SYSTEM AND METHOD FOR SSVEP BASED CONTROL OF ELECTRICAL DEVICES

Technical Field

The present disclosure relates to brain – computer interface (BCI) techniques based upon steady state visual evoked potentials (SSVEPs). More particularly, aspects of the present disclosure relate to systems and methods for SSVEP based electrical device or appliance control that provide a simple electrode configuration for the capture of electroencephalographic (EEG) signals; a computationally efficient, accurate process by which EEG signals are analyzed and a visual stimulus generator associated with an appliance identified; a simple, reliable multi-device power interface unit; and a simple, robust, assistance-free system activation process that avoids or eliminates visual fatigue and/or user distraction.

Background

Aspects of brain waves measured from the human scalp have been intensely researched as a result of efforts to develop brain-computer interface (BCI) systems and devices. A BCI is a direct communication pathway between a brain and an external device. BCIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions.

BCI techniques play a prominent role in the development of systems that utilize electromyogram (EMG), electrocorticogram (ECoG), or electroencephalogram (EEG) signals to facilitate a disabled user's control of a neuroprosthetic device. EEG is a common non-invasive modality that can be used with persons with serious disability. EEG signals arise from electrical activity that can be detected external to the human scalp. EEG signals are produced by neural firing within the brain, and reflect correlated synaptic activity caused by post-synaptic potentials generated by thousands or millions of cortical neurons having similar spatial orientation.

Acquisition of EEG signals involves scalp electrodes or leads, typically using locations specified by the International 10-20 system. In EEG, minute potentials evoked by sensory stimuli are of particular importance as these time-locked transient wavelets show how populations of cells behave in response to afferent volleys carried by primary sensory fibers. When a brief stimulus is presented to a subject, a transient brain response to that stimulation occurs.

In general, EEG-based neuroprosthetic systems consist of a signal acquisition system, signal processing algorithms and application devices. Two modalities widely used in EEG-based neuroprosthetic systems are spontaneous EEG and event related potentials (ERPs) such as visual evoked potentials (VEPs). An evoked potential indicates the effect of a stimulus on the brain, and is sensitive to changes in sensory and perceptual processes. A primary advantage of the VEP technique is its temporal resolution, which is limited only by measurement device sampling rate.

VEPs can be categorized into transient visual evoked potentials (TVEPs) and steady state visual evoked potentials (SSVEPs). The SSVEP is a periodic response to a visual stimulus modulated at a frequency higher than 6 Hz, and can be recorded at scalp locations corresponding to the visual cortex. The visual stimulus can be generated by a light emitting diode (LED) or a checkerboard or other pattern displayed by a liquid crystal display (LCD) screen. The SSVEP has the same fundamental frequency as that of the visual stimulus as well as its harmonics. In SSVEP-based systems, several stimuli coded by different frequencies are presented in the field of vision and different SSVEP responses can be produced by shifting a user's interest or attention to one of a number of frequency-coded stimuli.

Prior techniques directed to stimulus selection fail to produce reliable SSVEP signals for accurate operation of EEG-based neuroprosthetic systems without incurring visual fatigue in the subject under consideration. Further, prior stimulus systems can require unnecessarily complex circuitry, leading to increased system overhead and/or cost.

Prior electrode configurations are also unnecessarily complex. For instance, in order to obtain reliable SSVEP signals, electrodes have been positioned at as many as 64 different scalp locations, resulting in increased cost and undesirably long signal processing times. Several attempts have been made to place fewer electrodes on the human scalp to obtain SSVEP signals, but such attempts have led to poor and inaccurate SSVEP signals, and hence poor, inaccurate, and unreliable neuroprosthectic device control.

Another problem arises from existing algorithms used to process the SSVEP signals. Current algorithms are complex and produce inaccurate or inconsistent results, and lack the capability to effectively discriminate similar stimuli which are near or next to each other. Yet another problem arises because current implementations of EEG-based neuroprosthetic systems lack an easy to use, flexible, reliable and cost effective way of controlling multiple devices in response to EEG signals.

