cranial sensor support may comprise a plate and/or cap on which the sensors are mounted, the plate being connected to or integrally formed with a strap which is configured to extend around a top of a head of a user, the strap being connected at its ends to the display system support. The head set may thus form an easily wearable unit.

[0049] In an embodiment, the cranial sensor support may comprise a plurality of pad, a first group of pads being arranged to extend from a first pad support which extends in an approximately orthogonal direction from the display unit support, a second group of pads being arranged to extend from a second pad support which extends in an approximately orthogonal direction from the display unit support.

[0050] In an embodiment, the headset may incorporate a plurality of sensors configured to measure different physiological parameters, selected from a group comprising EEG sensors, an ECOG sensor, an eye movement sensor, and a head movement sensor.

[0051] In an embodiment, the headset may further incorporates one of said position/motion detection system operable to detect a position/motion of a body part of a user.

[0052] In an embodiment, the position/motion detection system may comprise one or more colour cameras, and a depth sensor.

[0053] In an embodiment, the headset comprises a wireless data transmitting means configured to wirelessly transmit data from one or more of the following systems: the physiological parameter sensing system; the position/motion detection system; the head movement sensing unit.

[0054] In an embodiment, the system may further comprise a functional electrical stimulation (FES) system connect to the control system and operable to electrically stimulate one or more body parts of the user, the FES including one or more stimulation devices selected from a group consisting of electrodes configured to stimulate nerves or muscles, trans-cranial alternating current stimulation (tACS), direct current stimulation (tDCS), trans-cranial magnetic stimulation (TMS) and trans-cranial Ultrasonic stimulation.

[0055] In an embodiment, the system may further comprise a robotic system for driving movements of a limb of the user and configured to provide haptic feedback.

[0056] In an embodiment, the system may further comprises an exercise logic unit configured to generate visual display frames including instructions and challenges to the display unit.

[0057] In an embodiment, the system may further comprise an events manager unit configured to generate and transmit stimulation parameters to the stimulation unit.

[0058] In an embodiment, each stimulation device may comprise an embedded sensor whose signal is registered by a synchronization device.

[0059] In an embodiment, the system may further comprise a display register configured to receive display content representing a final stage before the display content is activated on the display, the display register being configured to generate a display content code for transmission to the control system, a time stamp being attached to the display content code by the clock module.

[0060] In an embodiment, the stimulation system comprises stimulation devices that may comprise audio stimulation device, Functional Electrical Stimulation (FES) devices, and haptic feedback devices.

[0061] The clock module may be configured to be synchronized with clock module of other systems, including external computers.

[0062] Further objects and advantageous features of the invention will be apparent from the claims, from the detailed description, and annexed drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0063] For a better understanding of the invention, and to show how embodiments of the same may be carried into effect, reference will now be made, by way of example, to the accompanying diagrammatic drawings in which:

[0064] FIGS. 1a and 1b are schematic illustrations of prior art systems;

[0065] FIG. 2a is a schematic diagram illustrating an embodiment of the invention in which display content displayed to a user is synchronized with response signals (e.g. brain activity signals) measured from the user;

[0066] FIG. 2b is a schematic diagram illustrating an embodiment of the invention in which audio content played to a user is synchronized with response signals (e.g. brain activity signals) measured from the user;

[0067] FIG. 2c is a schematic diagram illustrating an embodiment of the invention in which a plurality of signals applied to a user are synchronized with response signals (e.g. brain activity signals) measured from the user;

[0068] FIG. 2d is a schematic diagram illustrating an embodiment of the invention in which a haptic feedback system is included;

[0069] FIG. 2e is a schematic diagram illustrating an embodiment of the invention in which a neuro-stimulation signal is applied to a user;

[0070] FIG. 3a is a simplified schematic diagram of a physiological parameter measurement and motion tracking system according to the invention;

[0071] FIG. 3b is a detailed schematic diagram of a control system of the system of FIG. 3a;

[0072] FIG. 3c is a detailed schematic diagram of a physiological tracking module of the control system of FIG. 3b;

[0073] FIGS. 4a and 4b are perspective views of a headset according to an embodiment of the invention;

[0074] FIG. 5 is a plan view of an exemplary arrangement of EEG sensors on a head of a user;

[0075] FIG. 6 is a front view of an exemplary arrangement of EMG sensors on a body of a user;

[0076] FIG. 7 is a diagrammatic view of a process for training a stroke victim using an embodiment of the system;

[0077] FIG. 8 is a view of screen shots which are displayed to a user during the process of FIG. 7;

[0078] FIG. 9 is a perspective view of a physical setup of a physiological parameter measurement and feedback system according to an exemplary embodiment of the invention;

[0079] FIG. 10 is a schematic block diagram of an example stimulus and feedback trial of a physiological parameter measurement and feedback system according to an exemplary embodiment of the invention;

[0080] FIG. 11 is a schematic block diagram of an acquisition module of a physiological parameter measurement and feedback system according to an exemplary embodiment of the invention;

[0081] FIG. 12 is a diagram illustrating time stamping of a signal by a clock module of a physiological parameter measurement and feedback system according to an exemplary embodiment of the invention;

[0082] FIG. 13 is a data-flow diagram illustrating a method of processing physiological signal data in a control system of a physiological parameter measurement and feedback system according to an exemplary embodiment of the invention;

[0083] FIG. 14 is a flowchart diagram illustrating a method of processing events in a control system of a physiological parameter measurement and feedback system according to an exemplary embodiment of the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0084] Referring to the figures, a physiological parameter measurement and motion tracking system according to embodiments of the invention generally comprises a control system 12, a sensing system 13, and a stimulation system 17.

[0085] The sensing system comprises one or more physiological sensors including at least brain electrical activity sensors, for instance in the form of electroencephalogram (EEG) sensors 22. The sensing system may comprise other physiological sensors selected from a group comprising Electromyogram (EMG) sensors 24 connected to muscles in user's body, Electrooculography (EOG) sensors 25 (eye movement sensors), Electrocardiogram (ECG) sensors 27, Inertial Sensors (INS) 29 mounted on the user's head and optionally on other body parts such as the users limbs, Body temperature sensor, Galvanic skin sensor. The sensing system further comprises position and/or motion sensors to determine the position and/or the movement of a body part of the user. Position and motion sensors may further be configured to measure the position and/or movement of an object in the field of vision of the user. It may be noted that the notion of position and motion is related to the extent that motion can be determined from a change in position. In embodiments of the invention, position sensors may be used to determine both position and motion of an object or body part, or a motion sensor (such as an inertial sensor) may be used to measure movement of a body part or object without necessarily computing the position thereof. In an advantageous embodiment at least one position/motion sensor comprises a camera 30 and optionally a distance sensor 28, mounted on a head set 18 configured to be worn by the user.

[0086] The Stimulation system 17 comprises one or more stimulation devices including at least a visual stimulation system 32. The stimulation system may comprise other stimulation devices selected from a group comprising audio stimulation device 33, and Functional Electrical Stimulation (FES) devices 31 connected to the user (for instance to stimulate nerves, or muscles, or parts of the user's brain e.g. to stimulate movement of a limb), and haptic feedback devices (for instance a robot arm that a user can grasp with his hand and that provides the user with haptic feedback). The stimulation system may further comprise Analogue to Digital Con-

verters (ADC) 37a and Digital to Analogue Converters (DAC) 37b for transfer and processing of signals by a control module 51 of the control system. Devices of the stimulation system may further advantageously comprise means to generate content code signals 39 fed back to the control system 12 in order to timestamp said content code signals and to synchronise the stimulation signals with the measurement signals generated by the sensors of the sensing system.

[0087] The control system 12 comprises a clock module 106 and an acquisition module 53 configured to receive content code signals from the stimulation system and sensor signals from the sensing system and to time stamp these signals with a clock signal from the clock module. The control system further comprises a control module that processes the signals from the acquisition module and controls the output of the stimulation signals to devices of the stimulation system. The control module further comprises a memory 55 to store measurement results, control parameters and other information useful for operation of the physiological parameter measurement and motion tracking system.

[0088] FIG. 3a is a simplified schematic diagram of a physiological parameter measurement and motion tracking system 10 according to an embodiment of the invention. The system 10 comprises a control system 12 which may be connected to one or more of the following units: a physiological parameter sensing system 14; position/motion detection system 16; and a head set 18, all of which will be described in more detail in the following.

[0089] The physiological parameter sensing system 14 comprises one or more sensors 20 configured to measure a physiological parameter of a user. In an advantageous embodiment the sensors 20 comprise one or more sensors configured to measure cortical activity of a user, for example, by directly measuring the electrical activity in a brain of a user. A suitable sensor is an electroencephalogram (EEG) sensor 22. EEG sensors measure electrical activity along the scalp, such voltage fluctuations result from ionic current flows within the neurons of the brain. An example of suitable EEG sensors is a G. Tech Medical Engineering GmbH g.scarabeo models. FIG. 4a shows an exemplary arrangement of electroencephalogram sensors 22 on a head of a user. In this example arrangement the sensors are arranged in a first group 22a such that cortical activity proximate a top of the head of the user is measured. FIG. 5 shows a plan view of a further exemplary arrangement, wherein the sensors are arranged into a first group 22c, second group 22d and third group 22e. Within each group there may be further subsets of groups. The groups are configured and arranged to measure cortical activity in specific regions. The functionality of the various groups that may be included is discussed in more detail in the following. It will be appreciated that the present invention extends to any suitable sensor configuration.

[0090] In an advantageous embodiment the sensors 22 are attached to a flexible cranial sensor support 27 which is made out of a polymeric material or other suitable material. The cranial sensor support 27 may comprise a plate 27a which is connected to a mounting strap 27b that extends around the head of the user, as shown in FIG. 4a. In another embodiment as shown in FIG. 4b the cranial sensor support 27 may comprise a cap 27c, similar to a bathing cap, which extends over a substantial portion of a head of a user. The sensors are suitably attached to the cranial sensor support, for example they may be fixed to or embedded within the cranial sensor support 27. Advantageously, the sensors can be arranged with

respect to the cranial sensor support such that when the cranial sensor support is positioned on a head of a user the sensors 20 are conveniently arranged to measure cortical activity specific areas, for example those defined by the groups 22a, 22c-d in FIGS. 4 and 5. Moreover, the sensors 20 are conveniently fixed to and removed from the user.

