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Kouider et al.

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(45) **Date of Patent: Aug. 12, 2025**

(54) **VISUAL BRAIN-COMPUTER INTERFACE**

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(73) Assignee: **NextMind SAS**, Paris (FR)

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PCT Pub. Date: **May 27, 2021**

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(51) **Int. Cl.**

G06F 3/01	(2006.01)
G06V 10/30	(2022.01)
G06V 40/10	(2022.01)

(52) **U.S. Cl.**
CPC ***G06F 3/015*** (2013.01); ***G06V 10/30*** (2022.01); ***G06V 40/10*** (2022.01); *G06V 40/15* (2022.01)

(58) **Field of Classification Search**
CPC G06F 3/015; G06V 40/10; G06V 40/15; G06V 10/30; A61B 5/11; A61B 5/165; A61B 5/4836
See application file for complete search history.

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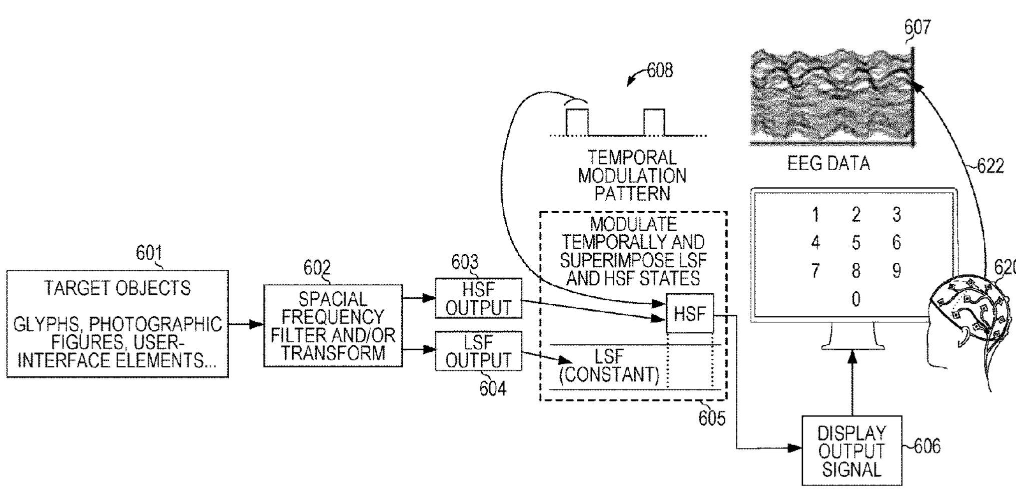
(57) **ABSTRACT**

A method and system for tracking visual attention are disclosed. By generating at least one visual stimulus with a characteristic modulation, the characteristic modulation being applied to high spatial frequency, HSF, components of the visual stimulus and displaying the or each visual stimulus via a graphical user interface, GUI, of a display, a neural response may be induced in the user's brain. By receiving neural signals of a user from a neural signal capture device, such as an EEG device, a point of focus of the user (when the user views the visual stimulus) may be determined based on the neural signals, since the neural signals include information associated with the characteristic modulation of

(Continued)



a visual stimulus to which the user's visual attention is directed.

15 Claims, 17 Drawing Sheets

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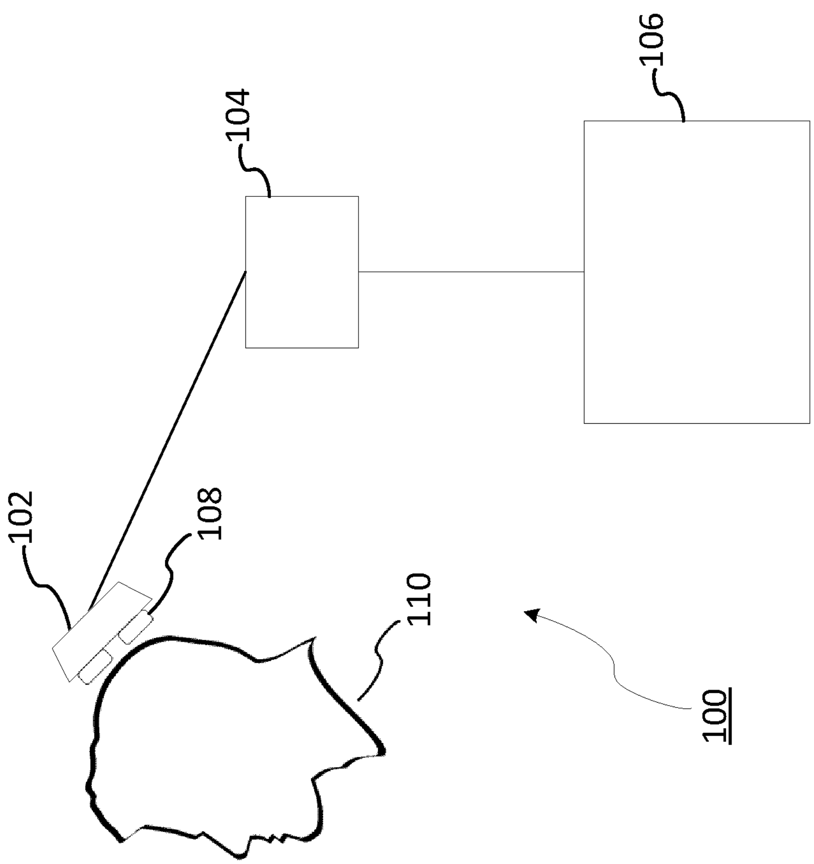