Because EEG-based neuroprosthetic systems offer the potential to provide a significant positive impact upon physically challenged individuals' lives, a need exists for improvement to existing EEG-based neuroprosthetic systems. It is therefore desirable to provide a solution to address at least one of the foregoing problems associated with EEG-based neuroprosthetic systems.

Summary

An aspect of the disclosure provides an automated process for controlling a set of devices based upon the EEG data generated by an individual's brain. The set of devices can include a set of visual stimulus generators and a set of electrical devices, where each electrical device is associated with a given visual stimulus generator. The process can include transitioning each visual stimulus generator to a first state (e.g., a quiescent or inactive state, or a state in which SSVEP generation at frequencies corresponding to device control operations is avoided) in which the output of visual stimuli by each visual stimulus generator in a distinct manner relative to each other visual stimulus generator is avoided; accessing first EEG data generated by the individual's brain; determining whether the first EEG data corresponds to an unassisted behaviour by the individual that represents a visual stimulus generator activation command; and transitioning each visual stimulus generator within the set of visual stimulus generators to a second state in which each visual stimulus generator outputs visual stimuli in a distinct manner relative to each other visual stimulus generator within the set of visual stimulus generators in response to the visual stimulus generator activation command. In the absence of the detection of a visual stimulus generator activation command, the visual stimulus generators can be maintained in the first state. When in the second state, each visual stimulus generator can provide visual stimuli at a distinct presentation frequency relative to each other visual stimulus. Determining that the first EEG data corresponds to an unassisted behaviour that represents a visual stimulus generator activation command can involve analyzing the first EEG data to identify an awake individual eyes-closed condition and/or eye closure – eye opening sequence across or with respect to a particular time interval, such as an activation command interval.

A process according to the disclosure can further involve accessing second EEG data corresponding to SSVEPs generated by the individual's brain while the user directed their visual attention to a particular visual stimulus generator, and determining whether the second EEG data indicates the particular visual stimulus generator to which the user directed their visual attention. Each visual stimulus generator can be transitioned to the first state in the event

that analysis of the second EEG data fails to indicate the particular visual stimulus generator within the set of visual stimulus generators to which the user directed their attention. The process can additionally include identifying the particular visual stimulus generator to which the user directed their visual attention; and adjusting an operational state (e.g., by establishing, changing, or toggling a power state) of a particular electrical device associated with or corresponding to the particular visual stimulus generator. In association with (e.g., before, during, or after) adjusting the particular electrical device's operating state, each visual stimulus generator can be transitioned or returned to the first state.

According to particular aspects of the disclosure, a system for controlling a set of electrical devices based upon SSVEP generation by a system user's brain includes a set of visual stimulus generators, each of which is configured to output visual stimuli; a visual stimulus generator controller coupled to each visual stimulus generator and configured to selectively enable each visual stimulus generator to output visual stimuli in a distinct manner relative to each other visual stimulus generator; an EEG system or unit configured to provide EEG data generated by the user's brain; and a device identification system. The device identification system includes a processing unit coupled to a memory in which portions of a user state detection module reside. The user state detection module includes a program instruction set that when executed determines whether EEG data generated in response to an unassisted user behaviour corresponds to a visual stimulus generator activation command such as an awake user eyes-closed condition and/or an eye closure – eye opening sequence across a particular time interval. The visual stimulus generator controller can maintain the stimulus generators in a first state in which in the output of visual stimuli by each visual stimulus generator in a distinct manner relative to each other visual stimulus generator is avoided until a visual stimulus generator activation command is detected, after which the visual stimulus generator controller can transition the visual stimulus generators to a second state in which each visual stimulus generator outputs visual stimuli in a distinct manner relative to each other visual stimulus generator.