[0091] In an advantageous embodiment, the size and/or arrangement of the cranial sensor support is adjustable to accommodate users with different head sizes. For example, the strap 27b may have adjustable portions or the cap may have adjustable portions in a configuration such as and adjustable strap found on a baseball cap.

[0092] In an advantageous embodiment one or more sensors 20 may additionally or alternatively comprise sensors 24 configured to measure movement of a muscle of a user, for example by measuring electrical potential generated by muscle cells when the cells are electrically or neurologically activated. A suitable sensor is an electromyogram EMG sensor. The sensors 24 may be mounted on various parts of a body of a user to capture a particular muscular action. For example for a reaching task, they may be arranged on one or more of the hand, arm and chest. FIG. 6 shows an exemplary sensor arrangement, wherein the sensors 24 are arranged on the body in: a first group 24a on the biceps muscle; a second group 24b on the triceps muscle; and a third group 24c on the pectoral muscle.

[0093] In an advantageous embodiment one or more sensors 20 may comprise sensors 25 configured to measure electrical potential due to eye movement. A suitable sensor is an electrooculography (EOG) sensor. In an advantageous embodiment, as shown in FIG. 4a, there are four sensors that may be arranged in operational proximity to the eye of the user. However it will be appreciated that other numbers of sensors may be used. In an advantageous embodiment the sensors 25 are conveniently connected to a display unit support 36 of the head set, for example they are affixed thereto or embedded therein.

[0094] The sensors 20 may alternatively or additionally comprise one or more of the following sensors: electrocorticogram (ECOG); electrocardiogram (ECG); galvanic skin response (GSR) sensor; respiration sensor; pulse-oximetry sensor; temperature sensor; single unit and multi-unit recording chips for measuring neuron response using a microelectrode system. It will be appreciated that sensors 20 may be invasive (for example ECOG, single unit and multi-unit recording chips) or non-invasive (for example EEG). Pulse-oximetry sensor is used for monitoring a patient's oxygen saturation, usually placed on finger tip and may be used to monitor the status of the patient. This signal is particularly useful with patients under intensive care or special care after recovery from cardio-vascular issues. It will be appreciated that for an embodiment with ECG and/or respiration sensors, the information provided by the sensors may be processed to enable tracking of progress of a user. The information may also be processed in combination with EEG information to predict events corresponding to a state of the user, such as the movement of a body part of the user prior to movement occurring. It will be appreciated that for an embodiment with GSR sensors, the information provided by the sensors may be processed to give an indication of an emotional state of a user. For example, the information may be used during the appended example to measure the level of motivation of a user during the task.

[0095] In an advantageous embodiment the physiological parameter sensing system 14 comprises a wireless transceiver which is operable to wirelessly transfer data sensory data to a wireless transceiver of the physiological parameter processing module 54. In this way the head set 18 is convenient to use since there are no obstructions caused by a wired connection.

[0096] Referring to FIGS. 4a, 4b, the position/motion detection system 16 comprises one or more sensors 26 suitable for tracking motion of the skeletal structure or a user, or part of the skeletal structure such as an arm. In an advantageous embodiment the sensors comprise one or more cameras which may be arranged separate from the user or attached to the head set 18. The or each camera is arranged to capture the movement of a user and pass the image stream to a skeletal tracking module which will be described in more detail in the following.

[0097] In an advantageous embodiment the sensors 26 comprise three cameras: two colour cameras 28a, 28b and a depth sensor camera 30. However, in an alternative embodiment there is one colour camera 28 and a depth sensor 30. A suitable colour camera may have a resolution of VGA 640×480 pixels and a frame rate of at least 60 frames per second. The field of view of the camera may also be matched to that of the head mounted display, as will be discussed in more detail in the following. A suitable depth camera may have a resolution of QQ VGA 160×120 pixels. For example, a suitable device which comprises a colour camera and a depth sensor is the Microsoft Kinect. Suitable colour cameras also include models from Aptina Imaging Corporation such as the AR or MT series.

[0098] In an advantageous embodiment two colour cameras 28a and 28b and the depth sensor 30 are arranged on a display unit support 36 of the head set 18 (which is discussed in more detail below) as shown in FIG. 4. The colour cameras 28a, 28b may be arranged over the eyes of the user such that they are spaced apart, for example, by the distance between the pupil axes of a user which is about 65 mm. Such an arrangement enables a stereoscopic display to be captured and thus recreated in VR as will be discussed in more detail in the following. The depth sensor 30 may be arranged between the two cameras 28a, 28b.

[0099] In an advantageous embodiment the position/motion detection system 14 sensing unit 14 comprises a wireless transceiver which is operable to wirelessly transfer data sensory data to a wireless transceiver of the skeletal tracking module 52. In this way the head set 18 is convenient to use since there are no obstructions caused by a wired connection.

[0100] Referring to FIG. 4 the head set 18 comprises a display unit 32 having a display means 34a, 34b for conveying visual information to the user. In an advantageous embodiment the display means 34 comprises a head-up display, which is mounted on an inner side of the display unit in front of the eyes of the user so that the user does not need to adjust their gaze to see the information displayed thereon. The head-up display may comprise a non-transparent screen, such as an LCD or LED screen for providing a full VR environment. Alternatively it may comprise a transparent screen, such that the user can see through the display whilst data is displayed on it. Such a display is advantageous in providing an augmented reality AR. There may be two displays 34a, 34b one for each eye as shown in the figure, or there may be a single display which is visible by both eyes. The display unit may comprise a 2D or 3D display which may be a stereoscopic display. Although the system is described herein as

providing a VR image to a user, it will be appreciated that in other embodiments the image may be an augmented reality image, mixed reality image or video image.

[0101] In the example of FIG. 4 the display unit 32 is attached to a display unit support 36. The display unit support 36 supports the display unit 32 on the user and provides a removable support for the headset 18 on the user. In the example the display unit support 36 extends from proximate the eyes and around the head of the user, and is in the form of a pair of goggles as best seen in FIGS. 4a and 4b.

[0102] In an alternative embodiment the display unit 32 is separate from the head set. For example the display means 34 comprises a monitor or TV display screen or a projector and projector screen.

[0103] In an advantageous embodiment part or all of the physiological parameter sensing system 14 and display unit 32 are formed as an integrated part of the head set 18. The cranial sensor support 27 may be connected to the display unit support 36 by a removable attachment (such as a stud and hole attachment, or spring clip attachment) or permanent attachment (such as an integrally moulded connection or a welded connection or a sewn connection). Advantageously, the head mounted components of the system 10 are convenient to wear and can be easily attached and removed from a user. In the example of FIG. 4a, the strap 27a is connected to the support 36 proximate the ears of the user by a stud and hole attachment. In the example of FIG. 4b, the cap 27c is connected to the support 36 around the periphery of the cap by a sewn connection.

[0104] In an advantageous embodiment the system 10 comprises a head movement sensing unit 40. The head movement sensing unit comprises a movement sensing unit 42 for tracking head movement of a user as they move their head during operation of the system 10. The head movement sensing unit 42 is configured to provide data in relation to the X, Y, Z coordinate location and the roll, pitch and yaw of a head of a user. This data is provided to a head tracking module, which is discussed in more detail in the following, and processes the data such that the display unit 32 can update the displayed VR images in accordance with head movement. For example, as the user moves their head to look to the left the displayed VR images move to the left. Whilst such an operation is not essential it is advantageous in providing a more immersive VR environment. In order to maintain realism it has been found that the maximum latency of the loop defined by movement sensed by the head movement sensing unit 42 and the updated VR image is 20 ms.

[0105] In an advantageous embodiment the head movement sensing unit 42 comprises an acceleration sensing means 44, such as an accelerometer configured to measure acceleration of the head. In an advantageous embodiment the sensor 44 comprises three in-plane accelerometers, wherein each in-plane accelerometer is arranged to be sensitive to acceleration along a separate perpendicular plate. In this way the sensor is operable to measure acceleration in three-dimensions. However, it will be appreciated that other accelerometer arrangements are possible, for example, there may only be two in-plane accelerometers arranged to be sensitive to acceleration along separate perpendicular plates such that two-dimensional acceleration is measured. Suitable accelerometers include piezoelectric, piezoresistive and capacitive variants. An example of a suitable accelerometer is the Xsens Technologies B. V. MTI 10 series sensors.

[0106] In an advantageous embodiment the head movement sensing unit 42 further comprises a head orientation sensing means 47 which is operable to provide data in relation to the orientation of the head. Examples of suitable head orientation sensing means include a gyroscope and a magnetometer 48. Which are configured to measure the orientation of a head of a user.

[0107] In an advantageous embodiment the head movement sensing unit 42 may be arranged on the headset 18. For example, the movement sensing unit 42 may be housed in a movement sensing unit support 50 that is formed integrally with or is attached to the cranial sensor support 27 and/or the display unit support 36 as shown in FIG. 4a, 4b.

[0108] In an advantageous embodiment the system 10 comprises an eye gaze sensing unit 100. The eye gaze sensing unit 100 comprises one or more eye gaze sensors 102 for sensing the direction of gaze of the user. In an advantageous embodiment the eye gaze sensor 102 comprises one or more cameras arranged in operation proximity to one or both eyes of the user. The or each camera 102 may be configured to track eye gaze by using the centre of the pupil and infrared/near-infrared non-collimated light to create corneal reflections (CR). However, it will be appreciated that other sensing means may be used for example: electrooculogram (EOG); or eye attached tracking. The data from the movement sensing unit 42 is provided to an eye tracking module, which is discussed in more detail in the following, and processes the data such that the display unit 32 can update the displayed VR images in accordance with eye movement. For example, as the user moves their eyes to look to the left the displayed VR images pan to the left. Whilst such an operation is not essential it is advantageous in providing a more immersive VR environment. In order to maintain realism it has been found that the maximum latency of the loop defined by movement sensed by the eye gaze sensing unit 100 and the updated VR image is about 50 ms, however in an advantageous embodiment it is 20 ms or lower.