FIG. 1

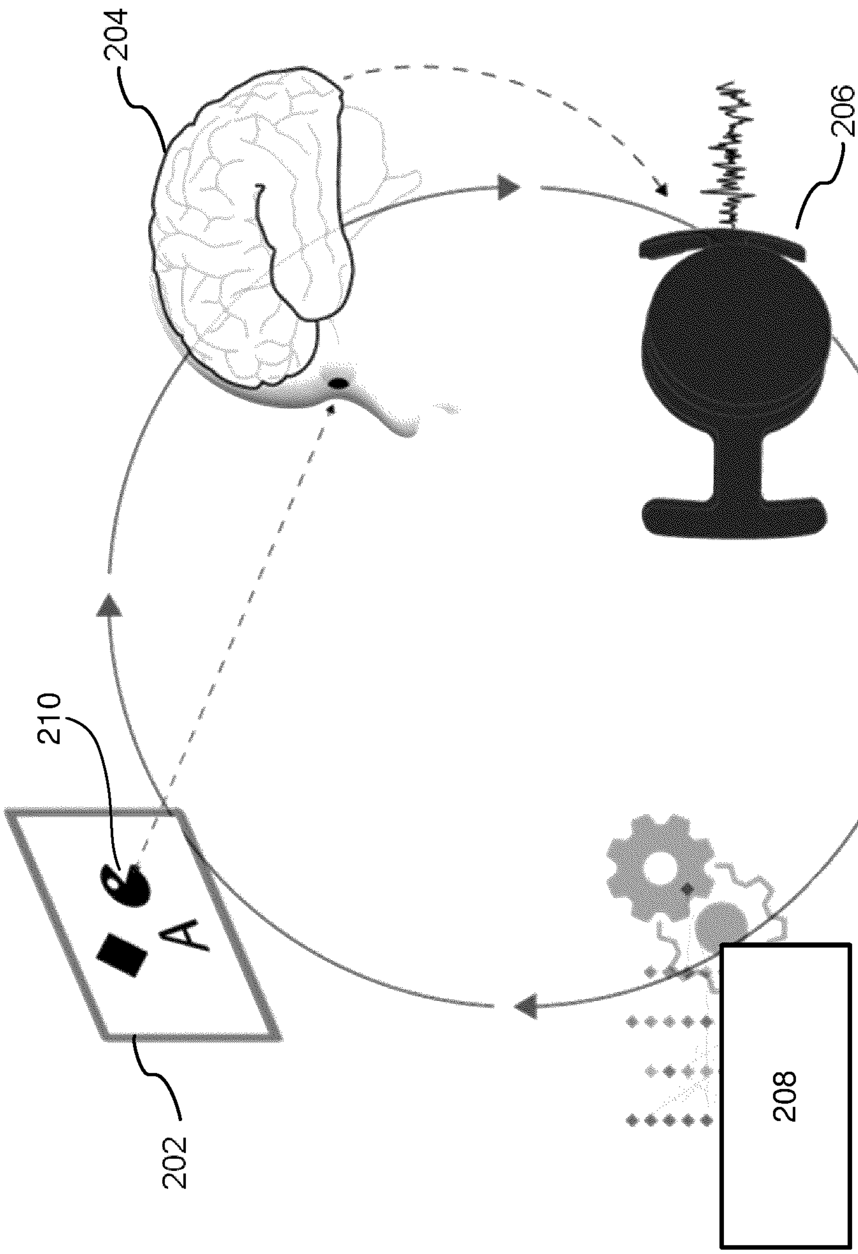


FIG. 2

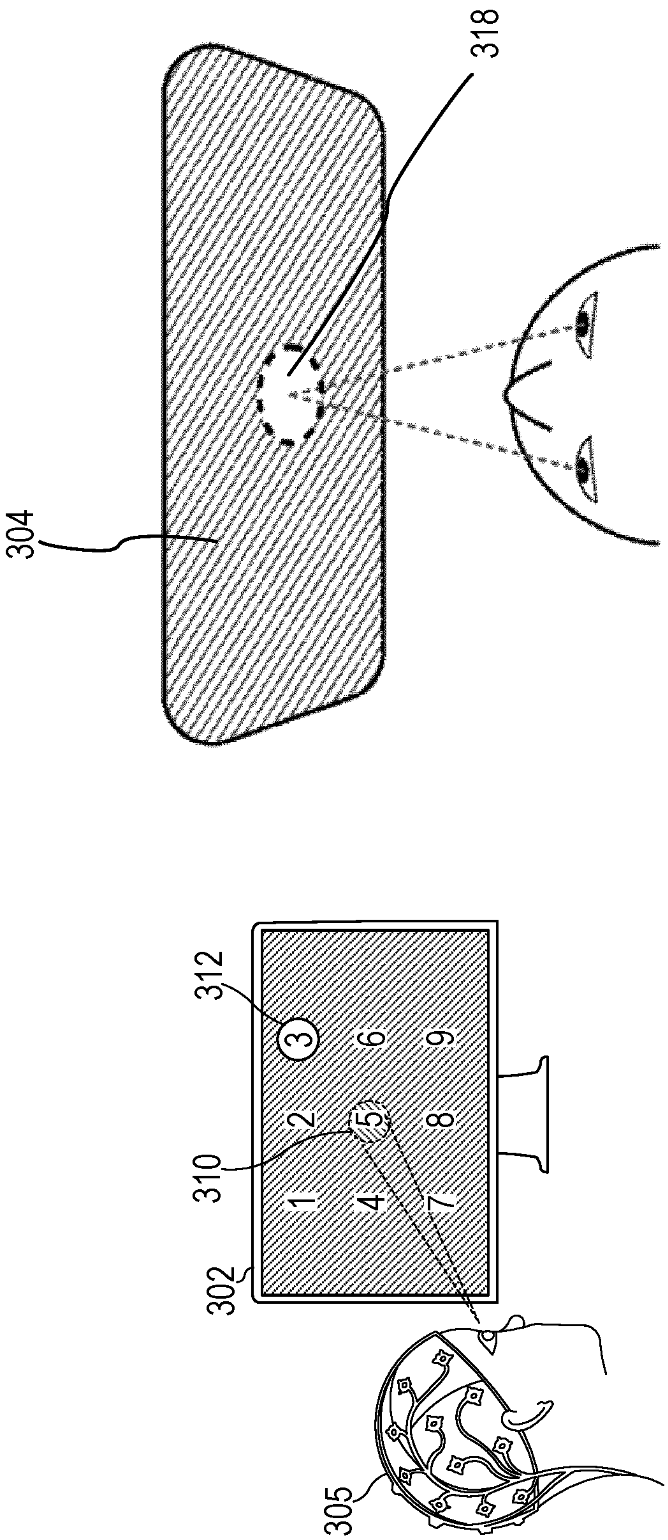


FIG. 3A

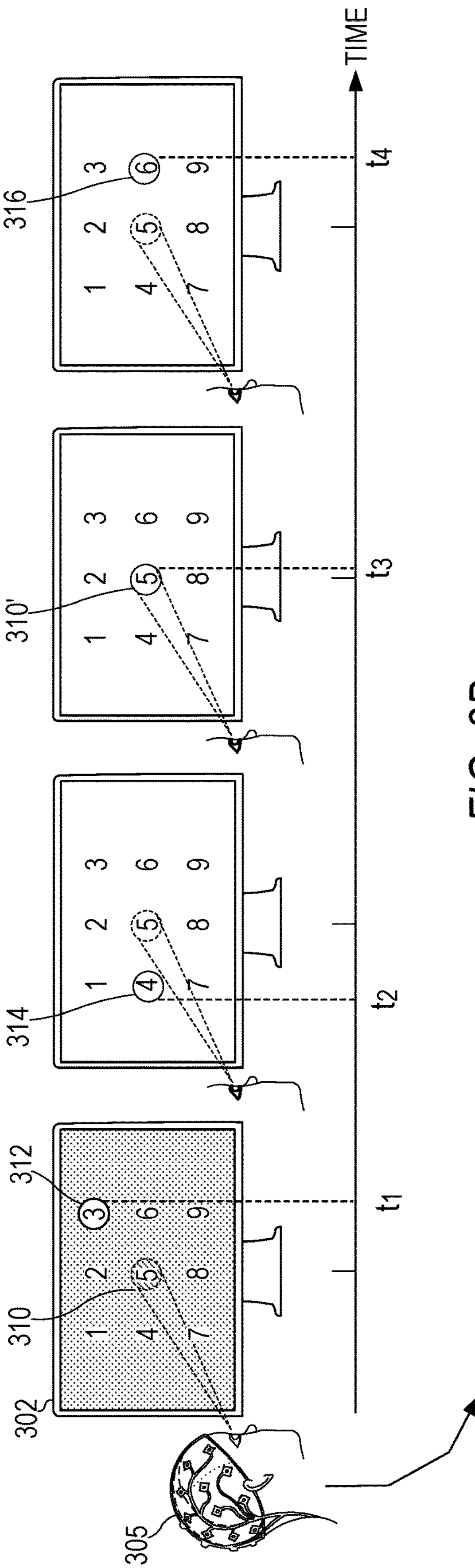


FIG. 3B

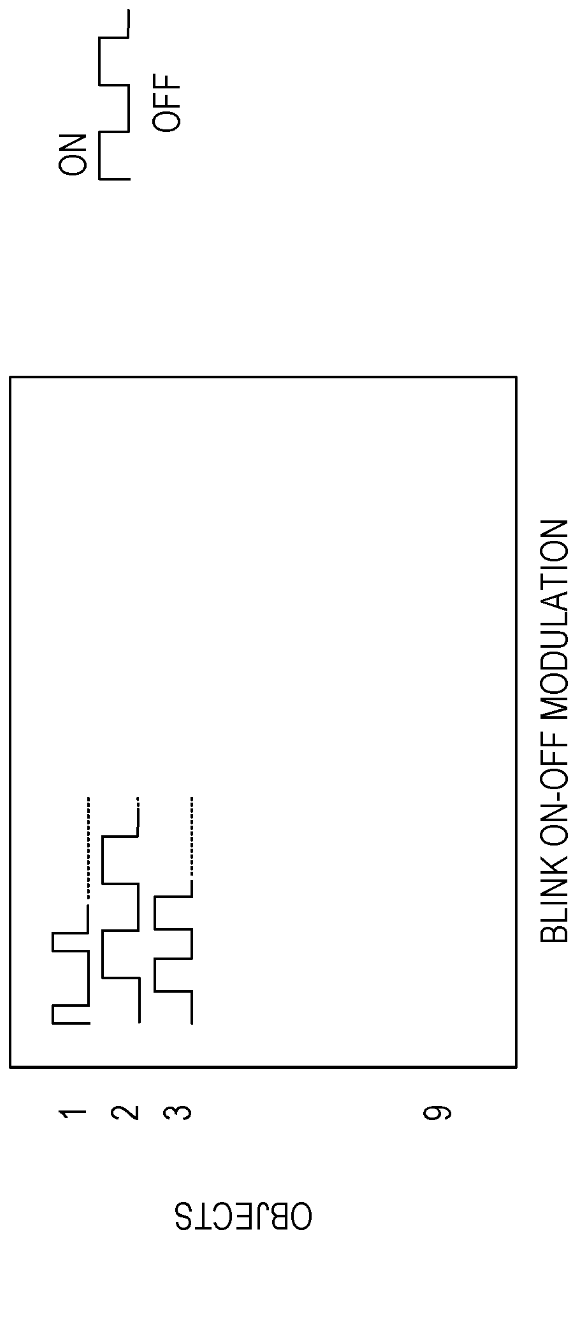


FIG. 4

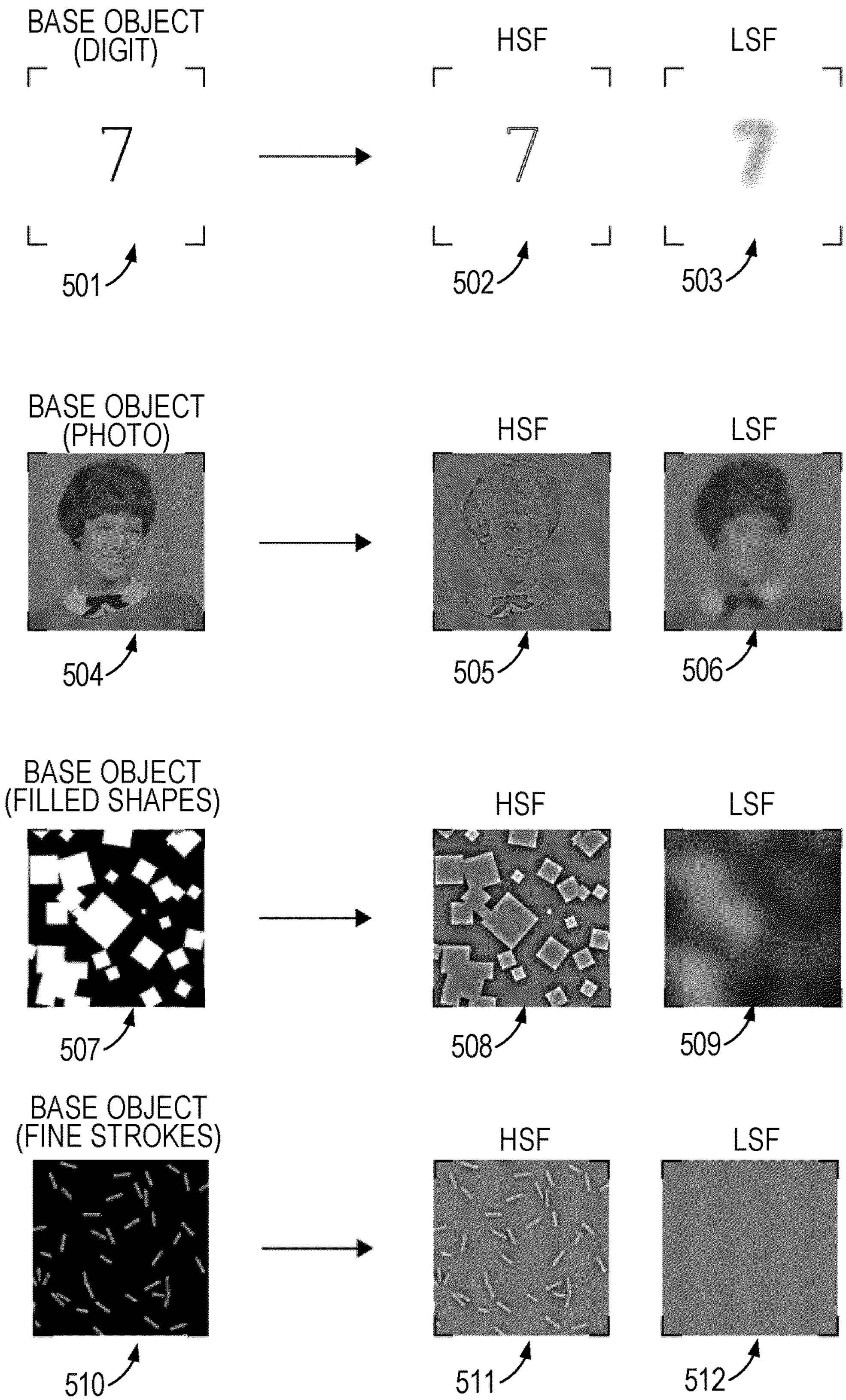

BASE OBJECT (DIGIT)
HSF
LSF
501
502
503
BASE OBJECT (PHOTO)
HSF
LSF
504
505
506
BASE OBJECT (FILLED SHAPES)
HSF
LSF
507
508
509
BASE OBJECT (FINE STROKES)
HSF
LSF
510
511
512