The memory further can further include a device identification module having a set of program instructions configured to identify a particular visual stimulus generator to which the user has directed their visual attention based upon captured EEG data, thereby facilitating the identification and selective control of an electrical device associated with the particular visual stimulus generator.

Certain aspects of the disclosure provide an EEG acquisition system having a set of electrodes spatially organized in accordance with a standard EEG 10-20 montage and configured to detect at least one of a first EEG signal difference between O1 – Fz and a second EEG signal difference between O2 – Fz. The set of electrodes can include fewer than five electrodes configured to detect EEG signals at any given time.

In addition or as an alternative to the foregoing, an aspect of the present disclosure provides a process for controlling a set of devices based upon SSVEPs generated by an individual's brain, which can include providing first EEG data corresponding to EEG signals generated by the individual's brain while the individual directed their visual attention to a baseline scene; generating a plurality of baseline power spectral density amplitude values corresponding to the first EEG data, the plurality of baseline power spectral density amplitude values corresponding to a set of fundamental frequencies f_k and a set of harmonic multiples nf_k of each fundamental frequency f_k; and generating a device identification threshold T_I using the plurality of baseline power spectral density amplitude values.

The process can further include providing second EEG data corresponding to SSVEPs generated by the individual's brain while the individual directed their visual attention to a particular visual stimulus generator within a set of visual stimulus generators, each of which is configured to provide visual stimuli at a unique presentation frequency approximately equal to a corresponding fundamental frequency f_k within the set of fundamental frequencies f_k; generating a plurality of active power spectral density values corresponding to the second EEG data, the plurality of active power spectral density values corresponding to the set of fundamental frequencies f_k and the set of harmonic multiples nf_k thereof; generating a plurality of thresholded active power spectral density amplitude values by selectively scaling each active power spectral density value within the plurality of active power spectral density values based upon a comparison with at least one of a baseline power spectral density value and the device identification threshold T_I; and determining whether a dominant active power spectral density amplitude value exists corresponding to the plurality of thresholded active power spectral density amplitude values.

Such a process can also include identifying a dominant frequency f_D corresponding to a dominant active power spectral density amplitude value, the dominant frequency f_D equal to a particular fundamental frequency f_k within the set of fundamental frequencies f_k; identifying a particular visual stimulus generator configured to provide visual stimuli at a presentation frequency corresponding to the dominant frequency f_D; identifying an electrical device associated with the particular visual stimulus generator; and one of establishing and adjusting an operating state of the electrical device associated with the particular visual stimulus generator.

According to an aspect of the disclosure, a system for controlling a set of devices based upon SSVEPs generated by an individual's brain can include a set of visual stimulus generators, each of which is configured to output visual stimuli; a visual stimulus generator controller coupled to each visual stimulus generator and configured to selectively enable each visual stimulus generator to output visual stimuli in a distinct manner relative to each other visual stimulus; an EEG data provision or acquisition system configured to provide EEG data generated by the user's brain; and a device identification system. The device identification system can include a processing unit coupled to a memory in which portions of a device identification module reside.

The device identification module includes a set of program instructions that when executed identifies a particular visual stimulus generator by way of device identification operations that include generating a plurality of active power spectral density values corresponding to EEG data acquired while the individual directed their visual attention to the particular visual stimulus generator, the plurality of active power spectral density values corresponding to a set of fundamental frequencies f_k and a set of harmonic multiples nf_k thereof; generating a plurality of thresholded active power spectral density amplitude values by selectively scaling each active power spectral density value within the plurality of active power spectral density values based upon a comparison with at least one of a baseline power spectral density value and a device identification threshold T_I; and determining whether a dominant active power spectral density amplitude value exists corresponding to the plurality of thresholded active power spectral density amplitude values.