[0109] In an advantageous embodiment the eye gaze sensing unit 100 may be arranged on the headset 18. For example, the eye gaze sensing unit 42 may be attached to the display unit support 36 as shown in FIG. 4a.

[0110] The control system 12 processes data from the physiological parameter sensing system 14 and the position/motion detection system 16, and optionally one or both of the head movement sensing unit 40 and the eye gaze sensing module 100, together with operator input data supplied to an input unit, to generate a VR (or AR) data which is displayed by the display unit 32. To perform such a function, in the advantageous embodiment shown in FIGS. 1 and 2, the control system 12 may be organized into a number of modules, such as: a skeletal tracking module 52; a physiological parameter processing module 54; a VR generation module 58; a head tracking module 58; and an eye gaze tracking module 104 which are discussed in the following.

[0111] The skeletal tracking module 52 processes the sensory data from the position/motion detection system 16 to obtain joint position/movement data for the VR generation module 58. In an advantageous embodiment the skeletal tracking module 52, as shown in FIG. 3b, comprises a calibration unit 60, a data fusion unit 62 and a skeletal tracking unit 64 the operations of which will now be discussed.

[0112] The sensors 26 of the position/motion detection system 16 provide data in relation to the position/movement of a whole or part of a skeletal structure of a user to the data fusion

unit 62. The data may also comprise information in relation to the environment, for example the size and arrangement of the room the user is in. In the exemplary embodiment, wherein the sensors 26 comprise a depth sensor 30 and a colour cameras 28a, 28b the data comprises colour and depth pixel information.

[0113] The data fusion unit 62 uses this data, and the calibration unit 62, to generate a 3D point cloud comprising a 3D point model of an external surface of the user and environment. The calibration unit 62 comprises data in relation to the calibration parameters of the sensors 26 and a data matching algorithm. For example, the calibration parameters may comprise data in relation to the deformation of the optical elements in the cameras, colour calibration and hot and dark pixel discarding and interpolation. The data matching algorithm may be operable to match the colour image from cameras 28a and 28b to estimate a depth map which is referenced with respect to a depth map generated from the depth sensor 30. The generated 3D point cloud comprises an array of pixels with an estimated depth such that they can be represented in a three-dimensional coordinate system. The colour of the pixels is also estimated and retained.

[0114] The data fusion unit 62 supplies data comprising 3D point cloud information, with pixel colour information, together with colour images to the skeletal tracking unit 64. The skeletal tracking unit 64 processes this data to calculate the position of the skeleton of the user and therefrom estimate the 3D joint positions. In an advantageous embodiment, to achieve this operation, the skeletal tracking unit is organised into several operational blocks: 1) segment the user from the environment using the 3D point cloud data and colour images; 2) detect the head and body parts of the user from the colour images; 3) retrieve a skeleton model of user from 3D point cloud data; 4) use inverse kinematic algorithms together with the skeleton model to improve joint position estimation. The skeletal tracking unit 64 outputs the joint position data to the VR generation module 58 which is discussed in more detail in the following. The joint position data is time stamped by a clock module such that the motion of a body part can be calculated by processing the joint position data over a given time period.

[0115] Referring to FIGS. 2 and 3, the physiological parameter processing module 54 processes the sensory data from the physiological parameter sensing system 14 to provide data which is used by the VR generation module 58. The processed data may, for example, comprise information in relation to the intent of a user to move a particular body part or a cognitive state of a user (for example, the cognitive state in response to moving a particular body part or the perceived motion of a body part). The processed data can be used to track the progress of a user, for example as part of a neural rehabilitation program and/or to provide real-time feedback to the user for enhanced adaptive treatment and recovery, as is discussed in more detail in the following.

[0116] The cortical activity is measured and recorded as the user performs specific body part movements/intended movements, which are instructed in the VR environment. Examples of such instructed movements are provided in the appended examples. To measure the cortical activity, the EEG sensors 22 are used to extract event related electrical potentials and event related spectral perturbations, in response to the execution and/or observation of the movements/intended movements which can be viewed in VR as an avatar of the user.

[0117] For example the following bands provide data in relation to various operations: slow cortical potentials (SCPs), which are in the range of 0.1-1.5 Hz and occur in motor areas of the brain provide data in relation to preparation for movement; mu-rhythm (8-12 Hz) in the sensory motor areas of the brain provide data in relation to the execution, observation and imagination of movement of a body part; beta oscillations (13-30 Hz) provide data in relation to sensory motor integration and movement preparation. It will be appreciated that one or more of the above potentials or other suitable potentials may be monitored. Monitoring such potentials over a period of time can be used to provide information in relation to the recovery or a user.

[0118] Referring to FIG. 5, an advantageous exemplary arrangement of sensors 20 is provided which is suitable for measuring neural events as a user performs various sensorimotor and/or cognitive tasks. EOG sensors 25 are advantageously arranged to measure eye movement signals. In this way the eye movement signals can be isolated and accounted for when processing the signals of other groups to avoid contamination. EEG sensors 22 may advantageously be arranged into groups to measure motor areas in one or more areas of the brain, for example: central (C1-C6, Cz); fronto-central (FC1-FC4, FCZ); centro-parietal (CP3, CP4, CPZ). In an advantageous embodiment contralateral EEG sensors C1, C2, C3 and C4 are arranged to measure arm/hand movements. The central, fronto-central and centro-parietal sensors may be used for measuring SCPs.

[0119] In an advantageous embodiment the physiological parameter processing module 54 comprises a re-referencing unit 66 which is arranged to receive data from the physiological parameter sensing system 14 and configured to process the data to reduce the effect of external noise on the data. For example, it may process data from one or more of the EEG, EOG or EMG sensors. The re-referencing unit 66 may comprise one or more re-referencing blocks: examples of suitable re-referencing blocks include mastoid electrode average reference, and common average reference. In the example embodiment a mastoid electrode average reference is applied to some of the sensors and common average reference is applied to all of the sensors. However, it will be appreciated that other suitable noise filtering techniques may be applied to various sensors and sensor groups.

[0120] In an advantageous embodiment, the processed data of the re-referencing unit 66 may be output to a filtering unit 68, however in an embodiment wherein there is no re-referencing unit the data from the physiological parameter sensing system 14 is fed directly to the filtering unit 68. The filtering unit 68 may comprise a spectral filtering module 70 which is configured to band pass filter the data for one or more of the EEG, EOG and EMG sensors. In respect of the EEG sensors, in an advantageous embodiment the data is band pass filtered for one or more of the sensors to obtain the activity on one or more of the bands: SCPs, theta, alpha, beta, gamma, mu, gamma, delta. In an advantageous embodiment the bands SCPs (0.1-1.5 Hz), alpha and mu (8-12 Hz), beta (18-30 Hz) delta (1.5-3.5 Hz), theta (3-8 Hz) and gamma (30-100 Hz) are filtered for all of the EEG sensors. In respect of EMG and EOG sensors similar spectral filtering may be applied but with different spectral filtering parameters. For example, for EMG sensors spectral filtering of a 30 Hz high pass cut off may be applied.

[0121] The filtering unit 66 may alternatively or additionally comprise a spatial filtering module 72. In an advanta-

geous embodiment a spatial filtering module 72 is applied to the SCPs band data from the EEG 10 sensors (which is extracted by the spectral filtering module 70), however it may also be applied to other extracted bands. A suitable form of spatial filtering is spatial smoothing which comprises weighted averaging of neighbouring electrodes to reduce spatial variability of the data. Spatial filtering may also be applied to data from the EOG and EMG sensors.

[0122] The filtering unit 66 may alternatively or additionally comprise a Laplacian filtering module 74, which is generally for data from the EEG sensors but may also be applied to data from the EOG and EMG sensors. In an advantageous embodiment a Laplacian filtering module 72 is applied to each of the Alpha, Mu and Beta band data of the EEG sensors which is extracted by the spectral filtering module 70, however it may be applied to other bands. The Laplacian filtering module 72 is configured to further reduce noise and increase spatial resolution of the data.

[0123] The physiological parameter sensing system 14 may further comprise an event marking unit 76. In an advantageous embodiment, when the physiological parameter sensing system 14 comprises a re-referencing unit and/or a filtering unit 68, the event marking unit 76 is arranged to receive processed data from either or both of these units when arranged in series (as shown in the embodiment of FIG. 3c). The event marking unit 76 is operable to use event based makers determined by an exercise logic unit (which will be discussed in more detail in the following) to extract segments of sensory data. For example, when a specific instruction to move a body part is sent to the user from the exercise logic unit, a segment of data is extracted within a suitable time frame following the instruction. The data may, in the example of an EEG sensor, comprise data from a particular cortical area to thereby measure the response of the user to the instruction. For example, an instruction may be sent to the user to move their arm and the extracted data segment may comprise the cortical activity for a period of 2 seconds following instruction. Other example events may comprise: potentials in response to infrequent stimuli in the central and centro-parietal electrodes; movement related potentials that are central SCPs (slow cortical potentials) which appear slightly prior to movement and; error related potentials.

[0124] In an advantageous embodiment the event marking unit is configured to perform one or more of following operations: extract event related potential data segments from the SCP band data; extract event related spectral perturbation marker data segments from Alpha and Beta or Mu or gamma band data; extract spontaneous data segments from Beta band data. In the aforementioned, spontaneous data segments correspond to EEG segments without an event marker, and are different to event related potentials, the extraction of which depends on the temporal location of the event marker.

[0125] The physiological parameter sensing system 14 may further comprise an artefact detection unit 78 which is arranged to receive the extracted data segments from the event marking unit 76 and is operable to further process the data segments to identify specific artefacts in the segments. For example, the identified artefacts may comprise 1) movement artefacts: the effect of a user movement on a sensor/sensor group 2) electrical interference artefacts: interference, typically 50 Hz from the mains electrical supply 3) eye movement artefacts: such artefacts can be identified by the EOG sensors 25 of the physiological parameter sensing system 14. In an advantageous embodiment the artefact detection unit 78

comprises an artefact detector module **80** which is configured to detect specific artefacts in the data segments. For example, an erroneous segment which requires deleting or a portion of the segment which is erroneous and requires removing from the segment. The advantageous embodiment further comprises an artefact removal module **82**, which is arranged to receive the data segments from the event marking unit **76** and artefact detected from the artefact detector module **80** to perform an operation of removing the detected artefact from the data segment. Such an operation may comprise a statistical method such as a regression model which is operable to remove the artefact from the data segment without loss of the segment. The resulting data segment is thereafter output to the VR generation module **58**, wherein it may be processed to provide real-time VR feedback which may be based on movement intention as will be discussed in the following. The data may also be stored to enable the progress of a user to be tracked.