FIG. 5A

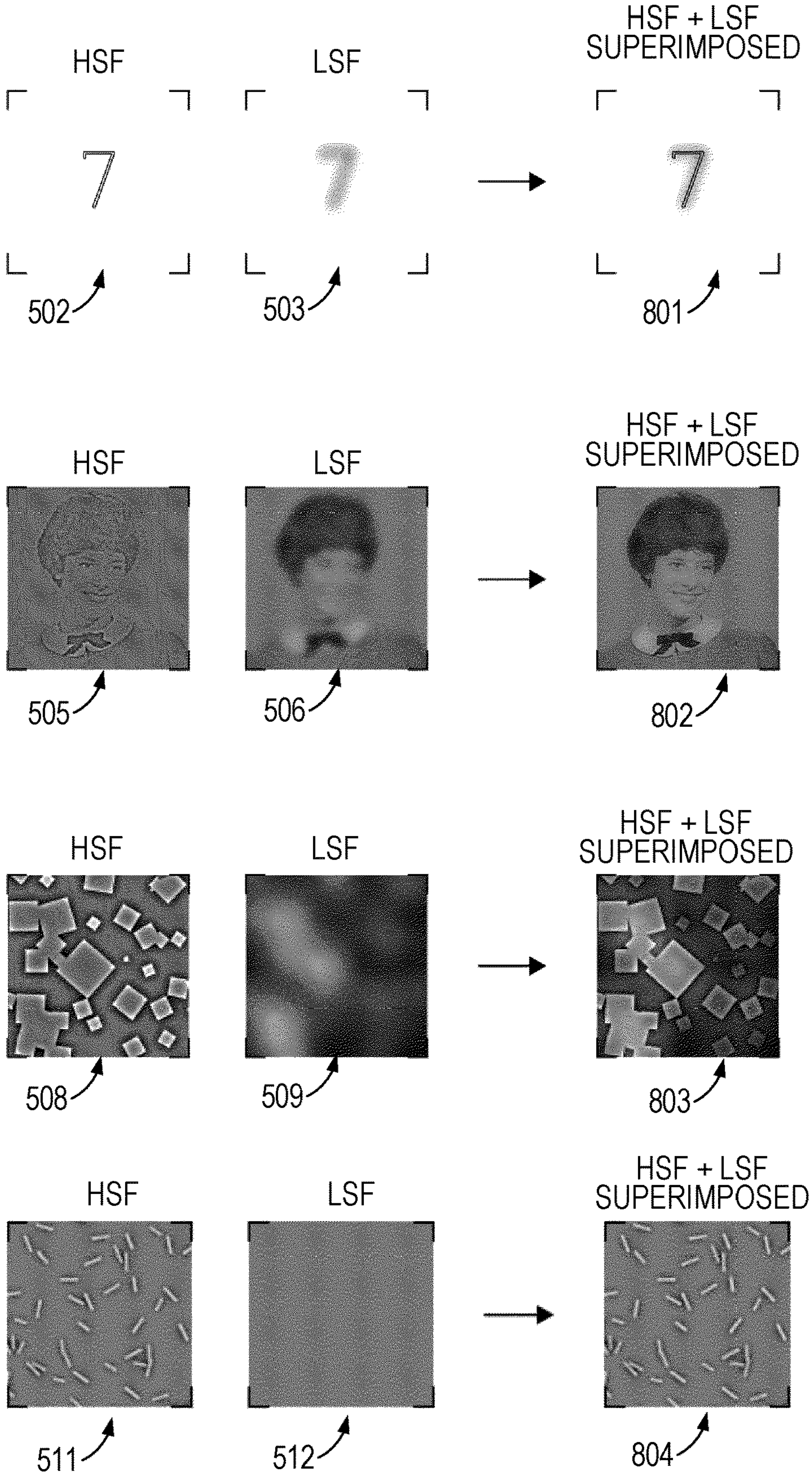

HSF
LSF
HSF + LSF SUPERIMPOSED
502
503
801
HSF
LSF
HSF + LSF SUPERIMPOSED
505
506
802
HSF
LSF
HSF + LSF SUPERIMPOSED
508
509
803
HSF
LSF
HSF + LSF SUPERIMPOSED
511
512
804

FIG. 5B

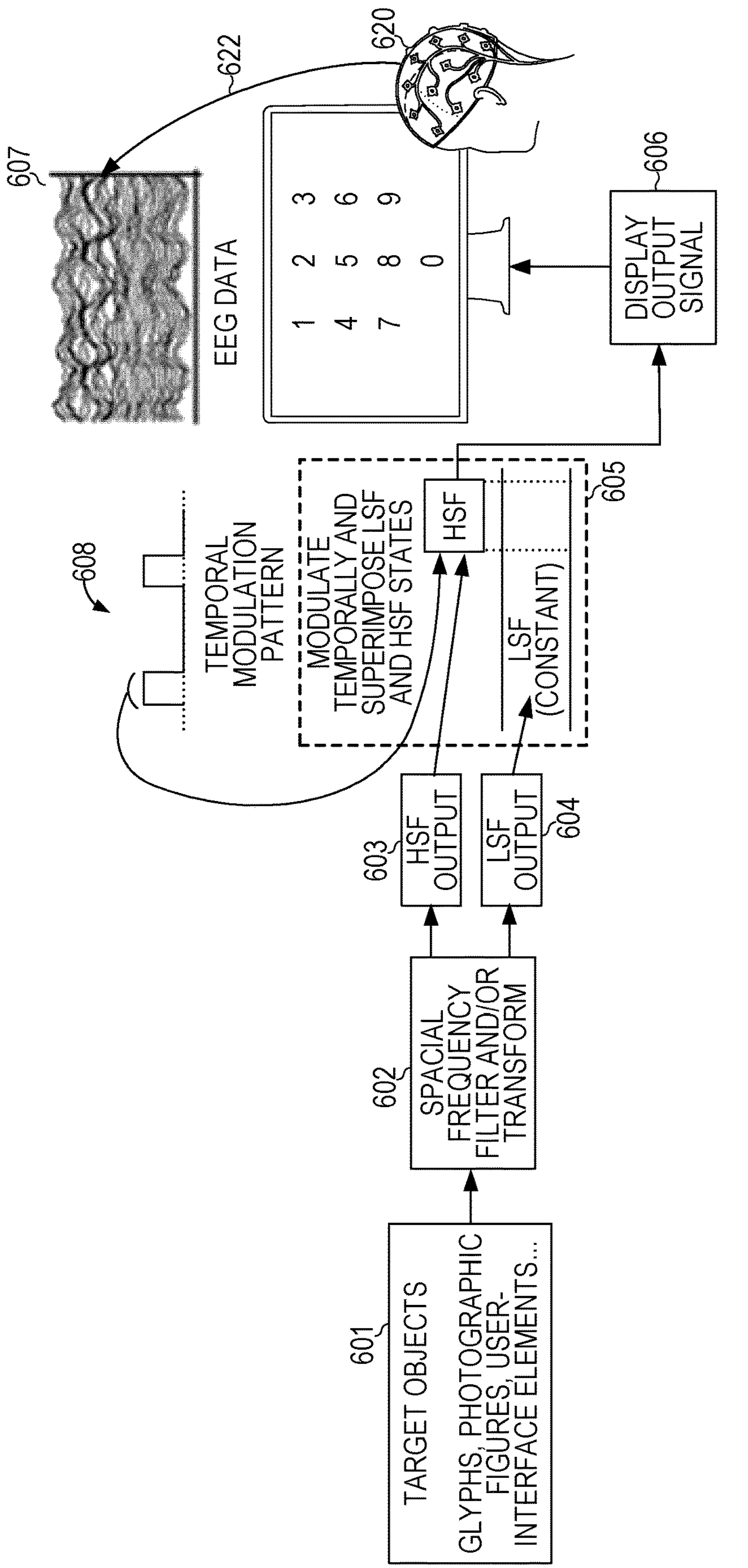
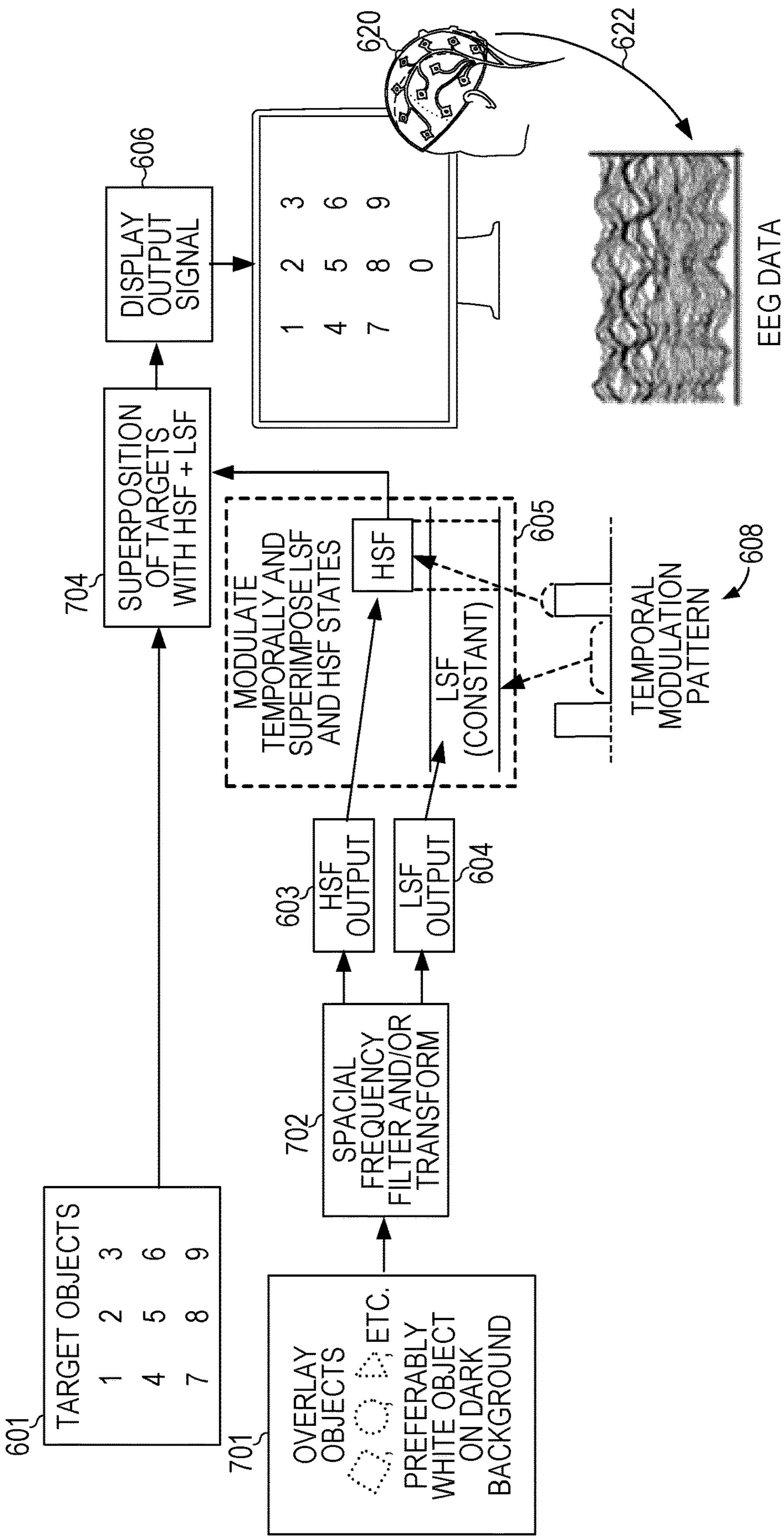

601
TARGET OBJECTS
GLYPHS, PHOTOGRAPHIC FIGURES, USER-INTERFACE ELEMENTS...
602
SPACIAL FREQUENCY FILTER AND/OR TRANSFORM
603
HSF OUTPUT
604
LSF OUTPUT
605
MODULATE TEMPORALLY AND SUPERIMPOSE LSF AND HSF STATES
HSF
LSF (CONSTANT)
608
TEMPORAL MODULATION PATTERN
606
DISPLAY OUTPUT SIGNAL
1 2 3
4 5 6
7 8 9
0
620
622
607
EEG DATA

FIG. 6



601
TARGET OBJECTS
1 2 3
4 5 6
7 8 9
701
OVERLAY OBJECTS
ETC.
PREFERABLY WHITE OBJECT ON DARK BACKGROUND
702
SPACIAL FREQUENCY FILTER AND/OR TRANSFORM
603
HSF OUTPUT
604
LSF OUTPUT
605
MODULATE TEMPORALLY AND SUPERIMPOSE LSF AND HSF STATES
HSF
LSF (CONSTANT)
608
TEMPORAL MODULATION PATTERN
704
SUPERPOSITION OF TARGETS WITH HSF + LSF
606
DISPLAY OUTPUT SIGNAL
1 2 3
4 5 6
7 8 9
0
620
622
EEG DATA