The device identification operations can further include determining a dominant frequency f_D corresponding to a dominant active power spectral density amplitude value, the dominant frequency f_D equal to a particular fundamental frequency f_k within the set of fundamental frequencies f_k; identifying a particualr visual stimulus generator within the set of visual stimulus generators that output visual stimuli at a frequency corresponding to the dominant frequency f_D; identifying an electrical device associated with the particular visual stimulus generator; and outputting a set of identifiers corresponding to at least one from the group of the particular visual stimulus generator and the electrical device associated therewith.

According to an aspect of the disclosure, the system can further include a system control unit configured to facilitate changing an operating state of the electrical device associated with the particular visual stimulus generator in response to receipt of one or more identifiers, commands, or instructions. The system control unit can be configured to output an electrical device control command based upon an identifier. The system can further include a device control interface configured for signal communication with the system control unit and further configured to one of establish and adjust an operating state of the electrical device associated with the particular visual stimulus generator.

The memory can also include a calibration unit, which includes a set of program instructions configured to perform calibration operations that involve analyzing baseline EEG data corresponding to EEG signals generated by the individual's brain while the individual directed their visual attention to a baseline scene; generating a plurality of baseline power spectral density amplitude values corresponding to the baseline EEG data, the plurality of baseline power spectral density amplitude values corresponding to the set of fundamental frequencies f_k and the set of harmonic multiples nf_k of each fundamental frequency f_k; and generating the device identification threshold T_I using the plurality of baseline power spectral density amplitude values.

Particular aspects of the present disclosure further provide one or more computer readable media storing program instructions that, when executed, facilitate or enable SSVEP based device control operations in accordance with embodiments of the disclosure, such as embodiments described herein.

Brief Description of the Drawings

Embodiments of the disclosure are described hereinafter with reference to the following drawings, in which:

FIG. 1 is a schematic illustration of an SSVEP based appliance control system according to an embodiment of the disclosure.

FIG. 2 is a schematic illustration of an electrode configuration with respect to the International EEG 10 – 20 montage according to an embodiment of the disclosure.

FIG. 3 is a block diagram of a system control and communication unit according to an embodiment of the disclosure.

FIG. 4 is a block diagram of a device identification unit according to an embodiment of the disclosure.

FIG. 5 is a schematic illustration of a representative configuration GUI 500 in accordance with an embodiment of the disclosure.

FIG. 6 is a flow diagram of a representative SSVEP based electrical device or appliance control process according to an embodiment of the disclosure.

FIG. 7 is a flow diagram of a representative baseline parameter generation process according to an embodiment of the disclosure

FIG. 8 is a flow diagram of a representative device identification process according to an embodiment of the disclosure.

Detailed Description

Embodiments of the present disclosure are directed to systems, apparatuses, devices, and processes for selectively controlling the operation of one or more electrical devices such as appliances based upon the capture and analysis of EEG signals corresponding to SSVEPs. The SSVEPs are generated while a user selectively directs their visual attention to a visual stimulus generator. Various embodiments include multiple visual stimulus generators, each of which can be associated with a given electrical device or appliance. Each visual stimulus generator is configured to generate, output, display, or present visual or optical stimuli or signals to a user in a distinct or distinguishable manner relative to each other visual stimulus generator. For instance, depending upon embodiment details, each visual stimulus generator can be configured to output visual stimuli at a unique or distinct presentation frequency and/or a distinct spatial presentation pattern. The visual stimuli can trigger, evoke, or give rise to SSVEPs within a portion of the user's brain at SSVEP frequencies that correspond to the presentation frequency. A visual stimulus generator can be an LED array, or another type of optical signal presentation device.

An EEG acquisition system, subsystem, or unit facilitates the capture or acquisition of EEG signals generated by the user's brain. User wearable headgear can carry a set of electrodes at particular locations relative to a user's scalp, such that the electrodes can capture EEG signals corresponding to SSVEPs. In various embodiments, the set of electrodes includes a small or minimal number of electrodes. A system control and communication unit can capture EEG signals as sampled EEG data. A device identification unit can analyze captured EEG signals by way of a computationally efficient process, and determines which visual stimulus generator gave rise to the captured EEG signals, thereby identifying the electrical device or appliance associated with the visual stimulus generator to which the user directed their visual attention.