[0126] In embodiments comprising other sensors, such as ECG, respiration sensors and GSR sensors, it will be appreciated that the data from such sensors can be processed using one or more of the above-mentioned techniques where applicable, for example: noise reduction; filtering; event marking to extract event related data segments; artefact removal from extracted data segments.

[0127] The head tracking module **56** is configured to process the data from the head movement sensing unit **40** to determine the degree of head movement. The processed data is sent to the VR generation module **58**, wherein it is processed to provide real-time VR feedback to recreate the associated head movement in the VR environment. For example, as the user moves their head to look to the left the displayed VR images move to the left.

[0128] The eye gaze tracking module **104** is configured to process the data from the eye gaze sensing unit **100** to determine a change in gaze of the user. The processed data is sent to the VR generation module **58**, wherein it is processed to provide real-time VR feedback to recreate the change in gaze in the VR environment.

[0129] Referring now to FIG. 3*b*, the VR generation module **58** is arranged to receive data from the skeletal tracking module **52**, physiological parameter processing module **54**, and optionally one or both of the head tracking module **56** and the eye gaze tracking module **104**, and is configured to process this data such that it is contextualised with respect to a status of an exercise logic unit (which is discussed in more detail in the following), and to generate a VR environment based on the processed data.-

[0130] In an advantageous embodiment the VR generation module may be organised into several units: an exercise logic unit **84**; a VR environment unit **86**; a body model unit **88**; an avatar posture generation unit **90**; a VR content integration unit **92**; an audio generation unit **94**; and a feedback generation unit **96**. The operation of these units will now be discussed.

[0131] In an advantageous embodiment the exercise logic unit **84** is operable to interface with a user input, such as a keyboard or other suitable input device. The user input may be used to select a particular task from a library of tasks and/or set particular parameters for a task. The appended example provides details of such a task.

[0132] In an advantageous embodiment a body model unit **88** is arranged to receive data from the exercise logic unit **84** in relation to the particular part of the body required for the

selected task. For example this may comprise the entire skeletal structure of the body or a particular part of the body such as an arm. The body model unit **88** thereafter retrieves a model of the required body part, for example from a library of body parts. The model may comprise a 3D point cloud model, or other suitable model.

[0133] The avatar posture generation unit **90** is configured to generate an avatar based on the model of the body part from the body part model **88**.

[0134] In an advantageous embodiment the VR environment unit **86** is arranged to receive data from the exercise logic unit **84** in relation to the particular objects which are required for the selected task. For example the objects may comprise a disk or ball to be displayed to the user.

[0135] The VR content integration unit may be arranged to receive the avatar data from the avatar posture generation unit **90** and the environment data from the VR environment unit **86** and to integrate the data in a VR environment. The integrated data is thereafter transferred to the exercise logic unit **58** and also output to the feedback generation unit **86**. The feedback generation unit **86** is arranged to output the VR environment data to the display means **34** of the headset **18**.

[0136] During operation of the task the exercise logic unit **84** receives data comprising joint position information from the skeletal tracking module **64**, data comprising physiological data segments from the physiological parameter processing module **54** data from the body model unit **88** and data from the VR environment unit **86**. The exercise logic unit **84** is operable to process the joint position information data which is in turn sent to the avatar posture generation unit **90** for further processing and subsequent display. The exercise logic unit **84** may optionally manipulated the data so that it may be used to provide VR feedback to the user. Examples of such processing and manipulation include amplification of erroneous movement; auto correction of movement to induce positive reinforcement; mapping of movements of one limb to another.

[0137] As the user moves, interactions and/or collisions with the objects, as defined by the VR environment unit **86**, in the VR environment, are detected by the exercise logic unit **84** to further update the feedback provided to the user.

[0138] The exercise logic unit **84** may also provide audio feedback. For example, an audio generation unit (not shown) may receive audio data from the exercise logic unit, which is subsequently processed by the feedback unit **94** and output to the user, for example, by headphones (not shown) mounted to the headset **18**. The audio data may be synchronised with the visual feedback, for example, to better indicate collisions with objects in the VR environment and to provide a more immersive VR environment.

[0139] In an advantageous embodiment the exercise logic unit **84** may send instructions to the physiological parameter sensing system **14** to provide feedback to the user via one or more of the sensors **20** of the physiological parameter sensing system **14**. For example, the EEG **22** and/or EMG **24** sensors may be supplied with an electrical potential that is transferred to the user. With reference to the appended example, such feedback may be provided during the task. For example at stage **5**, wherein there is no arm movement an electrical potential may be sent to EMG **24** sensors arranged on the arm and/or EEG sensors to attempt to stimulate the user into moving their arm. In another example, such feedback may be

provided before initiation of the task, for instance, a set period of time before the task, to attempt to enhance a state of memory and learning.

[0140] In an advantageous embodiment the control system comprises a clock module 106. The clock module may be used to assign time information to the data and various stages of input and output and processing. The time information can be used to ensure the data is processed correctly, for example, data from various sensors is combined at the correct time intervals. This is particularly advantageous to ensure accurate real-time processing of multimodal inputs from the various sensors and to generate real-time feedback to the user. The clock module may be configured to interface with one or more modules of the control system to time stamp data. For example: the clock module 106 interfaces with the skeletal tracking module 52 to time stamp data received from the position/motion detection system 16; the clock module 106 interfaces with the physiological parameter processing module 54 to time stamp data received from the physiological parameter sensing system 14; the clock module 106 interfaces with the head tracking module 58 to time stamp data received from the head movement sensing unit 40; the clock module 106 interfaces with the eye gaze tracking module 104 to time stamp data received from the eye gaze sensing unit 100. Various operations on the VR generation module 58 may also interface with the clock module to time stamp data, for example data output to the display means 34.

[0141] Unlike complex conventional systems that connect several independent devices together, in the present invention synchronization occurs at the source of the data generation (for both sensing and stimulation), thereby ensuring accurate synchronization with minimal latency and, importantly, low jitter. For example, for a stereo head-mounted display with refresh rate of 60 Hz, the delay would be as small as 16.7 ms. This is not presently possible with a combination of conventional stand-alone or independent systems. An important feature of the present invention is that it is able to combine a heterogeneous ensemble of data, synchronizing them into a dedicated system architecture at source for ensuring multimodal feedback with minimal latencies. The wearable compact head mounted device allows easy recording of physiological data from brain and other body parts.

Synchronization Concept:

[0142] Latency or Delay (T): It is the time difference between the moment of user's actual action or brain state to the moment of its corresponding feedback/stimulation. It is a positive constant in a typical application. Jitter (ΔT) is the trial to trial deviation in Latency or Delay. For applications that require for instance immersive VR or AR, both latency T and jitter ΔT should be minimized to the least possible. Whereas in brain computer interface and offline applications, latency T can be compromised but jitter ΔT should be as small as possible.

[0143] Referring to FIGS. 1a and 1b, two conventional prior-art system architectures are schematically illustrated. In these the synchronization may be ensured to some degree but jitter (ΔT) is not fully minimized.

Design-I (FIG. 1a):

[0144] In this design, the moment at which a visual cue is supplied to user is registered directly in the computer while acquiring the EEG signal that is acquired via a USB connec-

tion or serial connection. Meaning, the computer assumes, the moment at which it is registered with acquired from user's brain is the moment a cue is displayed to the user. Note that there are inherent delays and jitters in this design. First due to the USB/serial port connectivity to computer, the registration of the sample into computer is has nonzero variable latency. Second, the moment the display command is released from the computer, it undergoes various delay due to underlying display driver, graphical processing unit and signal propagation, which is also not a constant. Hence these two kind of delays add up and compromise alignment of visually evoked potentials.

Design-II (FIG. 1b):

[0145] To avoid the above problem, it is known to use a photo diode to measure the cue and synchronize its signal directly with an EEG amplifier. In this design, usually a photo-diode is placed on the display to sense a light. Usually, a cue is presented to user at the same time a portion of screen where the photo-diode is attached is lighted up. This way the moment at which the cue is presented is registered with photo-diode and supplied to EEG amplifier. This way EEG and visual cue information are directly synchronized at source. This procedure is accurate for alighting visually evoked trials, however has a number of drawbacks:

[0146] the number of visual cues it can code are limited to number of photodiodes. A typical virtual reality based visual stimulation would have large number of events to be registered together with physiological signals accurately.

[0147] the use of photo-diode in a typical micro-display (e.g., 1 square inch size, with pixel density of 800x600) of a head-mounted display would be difficult and even worse reduces usability. Note also that for the photo-diode to function, ample light should be supplied to the diode resulting in a limitation.

[0148] the above drawbacks are further complicated, when a plurality of stimuli (such as audio, magnetic, electrical and mechanical are needed to synchronize with plurality of sensors data (such as EEG, EMG, ECG, video camera, inertial sensors, respiration sensor, pulse oximetry, galvanic skin potentials etc.).

[0149] In embodiments of the present invention, the above drawbacks are addressed to provide a system that is accurate and scalable to many different sensors and many different stimuli. This is achieved by employing a centralized clock system that supplies a time-stamp information and each sensor's samples are registered in relation to this to the time-stamp.

[0150] In an embodiment, each stimulation device may advantageously be equipped with an embedded sensor whose signal is registered by a synchronization device. This way, a controller can interpret plurality of sensor data and stimulation data can be interpreted accurately for further operation of the system.

[0151] In an embodiment, in order to reduce the amount of data to synchronize from each sensor, instead of using a real sensor, video content code from a display register may be read.

[0152] Referring to FIG. 2a, an embodiment of the invention in which the content fed to a micro-display on the headset is synchronized with brain activity signals (e.g. EEG signals) is schematically illustrated.