FIG. 7

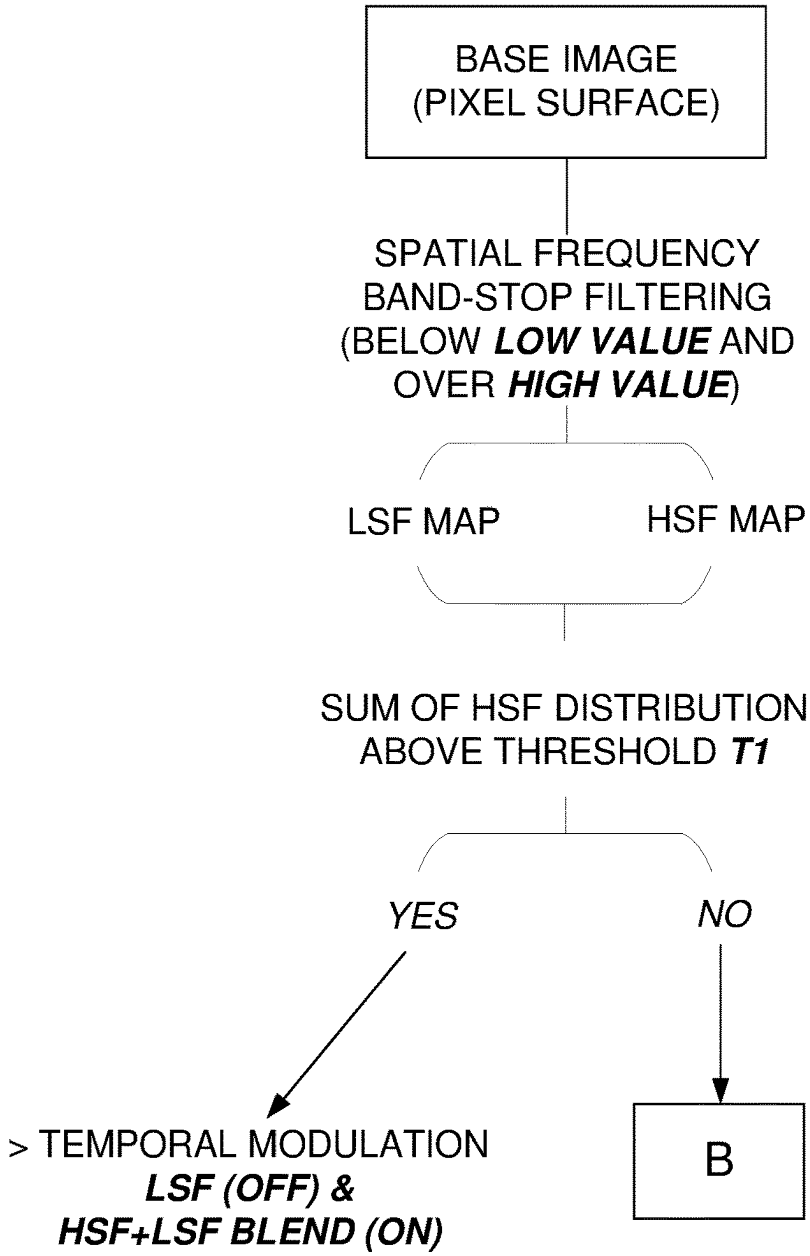

BASE IMAGE
(PIXEL SURFACE)
SPATIAL FREQUENCY
BAND-STOP FILTERING
(BELOW ***LOW VALUE*** AND
OVER ***HIGH VALUE***)
LSF MAP
HSF MAP
SUM OF HSF DISTRIBUTION
ABOVE THRESHOLD ***T1***
YES
NO
> TEMPORAL MODULATION
LSF (OFF) &
HSF+LSF BLEND (ON)
B

FIG. 8A

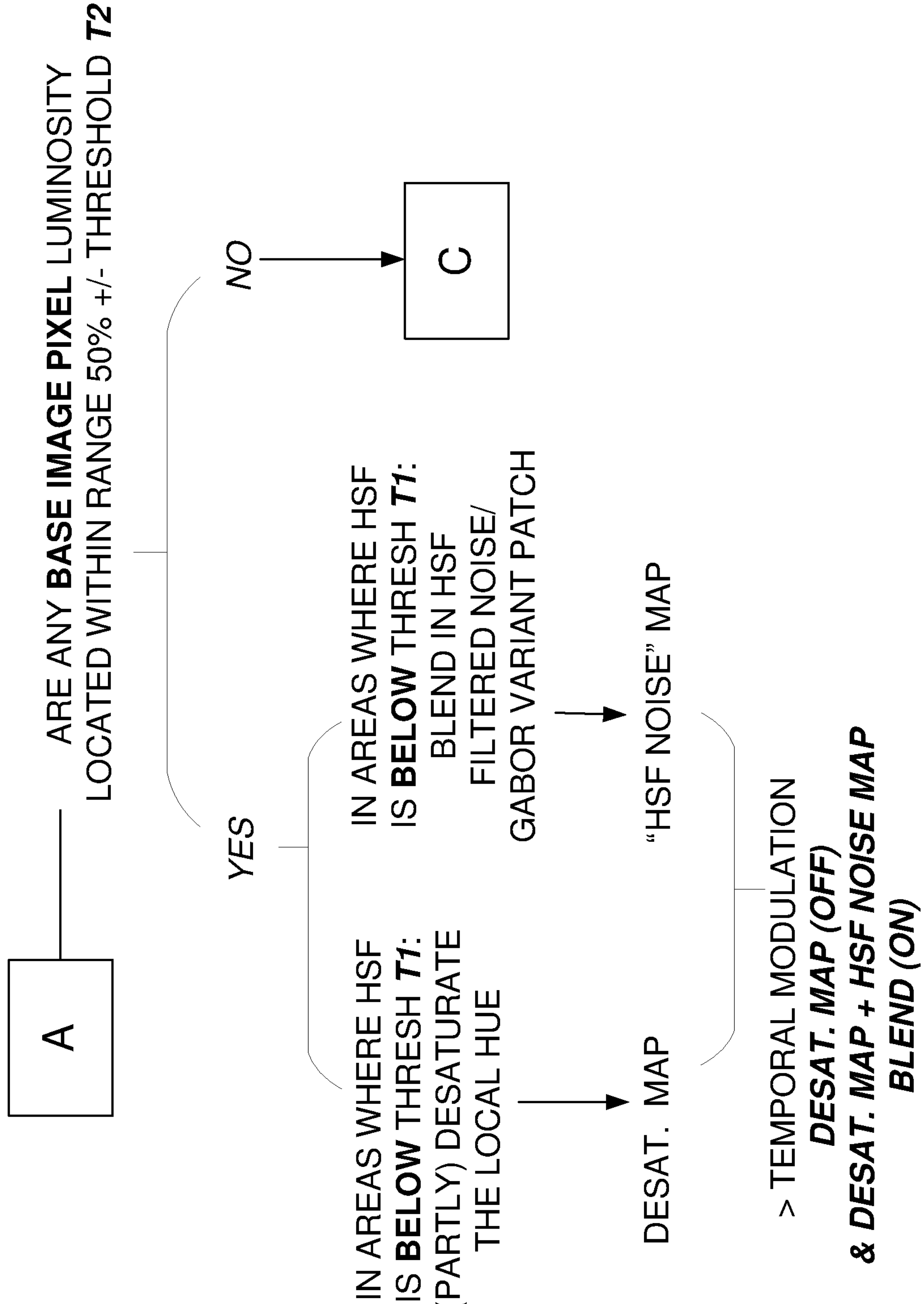

A
ARE ANY BASE IMAGE PIXEL LUMINOSITY
LOCATED WITHIN RANGE 50% +/- THRESHOLD T2
NO
C
YES
IN AREAS WHERE HSF
IS BELOW THRESH T1:
(PARTLY) DESATURATE
THE LOCAL HUE
IN AREAS WHERE HSF
IS BELOW THRESH T1:
BLEND IN HSF
FILTERED NOISE/
GABOR VARIANT PATCH
DESAT. MAP
“HSF NOISE” MAP
> TEMPORAL MODULATION
DESAT. MAP (OFF)
& DESAT. MAP + HSF NOISE MAP
BLEND (ON)

FIG. 8B

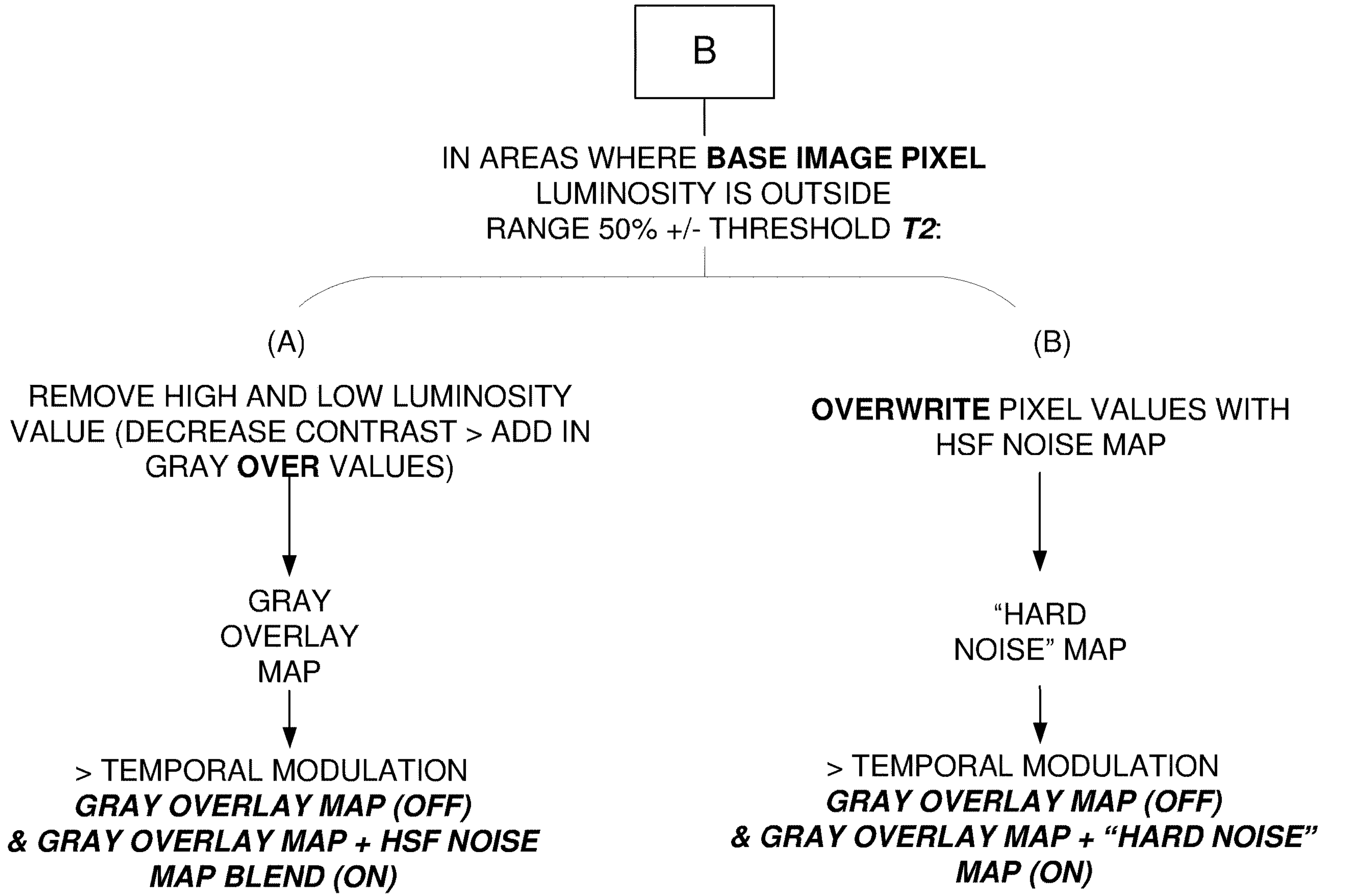

B
IN AREAS WHERE BASE IMAGE PIXEL LUMINOSITY IS OUTSIDE RANGE 50% +/- THRESHOLD T2:
(A)
REMOVE HIGH AND LOW LUMINOSITY VALUE (DECREASE CONTRAST > ADD IN GRAY OVER VALUES)
GRAY OVERLAY MAP
> TEMPORAL MODULATION GRAY OVERLAY MAP (OFF) & GRAY OVERLAY MAP + HSF NOISE MAP BLEND (ON)
(B)
OVERWRITE PIXEL VALUES WITH HSF NOISE MAP
"HARD NOISE" MAP
> TEMPORAL MODULATION GRAY OVERLAY MAP (OFF) & GRAY OVERLAY MAP + "HARD NOISE" MAP (ON)