The device identification unit can communicate or transfer a device identifier (ID) and/or a power interface ID to the system control and communication unit, which issues a corresponding device control command and/or a corresponding power interface control command to a multi-device interface unit. In response, the multi-device interface unit can transition, adjust, or establish an operating state of the electrical device or appliance associated with the visual stimulus generator. For instance, a multi-device power interface unit can transition a power interface corresponding to an electrical device or appliance from an off-state to an on-state, or an on-state to an off-state, thereby transitioning the electrical device or appliance associated with the visual stimulus generator from an off-state to an on-state, or an on-state to an off-state. The EEG acquisition unit, the system control and configuration unit, the device identification unit, and the multi-device interface unit thus facilitate automatically changing an operating state of an electrical device associated with a visual stimulus generator to which the user directed their visual attention.

In various embodiments, the system control and communication unit transitions the visual stimulus generators to a state in which the generation of visual stimuli by each active visual stimulator in a distinct manner relative to each other active visual stimulus generator is avoided unless the device identification unit determines or detects that an unassisted or self directed user activity or behaviour corresponding to or representative of a visual stimulus activation command has occurred. In multiple embodiments, the unassisted user behaviour includes an awake user eyes closed state or condition that exists across a predetermined time interval. Upon detection or identification of a user generated visual stimulus generator activation command, the device identification unit can communicate an activation notification to the system control and communication unit, which can enable the generation of visual stimuli by each active visual stimulus generator in a manner that is distinct (e.g., temporally and/or spatially distinct) relative to each other active visual stimulus generator.

In several embodiments, the device identification unit can determine whether captured EEG signals indicate or correspond to an eyes closed condition, and possibly whether an eyes closed condition corresponds to a user awake state or a user sleep state. In response to or following the detection of an eyes closed, awake user state across a predetermined period of time, the system control and communication unit transitions the set of visual stimulus generators to an active state, such that a user with eyes open can direct their visual attention to an active visual stimulus generator associated with an electrical device of interest. Thus, the system can be enabled, activated, or reset for electrical device identification and control operations in response to a user closing their eyes for a predetermined amount of time. In some embodiments, (re)activation of the set of visual stimulus generators can occur in response to the detection of an eyes closed, awake user state across a predetermined time interval has been detected, followed by the detection of an eyes open state (e.g, which immediately succeeds the eyes closed state).

Multiple embodiments of the present disclosure avoid continual, ongoing, or unnecessarily sustained or prolonged activation of visual stimulus generators during normal device or appliance operation (e.g., visual stimulus generators remain inactive unless a visual stimulus generator activation command corresponding to a particular awake user eye closure behaviour is detected), or while the user sleeps or attempts to sleep. As a result, embodiments of the disclosure can minimize or eliminate user distraction and/or visual fatigue.

After system (re)activation or reset in response to the detection of an eyes closed condition across a particular time interval, the device identification unit can analyze captured EEG signals and identify an electrical device of interest to the user in one or more manners described herein. The system control and communication unit can issue an appropriate control command to the multi-device interface unit, thereby toggling an operating state of the electrical device of interest. The system control and communication unit can subsequently transition the set of visual stimulus generators to a quiescent or off state, thereby reducing, minimizing, or eliminating user visual fatigue. In some embodiments, the system can additionally transition the set of visual stimulus generators to or maintain the set of visual stimulus generators in an inactive state in response to the detection of an eyes closed, user asleep state.

Embodiments of the present disclosure are configured to activate or deactivate electrical devices by way of an EEG based determination of which visual stimulus generator gave rise to a SSVEP signals correlated with the presentation frequency at which the visual stimulus generator is