[0153] Generally, the visual/video content that is generated in the control system is first pushed to a display register (a final stage before the video content is activated on the display). In our design together with video content, the controller sends a code to a part of the register (say N bits) corresponding to one or more pixels (not too many pixels, so that the user is not disturbed; the corner pixels in the micro display are recommended as they may not be visible to user). The code will be defined by controller describing what exactly is the display content. Now using a clock signal the acquisition module reads the code from the display register and attaches a time stamp and sends to next modules. At the same moment EEG samples are also sampled and attached with the same time stamp. This way when EEG samples and the video code samples are arrived at the controller, these samples could be interpreted accordingly.

[0154] Note that all these modules are employed in one embedded system that has a single clock. This leads least latency as well as least jitter.

[0155] The same principle may be used for an audio stimulation as illustrated in FIG. 2b. The audio stimulation can be sampled by the data sent to a digital to analog (DAC) converter.

[0156] More generally, any kind of stimulation, as illustrated in FIG. 2c, (such as trans-cranial stimulations (tACS), tDCS, TMS, etc.) could be directed to the acquisition module using a sensor and an analog to digital (ADC) converter. This can also be achieved by sending the digital signals supplied to DAC as illustrated in the case of audio stimulation. Plural data from an EEG, video camera data or any other sensor (e.g. INS: Inertial sensor) is synchronized in the same framework. Note that each sensor or stimulation could be sampled with different sampling frequency. An important point is that the sensor or stimulation data samples are attached with the time-stamp defined with the clock module.

EXAMPLE 1

Operation of System (10) in Exemplary "Reach an Object" Task

[0157] In this particular example an object 110, such as a 3D disk, is displayed in a VR environment 112 to a user. The user is instructed to reach to the object using a virtual arm 114 of the user. In the first instance the arm 114 is animated based on data from the skeletal tracking module 16 derived from the sensors of the position/motion detection system 16. In the second instance, wherein there is negligible or no movement detected by the skeletal tracking module 16, then the movement is based data relating to intended movement from the physiological parameter processing module 52 detected by the physiological parameter sensing system 14, and in particular the data may be from the EEG sensors 22 and/or EMG sensors 24.

[0158] FIGS. 7 and 8a-8g describe the process in more detail. At stage 1 in FIG. 7, a user, such as a patient or operator, interfaces with a user input of the exercise logic unit 84 of the VR generation module 58 to select a task from a library of tasks which may be stored. In this example a 'reach an object task' is selected. At this stage the user may be provided with the results 108 of previous like tasks, as shown in FIG. 8a. These results may be provided to aid in the selection of the particular task or task difficulty. The user may also input parameters to adjust the difficulty of the task, for example based on a level of success from the previous task.

[0159] At stage 2, the exercise logic unit 84 initialises the task. This comprises steps of the exercise logic unit 84 interfacing with the VR environment unit 86 to retrieve the parts (such as the disk 110) associated with the selected task from a library of parts. The exercise logic unit 84 also interfaces with the body model unit 88 to retrieve, from a library of body parts, a 3D point cloud model of the body part (in this example a single arm 114) associated with the exercise. The body part data is then supplied to the avatar posture generation unit 90 so that an avatar of the body part 114 can be created. The VR content integration unit 92 receives data in relation to the avatar of the body part and parts in the VR environment and integrates them in a VR environment. This data is thereafter received by the exercise logic unit 84 and is output to the display means 34 of the headset 18 as shown in FIG. 8b. The target path 118 for the user to move a hand 115 of the arm 114 along is indicated, for example, by colouring it blue.

[0160] At stage 3, the exercise logic unit 84 interrogates the skeletal tracking module 16 to determine whether any arm movement has occurred. The arm movement being derived from the sensors of the position/motion detection system 16 which are worn by the user. If a negligible amount of movement (for example an amount less than a predetermined amount, which may be determined by the state of the user and location of movement) or no movement has occurred then stage 5 is executed, else stage 4 is executed.

[0161] At stage 4 the exercise logic unit 84 processes the movement data to determine whether the movement is correct. If the user has moved their hand 115 in the correct direction, for example, towards the object 110, along the target path 118, then stage 4a is executed and the colour of the target path may change, for example it is coloured green, as shown in FIG. 8c. Else, if the user moves their hand 115 in an incorrect direction, for example, away from the object 110, Then stage 4b is executed and the colour of the target path may change, for example it is coloured red, as shown as FIG. 8d.

[0162] Following stage 4a and 4b stage 4c is executed, wherein the exercise logic unit 84 determines whether the hand 115 has reached the object 110. If the hand has reached the object, as shown in FIG. 8e then stage 6 is executed, else stage 3 is re-executed.

[0163] At stage 5 the exercise logic unit 84 interrogates the physiological parameter processing module 52 to determine whether any physiological activity has occurred. The physiological activity is derived from the sensors of the physiological parameter sensing system module 14, which are worn by the user, for example the EEG and/or EMG sensors. EEG and EMG sensors may be combined to improve detection rates, and in the absence of a signal from one type of sensor a signal from the other type of sensor maybe used. If there is such activity, then it may be processed by the exercise logic unit 84 and correlated to a movement of the hand 115. For example a characteristic of the event related data segment from the physiological parameter processing module 52, such as the intensity or duration of part of the signal, may be used to calculate a magnitude of the hand movement 115. Thereafter stage 6 is executed.

[0164] At stage 6a if the user has successfully completed the task, then to provide feedback 116 to the user a reward score may be calculated, which may be based on the accuracy of the calculated trajectory of the hand 115 movement. FIG. 8e shows the feedback 116 displayed to the user. The results from the previous task may also be updated.

[0165] Thereafter stage 6b is executed, wherein a marker strength of the sensors of the physiological parameter sensing system module 14, for example the EEG and EMG, sensors may be used to provide feedback 118. FIG. 8f shows an example of the feedback 120 displayed to the user, wherein the marker strength is displayed as a percentage of a maximum value. The results from the previous task may also be updated. Thereafter, stage 7 is executed, wherein the task is terminated.

[0166] As stage 8 if there is no data provided by either of the sensors of the physiological parameter sensing system module 14 or the sensors of the position/motion detection system 16 within a set period of time then time out 122 occurs, as shown in FIG. 8g and stage 7 is executed.

EXAMPLE 2

Hybrid Brain Computer Interface with Virtual Reality Feedback with Head-Mounted Display, Robotic System and Functional Electrical Stimulation

Objective:

[0167] To provide optimal training for patients with upper movements movement deficits resulting from neurological problems (e.g., ALS, stroke, brain injury, locked-in syndrome, Parkinson disease etc.). These patients would require training to reintegrate the lost/degraded movement function. A system that reads their intention to make a functional movement and provide an assistance in completing the movement could enhance the rehabilitation outcome.

[0168] For this purpose, the system could exploit Hebbian learning in associating brain's input and output areas in reintegrating the lost movement function. The Hebbian principle is "Any two systems of cells in the brain that are repeatedly active at the same time will tend to become 'associated', so that activity in one facilitates activity in the other."

[0169] In the present example, the two systems of cells are the areas of the brain that are involved in sensory processing and in generating motor command. When the association is lost due to neural injury, it could be restored or re-built via Hebbian training. For the optimal results of this training, one must ensure near perfect synchronization of system inputs and outputs and in providing realtime multi-sensory feedback to the patient with small delay and more importantly almost negligible jitter.

[0170] The physical embodiment illustrated in FIG. 9, comprises a wearable system having a head-mounted display (HMD) 18 to display virtual reality 3D video content on micro-displays (e.g., in first person perspective), a stereo video camera 30 and a depth camera 28, whose data is used for tracking the wearer's own arm, objects and any second person under the field of view (motion tracking unit). Additionally, the EEG electrodes 22 placed over the head of the wearer 1, EMG electrodes 24 placed on the arm will measure electrical activity of the brain and of muscles respectively, used for inferring user's intention in making a goal directed movement. Additionally, there exists an Inertial Measurement Unit (IMU) 29 that is used for tracking head movements. The executed or intended movements are rendered in the virtual reality display. In case of evidence of the movements through the biological sensor data (ie, EEG, EMG, and motion tracing) feedback mechanisms aid the patient in making goal directed movement using a robotic system 41. Fur-

thermore, functional electrical stimulation (FES) system 31 activates muscles of the arm in completing the planned movement. Additionally, the feedback mechanisms shall provide appropriate stimulation tightly coupling to the intention to move to ensure the implementation of Hebbian learning mechanism. In the following text we describe an architecture that implements high quality synchronization of sensor data with stimulation data.

[0171] The following paragraph describes a typical trial in performing a typical goal directed task, which could be repeated by the patient several times to complete a typical training session. As shown in FIG. 10, a 3D visual cue 81, in this case a door knob, when displayed in the HMD could instruct the patient 1 to make a movement corresponding to opening the door. Followed by the visual cue, the patient may attempt to make the suggested movement. Sensor data (EEG, EMG, IMU, motion data) is acquired in synchronization with the moment of presentation of the visual cue. The control system 51 then extracts the sensor data and infers user intention and a consensus is made in providing feedback to the user through a robot 41 that moves the arm, and HMD displays movement of an avatar 83, which is animated based on the inferred data. A Functional Electrical Stimulation (FES) 31 is also synchronized together with other feedbacks ensuring a congruence among them.

[0172] An exemplary architecture of this system is illustrated in FIG. 2d. The acquisition unit acquires physiological data (i.e., EEG 22, EMG 24, IMU 29 and camera system 30). The camera system data include stereo video frames and depth sensor data. Additionally the stimulation related data such as the moment at which a particular image frame of the video is displayed on the HMD, robot's motor data and sensors 23 and that of FES 31 stimulation data are also sampled by the acquisition unit 53. This unit associates each sensor and stimulation sample with a time stamp (TS) obtained from the clock input. The synchronized data is then processed by control system and is used in generating appropriate feedback content to the user through VR HMD display, robotic movement as well as FES stimulation.

Inputs of the System:

[0173] Inertial measurement unit (IMU) sensors 29, for instance including an accelerometer, a gyroscope, amagneto-meter: Purpose, to track head movements. This data is used for rendering VR content as well as to segment EEG data where the data quality might be degraded due to movement.