FIG. 8C

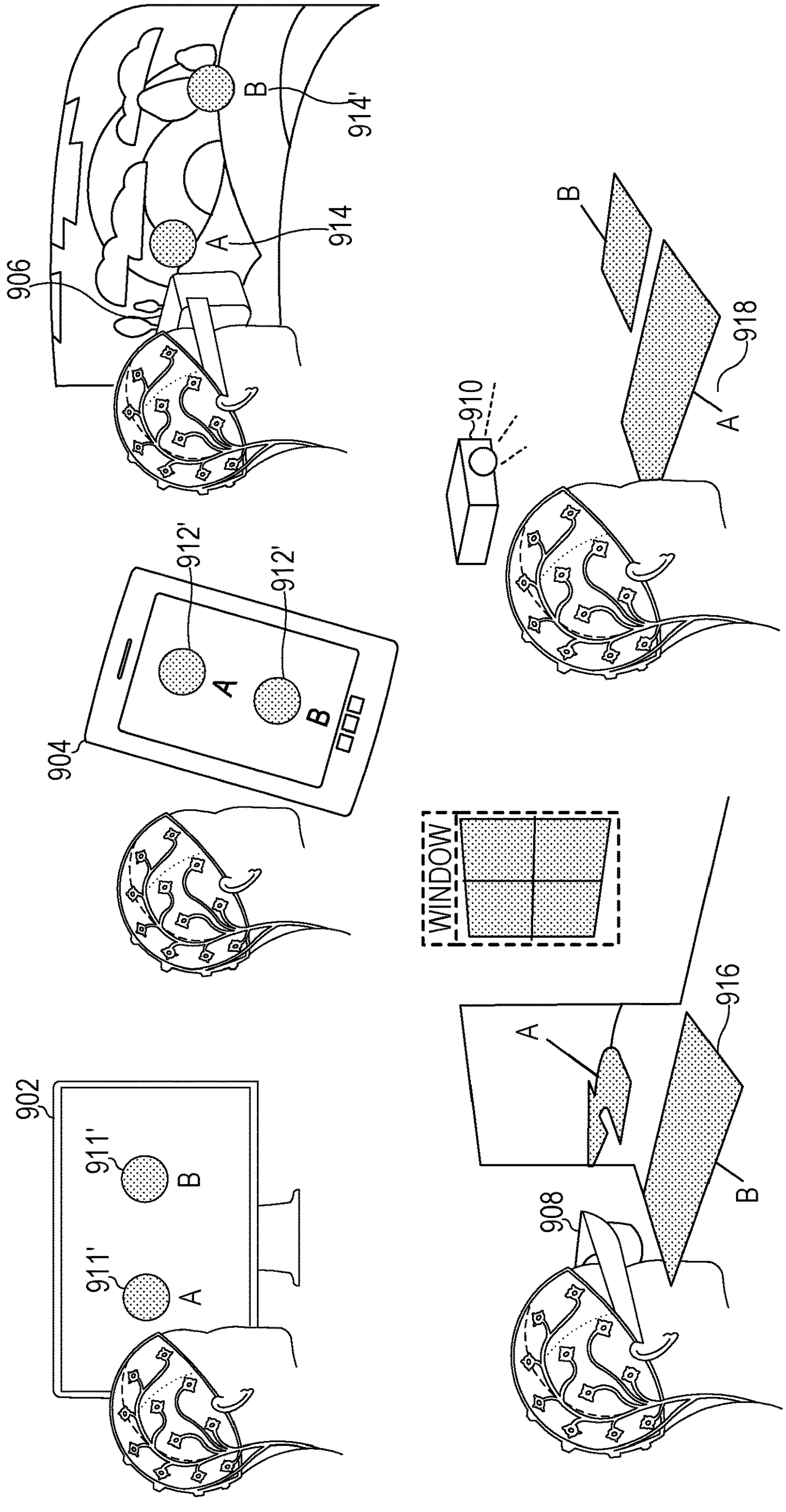

902
911'
911'
A
B
904
912'
912'
A
B
906
914
914'
A
B
908
916
A
B
WINDOW
910
918
A
B

FIG. 9

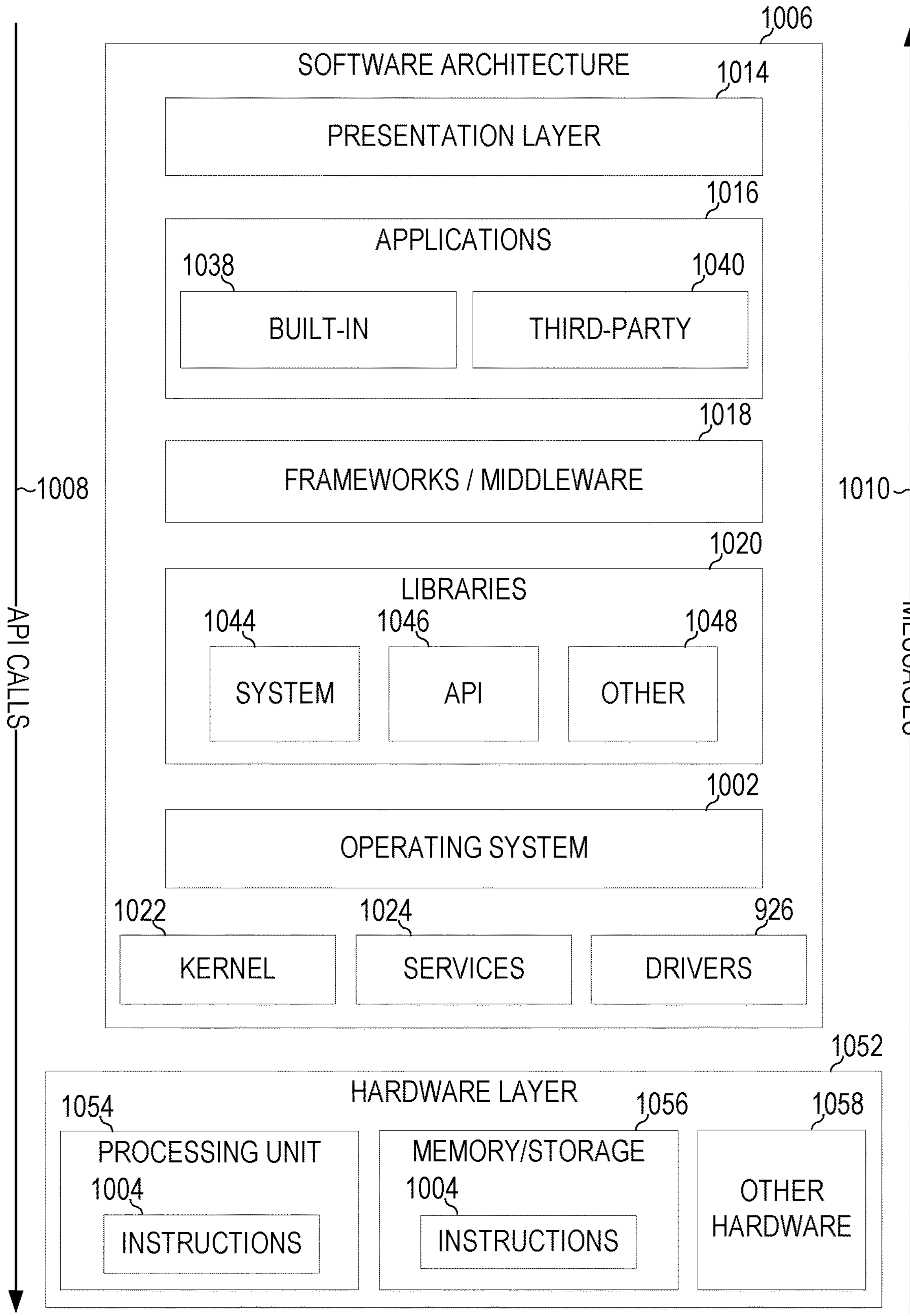

1006
SOFTWARE ARCHITECTURE
1014
PRESENTATION LAYER
1016
APPLICATIONS
1038
1040
BUILT-IN
THIRD-PARTY
1018
FRAMEWORKS / MIDDLEWARE
1008
1010
1020
LIBRARIES
1044
1046
1048
SYSTEM
API
OTHER
API CALLS
MESSAGES
1002
OPERATING SYSTEM
1022
1024
926
KERNEL
SERVICES
DRIVERS
1052
HARDWARE LAYER
1054
1056
1058
PROCESSING UNIT
1004
INSTRUCTIONS
MEMORY/STORAGE
1004
INSTRUCTIONS
OTHER HARDWARE