[0174] Camera system 30, 28: The camera system comprises a stereo camera 30, and a depth sensor 28. The data of these two sensors are combined to compute tracking data of a wearer's own movements of upper limbs, and for tracking wearer's own arm movements. These movements are then used in animating the avatar in the virtual reality on micro displays 32 and in detecting if there was a goal directed movements, which is then used for triggering feedback through display 32, robot 41, and stimulation device FES 31. Sensors EEG 22 & EMG 24 are used for inferring if there was an intention to make a goal directed movement.

Outputs of the System/Feedback Systems

[0175] Micro-displays 34 of headset 18: Renders 2D/3D virtual reality content, where a wearer experiences the

first person perspective of the virtual world as well as of his own avatar with its arms moving in relation to his own movements.

[0176] Robotic system **41**: Robotic system described in this invention is used for driving movements of the arm, where the user **1** holds a haptic knob. The system provides a range of movements as well as haptic feedback of natural movements of activities of daily living.

[0177] Functional Electrical Stimulation (FES) device **31**: Adhesive electrodes of FES system are placed on user's arms to stimulate nerves, which up on activated can restore the lost voluntary movements of the arm. Additionally, the resulting movements of the hand results in kinesthetic feedback to the brain.

Data Processing

[0178] The following paragraphs describe the data manipulations from inputs till outputs.

Acquisition Unit **53**:

[0179] The description of acquisition unit **53** ensures near perfect synchronization of inputs/sensor data and outputs/Stimulation/feedback of the system as illustrated in the FIG. **11**. Each sensor data may have different sampling frequency and whose sampling may have not initiated at exact same moment due to non-shared internal clock. In this example, the sampling frequency of EEG data is 1 kHz, EMG data is 10 KHz, IMU data is 300 Hz, Video camera data is 120 frames per second (fps). Similarly, the stimulation signals have different frequencies, where the display refresh rate is at 60 Hz, robot sensors of 1 KHz, and FES data at 1 KHz.

[0180] The acquisition unit **53** aims at solving the issue of synchronization of inputs and outputs accurately. In achieving so, the outputs of the system are sensed either with dedicated sensors or indirectly recorded from a stage before stimulation, for instance as follows:

[0181] Sensing the micro-display: Generally, the video content that is generated in the control system is first pushed to a display register **35** (a final stage before the video content is activated on the display). Together with video content, the controller sends a code to a part of the register (say N bits) corresponding to one or more pixels (not too many pixels, so that the user is not disturbed). The corner pixels in the micro display are preferred as they may not be visible to user. The codes (a total of 2^N) may be defined by the controller or the exercise logic unit describing the display content.

[0182] Sensing FES: The FES data can be read from its last stage of generation, i.e., from the DAC.

[0183] Sensing Robot's movements: The robots motors are embedded with sensors providing information on angular displacement, torque and other control parameters of the motors.

[0184] Now using a clock signal with preferably a much higher frequency than that of the inputs and outputs (e.g., 1 GHz), but at least double the highest sampling frequency among sensors and stimulation units, the acquisition module reads the sensor samples and attaches a time stamp as illustrated in the FIG. **12**. When a sample of a sensor arrives from its ADC **37a**, its time of arrival is annotated with next immediate rising edge of the clock signal. Similarly for every sensor and stimulation data a time-stamp is associated. When these samples arrive at the controller, it interprets the samples

according to the time stamp of arrival leading to minimized jitters across sensors and stimulations.

Physiological Data Analysis

[0185] The physiological data signals EEG and EMG are noisy electrical signals and preferably are pre-processed using appropriate statistical methods. Additionally the noise can also be reduced by better synchronizing the events of stimulation and behaviour with the physiological data measurements with negligible jitter.

[0186] FIG. **13** illustrates various stages of the pre-processing (filtering **68**, epoch extraction and feature extraction stages). EEG samples from all the electrodes are first spectrally filtered in various bands (e.g., 0.1-1 Hz, for slow cortical potentials, 8-12 Hz for alpha waves and Rolandic mu rhythms, 18-30 Hz for beta band and from 30-100 Hz for gamma band). Each of these spectral bands contains different aspects of neural oscillations at different locations. Following this stage the signals undergo spatial filtering to improve signal-to-noise ratio additionally. The spatial filters include simple processes such as common average removal to spatial convolution with Gaussian window or Laplace windows. Following this stage the incoming samples are segmented into temporal windows based on event markers arriving from event manager **71**. These events correspond to the moment the patient is given a stimulus or made a response.

[0187] These EEG segments are then fed to feature extraction unit **69**, where temporal correction is first made. One simple example of temporal correction is removal of baseline or offset from the trial data from a selected spectral band data. The quality of these trials is assessed using statistical methods such as

[0188] Outliers detection. Additionally, if there is a head movement registered through IMU sensor data, the trials are annotated as artefact trials. Finally features are computed from each trial that well describe the underlying neural processing. These features are then fed to a statistical unit **67**.

[0189] Similarly, the EMG electrode samples are first spectrally filtered, and applied a spatial filter. The movement information is obtained from the envelope or power of the EMG signals. Similar to EEG trials, EMG spectral data is segmented and passed to feature extraction unit **69**. The output of EMG feature data is then sent to statistical unit **67**.

[0190] The statistical unit **67** combines various physiological signals and motion data to interpret the intention of the user in performing a goal directed movement. This program unit includes mainly machine learning methods for detection, classification and regression analysis in interpretation of the features. The outputs of this module are intention probabilities and related parameters which drive the logic of the exercise in the Exercise logic unit **84**. This exercise logic unit **84** generates stimulation parameters which are then sent to a feedback/stimulation generation unit of the stimulation system **17**.

[0191] Throughout these stages, it is ensured to have minimal lag and more importantly least jitter.

Event Detection & Event Manager

[0192] Events such as the moment at which the patient is stimulated or presented an instruction in the VR display, the moment at which the patient performed an action are necessary for the interpretation of the physiological data. FIG. **14** illustrates event detection. The events corresponding to

movements and those of external objects or of a second person need to be detected. For this purpose the data from camera system **30** (stereo cameras, and 3D point cloud from the depth sensor) are integrated in the tracking unit module **73** to produce various tracking information such as: (i) patient's skeletal tracking data, (ii) object tracking data, and (iii) a second user tracking data. Based on the requirements of the behavioral analysis, these tracking data may be used for generating various events (e.g., the moment at which patient lifts his hand to hold door knob).

[0193] IMU data provides head movement information. This data is analyzed to get events such as user moving head to look at the virtual door knob.

[0194] The video display codes correspond to the video content (e.g., display of virtual door knob, or any visual stimulation). These codes also represent visual events. Similarly FES stimulation events, Robot movement and haptic feedback events are detected and transferred into event manager **71**. Analyzer modules **75**, including a movement analyser **75a**, an IMU analyser **75b**, an FES analyser **75c** and a robot sensor analyser **75d** process the various sensor and stimulation signals for the event manager **71**.

[0195] The event manager **71** then sends these events for tagging the physiological data, motion tracking data etc. Additionally these events also sent to Exercise logic unit for adapting the dynamics of exercise or challenges for the patient.

Other Aspects of Control System

[0196] The control system interprets the incoming motion data, intention probabilities from the physiological data and activates exercise logic unit and generates stimulation/feedback parameters. The following blocks are main parts of the control system.

[0197] VR feedback: The motion data (skeletal tracking, object tracking and user tracking data) is used for rendering 3D VR feedback on the head-mounted displays, in form of avatars and virtual objects.

[0198] Exercise logic unit **84**: The exercise logic unit implements sequence of visual display frames including instructions and challenges (target task to perform, in various difficulty levels) to the patient.

[0199] The logic unit also reacts to the events of the event manager **71**. Finally this unit sends stimulation parameters to the stimulation unit.

[0200] Robot & FES stimulation generation unit: this unit generates inputs required to perform a targeted movement of the robotic system **41** and associated haptic feedback. Additionally, stimulation patterns (current intensity and electrode locations) for the FES module could be made synchronous and congruent to the patient.

EXAMPLE 3

Brain Computer Interface and Motion Data Activated
Neural Stimulation with Augmented Reality
Feedback

OBJECTIVE

[0201] A system could provide precise neural stimulation in relation to the actions performed by a patient in real world, resulting in reinforcement of neural patterns for intended behaviors.

DESCRIPTION

[0202] Actions of the user and that of a second person and objects in the scene are captured with a camera system for behavioral analysis. Additionally neural data is recorded with one of the modalities (EEG, ECOG etc.) are synchronized with IMU data. The video captured from the camera system is interleaved with virtual objects to generate 3D augmented reality feedback and provided to the user through head-mounted display. Finally, appropriate neural stimulation parameters are generated in the control system and sent to the neural stimulation.

[0203] For delay and jitter between user's behavioral and physiological measures and neural stimulation should be optimized for effective reinforcement of the neural patterns.

[0204] The implementation of this example is similar to Example **2**, except that the head mounted display (HMD) displays Augmented Reality content instead of Virtual Reality (see FIG. **2e**). Meaning, virtual objects are embedded in 3D seen captured using stereo camera and displayed on micro displays insuring first person perspective of the scene. Additionally, direct neural stimulation is implemented through such as deep brain stimulation and cortical stimulation, and non-invasive stimulations such as trans-cranial direct current stimulation (tDCS), trans-cranial alternating current stimulation (tACS), trans-cranial magnetic stimulation (TMS) and trans-cranial Ultrasonic stimulation. The system can advantageously use one or more than one stimulation modalities at time to optimize the effect. This system exploits the acquisition unit described in the example **1**.

[0205] Various aspects or configurations of embodiments of the physiological parameter measurement and motion tracking system are summarised in paragraphs §1 to §41 hereinbelow:

[0206] §1. A physiological parameter measurement and motion tracking system comprising: a display system to display information to a user; a physiological parameter sensing system comprising one or more sensing means configured to sense electrical activity in a brain of a user and/or in the muscles of a user, the physiological parameter sensing unit being operable to provide electrical activity information in relation to electrical activity in the brain and/or the muscles of the user; a position/motion detection unit configured to provide a body part position information corresponding to a position/movement of a body part of the user; a control system arranged to receive the electrical activity information from the physiological parameter sensing system and the body part position information from the position/movement detection system, the control system being configured to provide a target location information to the display system comprising a target location for the body part, the display system being configured to display the target location information, the control system being further configured to provide a fourth piece of information to the display system based on the body part position information, the fourth piece of information providing the user with a view of the movement of the body part, or a movement correlated to the movement of the body part, the control system being further configured to measure the physiological and/or behavioural response to the displayed movement of the body part based upon the electrical activity information.