FIG. 10

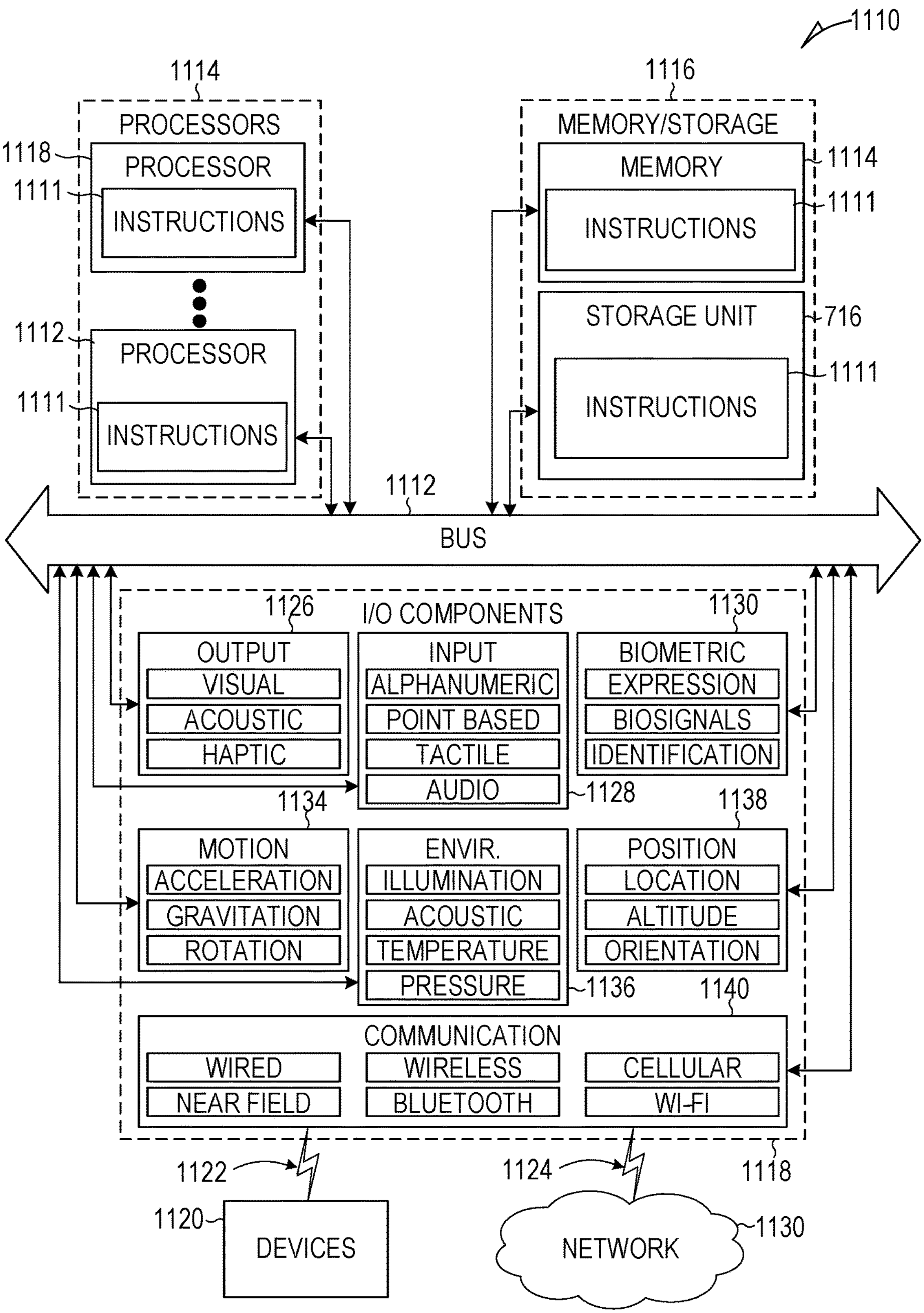

1110
1114
PROCESSORS
1118
PROCESSOR
1111
INSTRUCTIONS
1112
PROCESSOR
1111
INSTRUCTIONS
1116
MEMORY/STORAGE
MEMORY
1114
INSTRUCTIONS
1111
STORAGE UNIT
716
INSTRUCTIONS
1111
1112
BUS
I/O COMPONENTS
1126
OUTPUT
VISUAL
ACOUSTIC
HAPTIC
INPUT
ALPHANUMERIC
POINT BASED
TACTILE
AUDIO
1128
1130
BIOMETRIC
EXPRESSION
BIOSIGNALS
IDENTIFICATION
1134
MOTION
ACCELERATION
GRAVITATION
ROTATION
ENVIR.
ILLUMINATION
ACOUSTIC
TEMPERATURE
PRESSURE
1136
1138
POSITION
LOCATION
ALTITUDE
ORIENTATION
1140
COMMUNICATION
WIRED
WIRELESS
CELLULAR
NEAR FIELD
BLUETOOTH
WI-FI
1122
1124
1118
1120
DEVICES
NETWORK
1130

FIG. 11

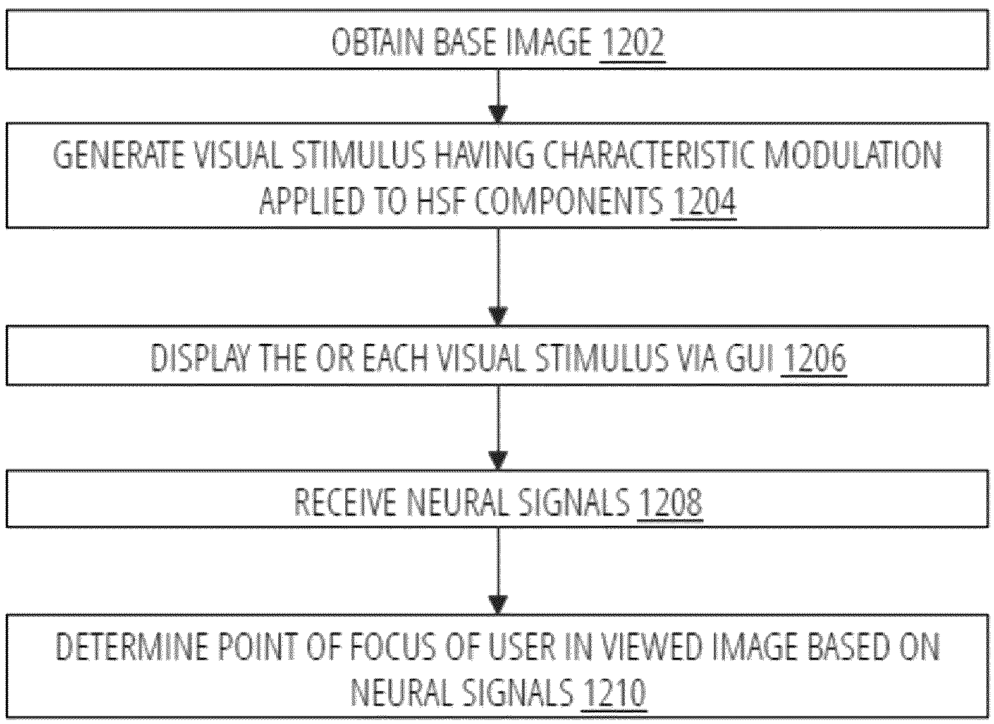

OBTAIN BASE IMAGE 1202
GENERATE VISUAL STIMULUS HAVING CHARACTERISTIC MODULATION APPLIED TO HSF COMPONENTS 1204
DISPLAY THE OR EACH VISUAL STIMULUS VIA GUI 1206
RECEIVE NEURAL SIGNALS 1208
DETERMINE POINT OF FOCUS OF USER IN VIEWED IMAGE BASED ON NEURAL SIGNALS 1210

FIG. 12

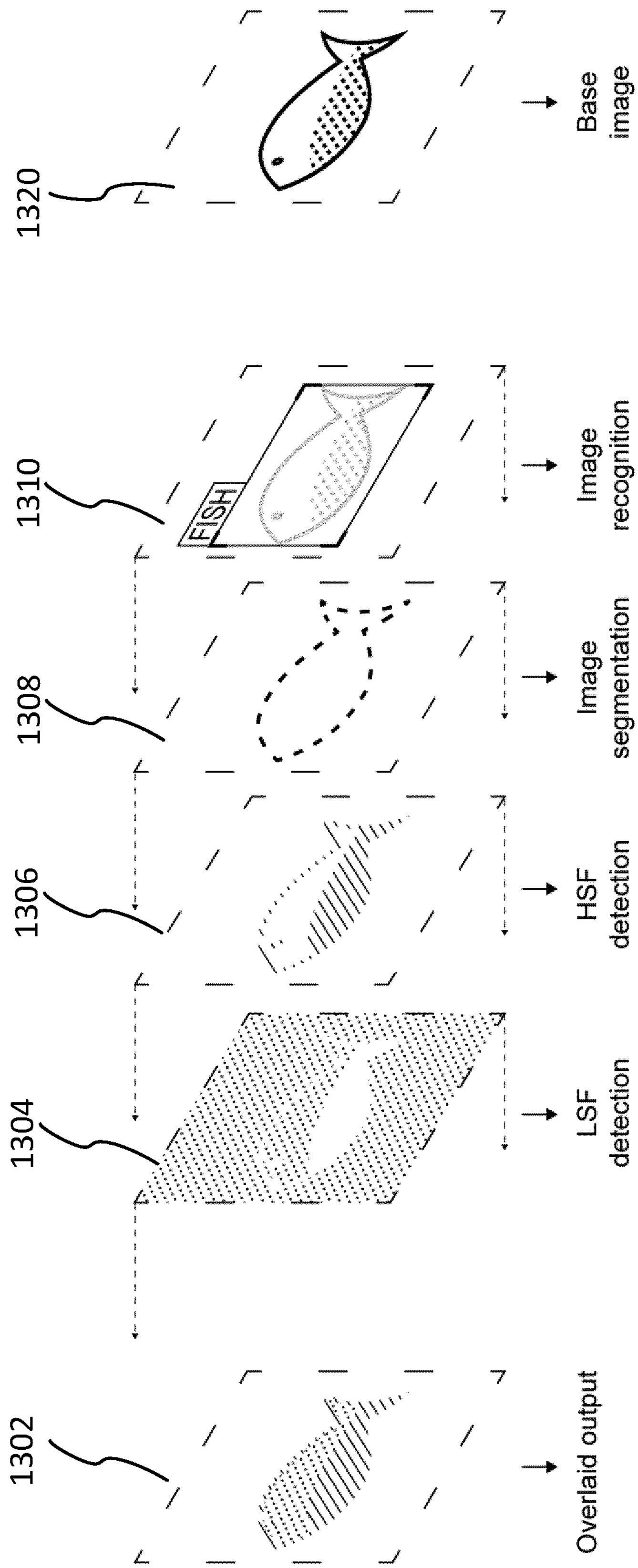

1320
Base image
1310
FISH
Image recognition
1308
Image segmentation
1306
HSF detection
1304
LSF detection
1302
Overlaid output

FIG. 13

VISUAL BRAIN-COMPUTER INTERFACE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a U.S. national-phase application filed under 35 U.S.C. § 371 from International Application Serial No. PCT/EP2020/081348, filed Nov. 6, 2020, and published as WO 2021/099148 on May 27, 2021, which claims the benefit of priority of U.S. Provisional Patent Application Ser. No. 62/938,098, filed Nov. 20, 2019, each of which are incorporated by reference herein in their entreties.

TECHNICAL FIELD OF THE INVENTION

The present invention relates to the operation of brain-computer interfaces involving visual sensing.

STATE OF THE ART

In visual brain-computer interfaces (BCIs), neural responses to a target stimulus, generally among a plurality of generated visual stimuli presented to the user, are used to infer (or "decode") which stimulus is essentially the object of focus at any given time. The object of focus can then be associated with a user-selectable or -controllable action.

Neural responses may be obtained using a variety of known techniques. One convenient method relies upon surface electroencephalography (EEG), which is non-invasive, has fine-grained temporal resolution and is based on well-understood empirical foundations. Surface EEG makes it possible to measure the variations of diffuse electric potentials on the surface of the skull (i.e. the scalp) of a subject in real-time. These variations of electrical potentials are commonly referred to as electroencephalographic signals or EEG signals.

In a typical BCI, visual stimuli are presented in a display generated by a display device. Examples of suitable display devices (some of which are illustrated in FIG. **9**) include television screens & computer monitors **902**, projectors **910**, virtual reality headsets **906**, interactive whiteboards, and the display screen of tablets **904**, smartphones, smart glasses **908**, etc. The visual stimuli **911**, **911'**, **912**, **912'**, **914**, **914'**, **916**, **918** may form part of a generated graphical user interface (GUI) or they may be presented as augmented reality (AR) or mixed reality graphical objects **916** overlaying a base image: this base image may simply be the actual field of view of the user (as in the case of a mixed reality display function projected onto the otherwise transparent display of a set of smart glasses) or a digital image corresponding to the user's field of view but captured in real time by an optical capture device (which may in turn capture an image corresponding to the user's field of view amongst other possible views).

Inferring which of a plurality of visual stimuli (if any) is the object of focus at any given time is fraught with difficulty. For example, when a user is facing multiple stimuli, such as for instance the digits displayed on an on-screen keypad, it has proven nearly impossible to infer which one is under focus directly from brain activity at a given time. The user perceives the digit under focus, say digit **5**, so the brain must contain information that distinguishes that digit from others, but current methods are unable to extract that information. That is, current methods can, with difficulty, infer that a stimulus has been perceived, but they cannot determine which specific stimulus is under focus using brain activity alone.

To overcome this issue and to provide sufficient contrast between stimulus and background (and between stimuli), it is known to configure the stimuli used by visual BCIs to blink or pulse (e.g. large surfaces of pixels switching from black to white and vice-versa), so that each stimulus has a distinguishable characteristic profile over time. The flickering stimuli give rise to measurable electrical responses. Specific techniques monitor different electrical responses, for example steady state visual evoked potentials (SSVEPs) and P-300 event related potentials. In typical implementations, the stimuli flicker at a rate exceeding 6 Hz. As a result, such visual BCIs rely on an approach that consists of displaying the various stimuli discretely rather than constantly, and typically at different points in time. Brain activity associated with attention focused on a given stimulus is found to correspond (i.e. correlate) with one or more aspect of the temporal profile of that stimulus, for instance the frequency of the stimulus blink and/or the duty cycle over which the stimulus alternates between a blinking state and a quiescent state.

Thus, decoding of neural signals relies on the fact that when a stimulus is turned on, it will trigger a characteristic pattern of neural responses in the brain that can be determined from electrical signals, i.e. the SSVEPs, picked up by electrodes of an EEG device, the electrodes of an EEG helmet, for example. This neural data pattern might be very similar or even identical for the various digits, but it is time-locked to the digit being perceived: only one digit may pulse at any one time so that the correlation with a pulsed neural response and a time at which that digit pulses may be determined as an indication that that digit is the object of focus.

By displaying each digit at different points in time, turning that digit on and off at different rates, applying different duty cycles, and/or simply applying the stimulus at different points in time, the BCI algorithm can establish which stimulus, when turned on, is most likely to be triggering a given neural response, thereby allowing a system to determine the target under focus.

Visual BCIs have improved significantly in recent years, so that real-time and accurate decoding of the user's focus is becoming increasingly practical. Nevertheless, the constant blinking of the stimuli, sometimes all over the screen when there are many of them, is an intrinsic limitation for a large-scale use of this technology. Indeed, it can cause discomfort and mental fatigue, and, if sustained, physiological responses such as headaches. In addition, the blinking effect can impede the ability of the user to focus on a specific target, and the system to determine the object of focus quickly and accurately.

FIG. **3**A illustrates the effects of peripheral vision. A subject **305** is shown viewing a display screen **302** displaying a plurality of digits **310**, **312** in a keyboard. When the subject tries to focus on digit "5" **310** in the on-screen keypad discussed above, the other (i.e., peripheral) digits (such as "3", **312**) act as distractors, their presence and the fact that they are exhibiting a blinking effect drawing the user's attention momentarily. The display of the peripheral digits induces interference in the user's visual system. This interference in turn impedes the performance of the BCI. Consequently, there is a need for an improved method for differentiating between screen targets and their display stimuli in order to determine which one a user is focusing on and for discriminating the object of focus (the target) from the objects peripheral to the target (the distractors) with speed and accuracy.

Conventionally, visual stimuli would take up a significant amount of screen surface, filled with either high energy uniform light (bright white shapes) or coarse checkerboards. These large surfaces would remain dedicated to the visual BCI system and cannot be used for any other purposes than the visual stimulation. These large stimulation surfaces are inconsistent with a fine and discrete integration of the visual BCI system and place limitations in design freedom for user interfaces in display devices, such as those illustrated in FIG. **9**.

Known systems in the medical or related research fields generally include a head-mounted device with attachment locations for receiving individual sensors/electrodes. Electronic circuits are then connected to the electrodes and to the housing of an acquisition chain (i.e. an assembly of connected components used in acquiring the EEG signals). The EEG device is thus typically formed of three distinct elements that the operator/exhibitor must assemble at each use. Again, the nature of the EEG device is such that technical assistance is desirable, if not essential.

Furthermore, user acceptability of the EEG device (and its electrodes) places aesthetic constraints, as well as constraints in comfort and ease of use. In many cases, these constraints are an effective significant barrier to the adoption of EEG technology. Examples of applications where comfort over prolonged use and the need for technical assistance prevent adoption include applications such as video games, training (e.g. for health and safety or flight simulation), sleep aids, etc.

It is therefore desirable to provide brain-computer interfaces that address the above challenges.

SUMMARY

The present disclosure relates to a brain-computer interface in which visual stimuli are presented on a graphical interface such they are neurally decodable and offer an improved user experience.

In certain aspects, the present disclosure describes a system and method for improving the accuracy and speed of determining the object of focus in a field of objects, or as a specific area in a single, large target. Image data for all objects are processed to extract a version composed of only high spatial frequency (HSF) components for each object.

The present disclosure relates to techniques for taking objects of (potential) interest within the field of view of a user (typically, but not always on a display presented to the user), extracting components that relate to visual properties of those objects (for example their edges), and applying a modulation to the high spatial frequency component of those visual properties. Thus, a blinking visual stimulus used to elicit neural responses, such as visual evoked potentials (VEPs), may be conveyed only through the HSF version of the objects. The modulation makes the object blink or otherwise visually alter so that the modulation acts as a stimulus for a correlated neural response. The neural response may in turn be measured and decoded to determine which object of interest is the focus of the user's attention.

In certain aspects, the image data may further be processed to extract a further version of the object composed only of the low spatial frequency (LSF) components. Where an LSF version is extracted, the modulated HSF version may be superimposed on the LSF version (which does not blink).

In one aspect, the present disclosure comprises a closed-loop feedback system wherein a user peers at a screen and its objects, neural activity is captured as signals using a helmet of electrodes, and the proportions of HSF detected from neural activity, and associated with each object, will vary as the user's object of focus changes. This is somewhat equivalent to blinking the objects at different rates and duty cycles but presents far less interference because of the filtering such that blinking display objects are those which evoke essentially HSF responses (e.g. HSF versions). If the object is peripheral, the blinking of its HSF version is naturally subdued by the human visual behavior. However, an object of focus, with its HSF version blinking, will evoke a readily identifiable neural response. As a result, interference is significantly quashed making the experience more comfortable and the identification of an object of focus both more accurate and timely.

The present disclosure further extends the technique to allow the imposition of a perceptible modulation in relation with a more general range of potential objects of interest. The extended technique is applicable to objects in a wider range of natural lighting and having a broader range of spatial texture. Uniform and smooth objects may be made neurally decodable stimuli even when they possess insufficient HSF components to permit effective direct modulation.

According to a further aspect, the present disclosure relates to a method of tracking visual attention, the method comprising: obtaining a base image; generating at least one visual stimulus, each stimulus having a characteristic modulation, the characteristic modulation being applied to high spatial frequency, HSF, components of the visual stimulus; displaying the or each visual stimulus via a graphical user interface, GUI, of a display; receiving neural signals of a user from a neural signal capture device; and when the user views the or each visual stimulus, determining a point of focus of the user in the viewed image based on the neural signals, the neural signals including information associated with the characteristic modulation of a visual stimulus to which the user's visual attention is directed.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

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

FIG. **1** illustrates an electronic architecture for receiving and processing EEG signals according to the present disclosure;

FIG. **2** illustrates a system incorporating a brain computer interface (BCI) according to the present disclosure;

FIG. **3**A illustrates foveal area versus peripheral vision as discussed in the present disclosure;

FIG. **3**B illustrates a user focusing on an object while the screen objects, including the focus object, all blink at different rates and times;

FIG. **4** is an example of a blink control pattern in which the objects are each given blinking patterns that are distinctive in terms of start time, frequency and duty cycle;

FIGS. **5**A and **5**B illustrate how a screen display object can be filtered so as to produce an HSF version and LSF version and then the versions superimposed;

FIG. **6** illustrates an exemplary embodiment in which HSF versions of screen objects are blinking whereas LSF versions are kept static;

FIG. **7** illustrates another exemplary embodiment in which screen objects are kept static while overlay objects are split into HSF and LSF versions, and, HSF overlay versions are blinking whereas LSF versions remain static;

FIGS. **8**A, **8**B and **8**C illustrate further aspects of the operation of the method of the present disclosure;

FIG. **9** illustrates various examples of display device suitable for use with the method of the present disclosure;

FIG. **10** is block diagram showing a software architecture within which the present disclosure may be implemented, in accordance with some example embodiments;

FIG. **11** is a diagrammatic representation of a machine, in the form of a computer system within which a set of instructions may be executed for causing the machine to perform any one or more of the methodologies discussed, in accordance with some example embodiments.

FIG. **12** illustrates the main functional blocks in a method of operation of the BCI in accordance with the present disclosure; and

FIG. **13** illustrates the processing of a base image to generate a visual stimulus as described above in relation to FIG. **12**.

DETAILED DESCRIPTION

The description that follows includes systems, methods, techniques, instruction sequences, and computing machine program products that embody illustrative embodiments of the disclosure. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide an understanding of various embodiments of the inventive subject matter. It will be evident, however, to those skilled in the art, that embodiments of the inventive subject matter may be practiced without these specific details. In general, well-known instruction instances, protocols, structures, and techniques are not necessarily shown in detail.

BCIs making use of visually associated neural signals can be used to determine which objects on a screen a user is focusing on.

It has been found that objects of focus, in the foveal vision area, are associated with a high degree of HSF signal components. Similarly, it has been found that objects in the peripheral vision area are associated with a high degree of LSF signal components. Thus, for example, a visual stimulus can, with an application of this observation, be made fully visible centrally but become effectively invisible in peripheral vision (while under normal circumstances, the visual stimulus would be visible in the periphery).

By enhancing those differences in HSF and LSF signal components through various filtering methods one can improve the accuracy and speed of BCIs.

FIG. **1** illustrates an example of an electronic architecture for the reception and processing of EEG signals by means of an EEG device **100** according to the present disclosure.

To measure diffuse electric potentials on the surface of the skull of a subject **110**, the EEG device **100** includes a portable device **102** (i.e. a cap or headpiece), analog-digital conversion (ADC) circuitry **104** and a microcontroller **106**. The portable device **102** of FIG. **1** includes one or more electrodes **108**, typically between 1 and 128 electrodes, advantageously between 2 and 64, advantageously between 4 and 16.

Each electrode **108** may comprise a sensor for detecting the electrical signals generated by the neuronal activity of the subject and an electronic circuit for pre-processing (e.g. filtering and/or amplifying) the detected signal before analog-digital conversion: such electrodes being termed "active". The active electrodes **108** are shown in use in FIG. **1**, where the sensor is in physical proximity with the subject's scalp. The electrodes may be suitable for use with a conductive gel or other conductive liquid (termed "wet" electrodes) or without such liquids (i.e. "dry" electrodes).

Each ADC circuit **104** is configured to convert the signals of a given number of active electrodes **108**, for example between 1 and 128.

The ADC circuits **104** are controlled by the microcontroller **106** and communicate with it for example by the protocol SPI ("Serial Peripheral Interface"). The microcontroller **106** packages the received data for transmission to an external processing unit (not shown), for example a computer, a mobile phone, a virtual reality headset, an automotive or aeronautical computer system, for example a car computer or a computer system. airplane, for example by Bluetooth, Wi-Fi ("Wireless Fidelity") or Li-Fi ("Light Fidelity").

In certain embodiments, each active electrode **108** is powered by a battery (not shown in FIG. **1**). The battery is conveniently provided in a housing of the portable device **102**.

In certain embodiments, each active electrode **108** measures a respective electric potential value from which the potential measured by a reference electrode (Ei=Vi−Vref) is subtracted, and this difference value is digitized by means of the ADC circuit **104** then transmitted by the microcontroller **106**.

In certain embodiments, the method of the present disclosure introduces target objects for display in a graphical user interface of a display device. The target objects include control items and the control items are in turn associated with user-selectable actions.

FIG. **2** illustrates a system incorporating a brain computer interface (BCI) according to the present disclosure. The system incorporates a neural response device **206**, such as the EEG device **100** illustrated in FIG. **1**. In the system, an image is displayed on a display of a display device **202**. The subject **204** views the image on the display, focusing on a target object **210**.

In an embodiment, the display device **202** displays at least the target object **210** as a graphical object with a varying temporal characteristic distinct from the temporal characteristic of other displayed objects and/or the background in the display. The varying temporal characteristic may be, for example, a constant or time-locked flickering effect altering the appearance of the target object at a rate greater than 6 Hz. Where more than one graphical object is a potential target object (i.e. where the viewing subject is offered a choice of target object to focus attention on), each object is associated with a discrete spatial and/or temporal code.