[0207] §2. A physiological parameter measurement and motion tracking system comprising: a display system to display information to a user; a physiological parameter sensing system comprising one or more sensing means configured to

sense electrical activity in a brain and/or muscles of a user, the physiological parameter sensing system being operable to provide a electrical activity information in relation to electrical activity in the brain and/or muscles of the user; a control system arranged to receive the electrical activity information from the physiological parameter sensing system, the control system being configured to provide a target location information to the display system comprising a target location for the body part, the display system being configured to display the target location information, the control system being further configured to provide a fourth piece of information to the display system based at least partially on the electrical activity information, the fourth piece of information providing the user with a view of the movement of the body part, or an intended movement of the body part.

[0208] §3. A physiological parameter measurement and motion tracking system according to paragraph §2, comprising: a position/motion detection system configured to provide a body part position information corresponding to a position/motion of a body part of the user; the control system being further configured to receive the body part position information from the position/motion detection system, wherein the control system is configured to determine whether there is no or an amount of movement less than a predetermined amount sensed by the position/motion detection system and if no or an amount of movement less than the predetermined amount is determined, then to provide the fourth piece of information to the display system based at least partially on the electrical activity information, such that the displayed motion of the body part is at least partially based on the electrical activity information.

[0209] §4. A physiological parameter measurement and motion tracking system according to paragraph §3, wherein the control system is operable to provide the fourth piece of information based on the body part position information if the amount of movement sensed by the position/motion detection system is above the predetermined amount.

[0210] §5. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§4, wherein the control system is configured to supply a fifth piece of information to the display means to provide the user with feedback in relation to a parameter of the electrical activity information obtained following completion of a movement of a body part or an intended movement of a body part.

[0211] §6. A physiological parameter measurement and motion tracking system according to paragraph §5, wherein the parameter is computed from a magnitude and/or duration of a sensed signal strength.

[0212] §7. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§6, wherein the physiological parameter sensing system comprises one or more EEG sensors and/or one or more ECOG sensors and/or one or more single or multi unit recording chip, aforementioned sensors being to measure electrical activity in a brain of a user.

[0213] §8. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§7, wherein the physiological parameter sensing system comprises one or more EMG sensors to measure electrical activity in a muscle of a user.

[0214] §9. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§8, wherein the physiological parameter sens-

ing system comprises one or more GSR sensors, the physiological parameter sensing system being operable to supply information from the or each GSR sensor to the control unit, the control unit being operable to process the information to determine a level of motivation of a user.

[0215] §10. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§9, wherein the physiological parameter sensing system comprises one or more: respiration sensors; and/or one or more ECG sensors; and/or temperature sensors, the physiological parameter sensing system being operable to supply information from the or each aforementioned sensor to the control unit, the control unit being operable to process the information predict an event corresponding to a state of the user.

[0216] §11. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1 and §3 to §10, wherein the position/motion detection system comprises one or more cameras operable to provide an image stream of a user.

[0217] §12. A physiological parameter measurement and motion tracking system according to paragraph §11, wherein the cameras comprise one or more colour cameras and a depth sensing camera.

[0218] §13. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§12 wherein the control using is operable to supply information to the physiological parameter sensing system cause a signal to be provided to the sensors to stimulate movement or a state of a user.

[0219] §14. A physiological parameter measurement and motion tracking system according to any one of the preceding paragraphs §1-§13 comprising a clock module, the clock module being operable to time stamp information transferred to and from one or more of the: physiological parameter sensing system; the position/motion detection system; the control system; the display system, the system being operable to process the information to enable real-time operation of the physiological parameter measurement and motion tracking system.

[0220] §15. A head set for measuring a physiological parameter of a user and providing a virtual reality display comprising: a display system operable to display a virtual reality image or augmented reality image or mixed reality or video to a user; a physiological parameter sensing system comprising a plurality of sensors, the sensors being operable to measure electrical activity in the brain of the user, the plurality of sensors being arranged such that they are distributed over the sensory and motor region of the brain of the user.

[0221] §16. A headset according to paragraph §15, wherein the sensors are arranged such that they are distributed over a substantial portion of a scalp of a user.

[0222] §17. A headset according to any one of the preceding paragraphs §15 to §16, wherein the sensors are arranged with a density of at least 1 sensor per 10 cm².

[0223] §18. A head set according to any one of the preceding paragraphs §15 to §17, wherein the sensors are arranged in groups to measure electrical activity in specific regions of the brain.

[0224] §19. A head set according to any one of the preceding paragraphs §15 to §18, wherein the display unit is mounted to a display unit support, the display unit support being configured to extend around the eyes of a user and at least partially around the back of the head of the user.

[0225] §20. A head set according to any one of the preceding paragraphs §15 to §19, wherein the sensors are connected to a flexible cranial sensor support that is configured to extend over a substantial portion of a head of a user.

[0226] §21. A headset according to paragraph §20, wherein the cranial sensor support comprises a cap, the cap being connected at a periphery to the display unit support.

[0227] §22. A headset according to paragraph §20, wherein the cranial sensor support comprises a plate on which sensors are mounted, the plate being connected to a strap which is configured to extend around a top of a head of a user, the strap being connected at its ends to the display system support, and being arranged approximately perpendicular to the support.

[0228] §23. A headset according to paragraph §20, wherein the cranial sensor support comprises a plurality of pads, a first group of pads being arranged to extend from a first pad support which extends in an approximately orthogonal direction from the display unit support, a second group of pads being arranged to extend from a second pad support which extends in an approximately orthogonal direction from the display unit support.

[0229] §24. A head set according to any one of paragraphs §15-§23, wherein the physiological parameter sensing system comprises one or more non-invasive sensors such as an EEG sensor.

[0230] §25. A head set according to any one of paragraphs §15-§24, wherein the physiological parameter sensing system comprises one or more invasive sensors such as an ECG sensor.

[0231] §26. A head set according to any one of paragraphs §15-§25, wherein the physiological parameter sensing system comprises one or more eye movement sensors, the or each eye movement sensor being arranged on the head set in operational proximity to one or both eyes of a user.

[0232] §27. A head set according to paragraph §26, wherein the or each eye movement sensor is operable to sense electrical activity due to eye movement.

[0233] §28. A head set according to paragraph §27, wherein the or each eye movement sensor is an EOG sensor.

[0234] §29. A head set according to any one of paragraphs §15-§28, wherein the headset further comprises a position/motion detection system operable to detect a position/motion of a body part of a user.

[0235] §30. A head set according to paragraph §29, wherein the position/motion detection system comprises one or more colour cameras, and a depth sensor.

[0236] §31. A head set according to any one of paragraphs §15-§30, wherein the head set comprises a head movement sensing unit being operable to sense the head movement of a user during operation of the device.

[0237] §32. A head set according to paragraph §31, wherein the head movement sensing unit comprises an acceleration sensor and an orientation sensor.

[0238] §33. A head set according to any one of paragraphs §15-§32, wherein the headset comprises a wireless data transmitting means configured to wirelessly transmit data from one or more of the following systems: the physiological parameter sensing system; the position/motion detection system; the head movement sensing unit.

[0239] §34. A head set according to any one of paragraphs §15-§33 wherein the display system and the physiological parameter sensing system comprises any one or more of the

features of the display system and the physiological parameter sensing system defined in any one of paragraphs §1 to §14.

[0240] §35. A physiological parameter measurement and motion tracking system comprising a control system, a sensing system, and a stimulation system, the sensing system comprising one or more physiological sensors including at least brain electrical activity sensors, the stimulation system comprising one or more stimulation devices including at least a visual stimulation system, the control system comprising an acquisition module configured to receive sensor signals from the sensing system, and a control module configured to process the signals from the acquisition module and control the generation of stimulation signals to one or more devices of the stimulation system, wherein the control system further comprises a clock module and wherein the control system is configured to time stamp signals related to the stimulation signals and the sensor signals with a clock signal from the clock module, enabling the stimulation signals to be synchronized with the sensor signals by means of the time stamps.

[0241] §36. A system according to §35 wherein said time stamped signals related to the stimulation signals are content code signals (39) received from the stimulation system.

[0242] §37. A system according to §36 wherein said system further comprises a display register configured to receive display content representing a final stage before the display content is activated on the display, the display register being configured to generate a display content code signal for transmission to the control system, a time stamp being attached to the display content code signal by the clock module.

[0243] §38. A system according to §35, §36 or §37 wherein the sensing system comprises physiological sensors selected from a group comprising Electromyogram (EMG) sensors, Electrooculography (EOG) sensors, Electrocardiogram (ECG) sensors, Inertial Sensors (INS), Body temperature sensor, Galvanic skin sensor.

[0244] §39. A system according to any of §35-38 wherein the sensing system comprises position and/or motion sensors to determine the position and/or the movement of a body part of the user.

[0245] §40. A system according to the §39 wherein at least one said position/motion sensor comprises a camera and optionally a depth sensor.

[0246] §41. A system according to any one of §35-40 wherein the stimulation system comprises stimulation devices selected from a group comprising audio stimulation device, Functional Electrical Stimulation (FES) devices, and haptic feedback devices.

[0247] §42. A system according to any one of §35-41 further comprising any one or more of the additional features of the system according to §1-§34.

LIST OF REFERENCES

- [0248]** 10 Physiological parameter measurement and motion tracking system
- [0249]** 12 Control system
- [0250]** 51 Control module
- [0251]** 57 output signals (video, audio, stimulation)
- [0252]** 53 Acquisition module
- [0253]** 55 Memory
- [0254]** 52 Skeletal tracking Module
- [0255]** 60 Data fusion unit
- [0256]** 62 Calibration unit
- [0257]** 64 Skeletal tracking unit

[0258] 54 Physiological parameter processing Module
 [0259] 66 Re-referencing unit
 [0260] 68 Filtering unit
 [0261] 70 Spectral filtering module
 [0262] 72 Spatial smoothing filtering module
 [0263] 74 Laplacian filtering module
 [0264] 76 Event marking unit
 [0265] 78 Artefact unit
 [0266] 80 Artefact detecting module
 [0267] 82 Artefact removal module
 [0268] 69 feature extraction unit
 [0269] 67 statistical unit
 [0270] 56 Head tracking module
 [0271] 104 Eye gaze tracking module
 [0272] 58 VR generation module
 [0273] 84 Exercise logic unit
 [0274] Input unit
 [0275] 86 VR environment unit
 [0276] 88 Body model unit
 [0277] 90 Avatar posture generation unit
 [0278] 92 VR content integration unit
 [0279] 94 Audio generation unit
 [0280] 96 Feedback generation unit
 [0281] 106 Clock module
 [0282] 71 Events manager
 [0283] 73 Tracking unit
 [0284] User tracking
 [0285] →64 Skeletal tracking unit
 [0286] →104 Eye gaze tracking module
 [0287] Object tracking
 [0288] 75 Analyzer modules
 [0289] 75a Movement
 [0290] 75b IMU
 [0291] 75c FES
 [0292] 75d Robot sensor
 [0293] 18 Head set
 [0294] 40 Head movement sensing Unit
 [0295] 42 Movement sensing unit
 [0296] 44 Acceleration sensing means
 [0297] 47 Head orientation sensing means
 [0298] 46 Gyroscope
 [0299] 48 Magnetometer
 [0300] 50 movement sensing unit support (mount to HMD system)
 [0301] 32 Display unit
 [0302] 34 Display means
 [0303] 35 Display register
 [0304] 36 Display unit support
 [0305] 33 Audio unit
 [0306] 27 Cranial sensor support (for mounting sensors 20)
 [0307] 27a plate
 [0308] 27b mounting strap
 [0309] 100 Eye gaze sensing Unit
 [0310] 102 eye gaze sensor
 [0311] 13 Sensing system
 [0312] 14 Physiological parameter sensing system
 [0313] 20 Sensors
 [0314] 22 Electroencephalogram (EEG)—connected of head display unit
 [0315] 24 Electromyogram (EMG)—connected to muscles in body
 [0316] 25 Electrooculography (EOG)—eye movement sensor
 [0317] 27 Electrocardiogram (ECG)

[0318] 29 Inertial Sensor (INS)/Inertial measurement unit (IMU) sensor
 [0319] 40 Head movement sensing Unit
 [0320] Body temperature sensor
 [0321] Galvanic skin sensor
 [0322] 16 Position/motion detection system
 [0323] 26 Sensors
 [0324] 28 Depth/distance sensor
 [0325] 30 Camera (colour)
 [0326] 21 sensor output signals
 [0327] 17 Stimulation system
 [0328] 31 Functional Electrical Stimulation (FES) system
 [0329] Audio stimulation system→audio unit 33
 [0330] Video stimulation system→display unit 32
 [0331] 37a Analogue to Digital Converter (ADC)
 [0332] 37b Digital to Analogue Converter (DAC)
 [0333] 39 content code signal
 [0334] 41 Haptic feedback device→robot
 [0335] 23 user feedback sensors

1. A physiological parameter measurement and motion tracking system comprising:

- a display system to display information to a user;
- a physiological parameter sensing system comprising one or more sensors configured to sense electrical activity in a brain of a user and to generate brain electrical activity information;
- a position/motion detection system configured to provide a body part position information corresponding to a position/motion of a body part of the user;
- a control system arranged to receive the brain electrical activity information from the physiological parameter sensing system and to receive the body part position information from the position/motion detection system, the control system being configured to provide a target location information to the display system comprising a target location for the body part, the display system being configured to display the target location information, the control system being further configured to provide body part position information to the display system providing the user with a view of the movement of the body part, or an intended movement of the body part; and

a clock module, the clock module being operable to time stamp information transferred from the physiological parameter sensing system and the position/motion detection system, the system being operable to process the information to enable real-time operation.

2. A system according to claim 1 wherein the clock module is configured to time stamp signals related to stimulation signals configured to stimulate brain activity of the user and the measured brain activity signals, enabling the stimulation signals to be synchronized with the brain activity signals by way of the time stamps.

3. A system according to claim 1, wherein the control system is configured to determine whether there is no or an amount of movement less than a predetermined amount sensed by the position/motion detection system and if no or an amount of movement less than the predetermined amount is determined, then to provide the body part position information to the display system based at least partially on the brain electrical activity information, such that the displayed motion of the body part is at least partially based on the brain electrical activity information.

4. A system according to claim 1, wherein the physiological parameter sensing system comprises a plurality of sensors configured to measure different physiological parameters, selected from a group consisting of EEG sensors, ECOG sensors, EMG sensors, GSR sensors, respiration sensors, ECG sensors, temperature sensors, respiration sensor, and pulse oximetry sensors.

5. A system according to claim 1, wherein the position/motion detection system comprises one or more colour cameras operable to provide an image stream of a user and a depth sensing camera.

6. A system according to claim 1, wherein the control system is operable to supply information to the physiological parameter sensing system to generate a signal to stimulate movement or a state of a user.

7. A system according to claim 1, further comprising a headset forming a single unit incorporating said display system operable to display a virtual or augmented reality image or video to the user; wherein said one or more sensors is configured to sense electrical activity in a brain, the one or more sensors comprising a plurality of sensors distributed over a sensory and motor region of the brain of the user.

8. A system according to claim 7, wherein plurality of sensors are connected to a flexible cranial sensor support that is configured to extend over a head of a user, and connected to the display system support.

9. A system according to claim 8, wherein the flexible cranial sensor support comprises a plurality of pads, a first group of pads being arranged to extend from a first pad support which extends in an approximately orthogonal direction from the display unit support, a second group of pads being arranged to extend from a second pad support which extends in an approximately orthogonal direction from the display unit support.

10. A system according to claim 7, wherein the headset incorporates said plurality of sensors configured to measure different physiological parameters, selected from a group consisting of EEG sensors, ECOG sensors, eye movement sensors, and head movement sensing unit.

11. A system according to claim 7, wherein the headset further incorporates one of said position/motion detection system operable to detect a position/motion of a body part of a user, the position/motion detection system comprising one or more colour cameras, and a depth sensor.

12. A system according to claim 7, wherein the headset comprises a wireless data transmitter configured to wirelessly transmit data from one or more of the following systems: the physiological parameter sensing system; the position/motion detection system; and the head movement sensing unit.

13. A system according to claim 1 further comprising a functional electrical stimulation (FES) system connected to the control system and operable to electrically stimulate one or more body parts of the user, the FES including one or more stimulation devices selected from a group consisting of electrodes configured to stimulate nerves or muscles, trans-cranial alternating current stimulation (tACS), direct current stimulation (tDCS), trans-cranial magnetic stimulation (TMS) and trans-cranial ultrasonic stimulation.

14. A system according to claim 1, further comprising a robotic system for driving movements of a limb of the user and configured to provide haptic feedback.

15. A system according to claim 1, further comprising an exercise logic unit configured to generate visual display frames including instructions and challenges to the display system.

16. A system according to claim 13, further comprising an events manager unit configured to generate and transmit stimulation parameters to the one or more stimulation devices.

17. A system according to claim 13, wherein each of the one or more stimulation devices comprises with an embedded sensor whose signal is registered by a synchronization device.

18. A system according to claim 1, further comprising a display register configured to receive display content representing a final stage before the display content is activated on the display system, the display register being configured to generate a display content code for transmission to the control system, a time stamp being attached to the lock content code by the clock module.

19. A physiological parameter measurement and motion tracking system comprising:

a control system;

a sensing system, the sensing system comprising one or more physiological sensors including at least brain electrical activity sensors; and

a stimulation system, the stimulation system comprising one or more stimulation devices including at least a visual stimulation system, the control system comprising an acquisition module configured to receive sensor signals from the sensing system, and a control module configured to process the signals from the acquisition module and control the generation of stimulation signals to one or more devices of the stimulation system, wherein the control system further comprises a clock module, wherein the control system is configured to time stamp signals related to the stimulation signals and the sensor signals with a clock signal from the clock module, enabling the stimulation signals to be synchronized with the sensor signals by means of the time stamps, and wherein said time stamped signals related to the stimulation signals are content code signals received from the stimulation system.

20. (canceled)

21. A system according to claim 19, further comprising a display register configured to receive display content representing a final stage before the display content is activated on the display, the display register being configured to generate a display content code signal for transmission to the control system, a time stamp being attached to the display content code signal by the clock module.

22. A system according to claim 19, wherein the sensing system comprises physiological sensors selected from a group comprising Electromyogram (EMG) sensors, Electrooculography (EOG) sensors, Electrocardiogram (ECG) sensors, Inertial Sensors (INS), Body temperature sensor, Galvanic skin sensor, pulse oximetry sensor, and respiration sensors.

23. A system according to claim 19, wherein the sensing system comprises at least one of position and motion sensors to determine at least one of position and movement of a body part of the user.

24. A system according to claim 23 wherein at least one said position/motion sensor comprises a camera and optionally a depth sensor.

25. A system according to claim **19** wherein the stimulation system comprises stimulation devices selected from a group comprising audio stimulation device, Functional Electrical Stimulation (FES) devices, and haptic feedback devices.

26. A system according to claim **19** wherein the clock module is configured to be synchronized with clock module of other systems, including external computers.

27. (canceled)

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摘要(译)

公开了一种生理参数测量和运动跟踪系统，包括控制系统，传感系统和刺激系统。传感系统包括一个或多个生理传感器，至少包括脑电活动传感器。刺激系统包括一个或多个刺激装置，其至少包括视觉刺激系统。控制系统包括：获取模块，被配置为从感测系统接收传感器信号；以及控制模块，被配置为处理来自获取模块的信号并控制刺激信号到刺激系统的一个或多个设备的生成。控制系统还包括时钟模块，并且控制系统被配置为从刺激系统接收内容代码信号，并利用来自时钟模块的时钟信号对内容代码信号和传感器信号加时间戳。