The neural response device **206** detects neural responses (i.e. tiny electrical potentials indicative of brain activity in the visual cortex) associated with attention focused on the target object; the visual perception of the varying temporal characteristic of the target object(s) therefore acts as a stimulus in the subject's brain, generating a specific brain response that accords with the code associated with the target object in attention. The detected neural responses (e.g. electrical potentials) are then converted into signals and transferred to a processing device **208** for decoding. Examples of neural responses include visual evoked potentials (VEPs), which are commonly used in neuroscience research. The term VEPs encompasses conventional SSVEPs, as mentioned above, where stimuli oscillate at a specific frequency and other methods such as the code-modulated VEP, stimuli are subject to a variable or pseudo-random temporal code.

The processing device **208** executes instructions that interpret the received neural signals to determine feedback indicating the target object having the current focus of (visual) attention in real time. Decoding the information in the neural response signals relies upon a correspondence between that information and one or more aspect of the temporal profile of the target object (i.e. the stimulus).

In certain embodiments, the processing device may conveniently generate the image data presented on the display device **202** including the temporally varying target object.

The feedback may conveniently be presented visually on the display screen. For example, the display device may display an icon, cursor, crosshair or other graphical object or effect in close proximity to the target object (or overlapping or at least partially occluding that object), highlighting the object that appears to be the current focus of visual attention. Clearly, the visual display of such feedback has a reflexive cognitive effect on the perception of the target object, amplifying the brain response. This positive feedback (where the apparent target object is confirmed as the intended target object by virtue of prolonged amplified attention) is referred to herein as "neurosynchrony".

FIG. **3**B illustrates the use of a neural response device such as that in FIGS. **1** and **2** in discriminating between a plurality of target objects. The neural response device worn by the user (i.e. viewer) **305**, in FIG. **3**B is an electrode helmet for an EEG device. Here, the user wearing the helmet, views a screen **302** displaying a plurality of target objects (the digits in an on-screen keypad), which are blinking at distinctly different times, frequencies and/or duty cycles. The electrode helmet can convey a signal derived from neural activity. Here, the user is focusing on the digit **5**, **310**, where at time t**1** the digit **3**, **312**, blinks, at time t**2** the digit **4**, **314**, blinks, at time t**3** the digit **5**, **310'**, blinks, and at time t**4**, the digit **6**, **316**, blinks. The neural activity as conveyed by the helmet signal would be distinctly different at t**3** than at the other points in time. That is because the user is focusing on digit **5**, **310**, which blinks on, **310'**, at t**3**. However, to differentiate that signal occurring at t**3** with those at the other times, all the objects on the screen must blink at distinctively different times. Thus, the screen would be alive with blinking objects making for an uncomfortable viewing experience.

The system in FIG. **3**B could be using a display signal pattern such as the exemplary pattern shown in FIG. **4** where the screen objects will blink at different points in time, with different frequencies and duty cycles.

One approach to the challenge of determining the object of focus (the target) from the objects peripheral to the target (the distractors) with speed and accuracy relies upon characteristics of the human visual system.

Research into the way in which the human visual sensing operates has shown that, when peering at a screen with multiple objects and focusing on one of those objects, the human visual system will be receptive to both high spatial frequencies (HSF) and low spatial frequencies (LSF). Evidence shows that the human visual system is primarily sensitive to the HSF components of the specific display area being focused on (e.g. the object the user is staring at): this corresponds to the central area in the retina of the subject that is packed with cone cells, known as the fovea centralis. This may be seen in the right-hand view of FIG. **3**A where the foveal area of the display **318**, where vision is sharpest, is contrasted with the peripheral area **304**.

For peripheral objects, conversely, the human visual system is primarily sensitive to their LSF components. In other words, the neural signals picked up will essentially be impacted by both the HSF components from the target under focus and the LSF components from the peripheral targets. However, since all objects evoke some proportion of both HSF and LSF, processing the neural signals to determine the focus object can be impeded by the LSF noise contributed by peripheral objects. This tends to make identifying the object of focus less accurate and less timely.

The underlying science for this approach relates to the difference in how our eye-brain system processes stimuli from objects of focus and peripheral objects. This dissociation between foveal (center of vision field) and peripheral vision is described in the literature in terms of special frequency channels from the retina to the visual cortex, in which foveal vision is primarily driven by HSF channels conveying visual details while peripheral vision is primarily driven by LSF channels conveying rough visual information such as the global shape of objects without details. These two types of information have been associated with separate neural pathways, distinct functional and different impacts on unconscious and conscious perception.

Spatial frequencies are usually computed in terms of cycles per degree. It mainly depends on three parameters: the density pixel per inch (dpi) also known as pixel per inch (ppi), the distance between user's eyes and monitor, and the cutoff frequency of the spatial filter. Spatial frequency filters can be used such that stimuli signals retain only HSF characteristics, or conversely only LSF characteristics. Spatial frequency filters used in the context of a visual BCI may conveniently perform high-pass filtering for values with over 7 cycles per degree and low-pass filtering for values below 3 cycles per degree. In certain cases, lower threshold values for the low pass filter may in some cases result in the output of a uniform flat tint (such "low pass filters" are still valid filters). By contrast, the maximum value for a high pass filter threshold is limited by either the display system's resolution, and ultimately, the subject's visual physiological capabilities. In any case, the present disclosure operates regardless of the low pass and high pass further thresholds, being agnostic to the specific values of frequency filter and/or transform. The main principle is to dissociate spatial frequency components to optimize a visual BCI.

The human visual system is tuned to process multiple stimuli in parallel at different locations of the visual field, typically unconsciously or subliminally. Consequently, peripheral object stimuli will continue triggering neural responses in the users' brains, even if they appear in the periphery of the visual field. As a result, this poses competition among multiple stimuli and renders the specific neural decoding of the object of focus (the target) more difficult.

In prior art neural capture systems, thanks to the operation of the human visual system, the neural signals picked up will essentially be impacted by both the HSF components from the target under focus and the LSF components from the peripheral targets. However, since all objects evoke some proportion of both HSF and LSF, processing the neural signals to determine the focus object can be impeded by the LSF noise contributed by peripheral objects. This tends to make identifying the object of focus less accurate and less timely.

Considering again the on-screen keypad of FIG. **3**B, the blinking peripheral signals, **312**, **314**, **316**, would evoke LSF neural activity in the viewer that would be captured and processed in parallel with signals evoking HSF neural activity in the viewer stimulated by the blinking digit **5**, **310**. These peripheral objects, therefore, could be considered distractors and the LSF signals they evoke can be considered noise. One result of this noise is that it takes longer for a system to accurately determine the object of focus.

In the approach of the present disclosure, a plurality of objects is displayed in such a way that each one is separated into a version composed only of the LSF components of the object and a version composed of only HSF components. In one example, the blinking visual stimulus used to elicit SSVEPs is conveyed only through the HSF version of the object. This blinking HSF version is superimposed on the LSF version (which does not blink).

FIG. **5**A shows four different screen display objects, a digit **501**, a photograph **504**, a cluster of various filled objects **507** and a cluster of multiple fine strokes each with respective, different orientations **510**. By filtering these objects, one may produce an HSF version of each (denoted **502**, **505**, **508** and **511** respectively) and an LSF version of each (denoted **503**, **506**, **509** and **512** respectively). Keeping in mind that the human vision system is naturally more responsive to HSF signals from objects of focus, and to LSF signals from peripheral objects, if a display is dissociated into HSF and LSF versions, and only the HSF versions are made to blink whereas the LSF versions are constantly displayed, the peripheral object "noise" produced by LSF can be subdued by keeping that LSF version of each object constant and only blinking the HSF versions of each object. This effectively reduces LSF noise from peripheral objects and reduces LSF signal from an object under focus. Since the human vision system naturally associates HSF with foveal objects (those under focus), keeping the LSF version constant will have essentially no effect on the neural signals stimulated by the object under focus but will have reduced LSF interference from objects on the periphery. It has been observed that, when the screen display objects are multiple fine strokes, the HSF version **511** of base object **510** effectively provides a particularly high possible spatial frequency (while remaining fully visible) relative to the base object, whereas the corresponding LSF version **512** of base object **510** offers a particularly low possible spatial frequency (as it is a plain uniform background).

FIG. **5**B shows the screen display result that occurs when a target object's LSF and HSF versions are superimposed and displayed. Because only one version is blinking (e.g. the HSF version), the apparent blinking of the object is more subdued for the peripheral objects whereas the blinking of the object of focus is apparent because the human vision system is more sensitive to HSF-evoking stimuli from objects of focus.

FIG. **6** is an exemplary illustration of one embodiment of the disclosed subject matter. Here, all target objects **601** are filtered to create HSF and LSF versions of themselves.

In the FIG. **6** embodiment, target objects **601** are distinct graphical elements within a graphical interface presented on a display of a display device. Examples of target objects include glyphs, photographic images, and user-interface elements. The display device may include a processing unit (not shown), a modulator subsystem **605** and a display driver subsystem **606**.

For each target object **601**, the processing unit of the display device operates to apply a spatial frequency filter **602** (or a spatial frequency transform) to generate HSF and LSF versions (denoted **603** and **604** respectively) of the target object **601**. In other embodiments, the target objects **601** may be filtered to create only an HSF version of each object. Thus, only an HSF version is generated. The HSF version of target objects in the form of multiple fine strokes is particularly adapted to such embodiments.

The modulator subsystem **605** processes and conveys HSF and LSF versions **603**, **604** of each object to the display driver subsystem **606**. The HSF and LSF versions **603**, **604** of each object are processed differently: LSF version signals **604** are encoded to produce a static (e.g. non-blinking) display, whereas the HSF version signals **603** are temporally modulated (e.g. made to blink at distinct times with optionally different frequency and/or duty cycle characteristics). Temporal modulation effects are typically periodic alterations in a visual characteristic of the object such as the luminosity, hue, color component, etc. and may be abrupt (switching between ON and OFF states) or may include more gradual transitions. Examples of temporal modulations include a blinking effect where the brightness characteristics of groups of pixels in the target object are switched between two distinguishable brightness levels. Conveniently the modulation effects encode an optical characteristic to which a user's brain responds (when the object is viewed) in a detectable and decodable manner. The processing may further include increasing contrast levels within the HSF version signals and/or reducing contrast levels in the LSF version signals.

In certain embodiments, the modulation effects may be random or pseudo-random in nature: alterations in a visual characteristic of the object, such as blinking, are performed at random times, e.g. following a pseudo-random temporal pattern. Conveniently, pseudo-random temporal patterns are used, rather than strictly random patterns, to reduce temporal overlap between distinct temporal patterns associated with respective different objects.

The display driver subsystem **606** receives processed HSF and LSF versions of each object from the modulator subsystem **605** (either as separate signals or as a superimposed signal combining modulated HSF and LSF versions). As a result, the signal driving the display includes screen objects where LSF-related signals produce constant display and HSF-related signals produce blinking effects (or other temporal modulation effects).

In certain embodiments, as noted above, the modulator subsystem **605** may process and convey only the HSF version of each object to the display driver subsystem **606**: so that only an HSF version is received at the display driver subsystem **606**. In such cases, the modulator subsystem **605** applies a high pass filter to generate only the HSF version of each object. In certain other embodiments, the modulator subsystem may apply one or more spatial frequency filters (or spatial frequency transforms) to generate both HSF and LSF versions of the target object but convey only the HSF version of each object to the display driver subsystem **606**. In each case, the HSF version is temporally modulated as described above so that the display driver subsystem drives the display with a signal that includes screen objects having HSF components that are temporally modulated. In another embodiment, the display driver subsystem **606** displays the generated HSF version **603** in addition to the (whole) target object **601**. In such cases, the contrast in the modulated HSF version may be increased to improve visibility of the visual stimulus over objects of focus.

User attention on the displayed (HSF modulated) object can then be detected (through capture **622** and decoding of neural responses, **607**). As a result, the effect of temporal modulation of peripherally viewed objects is significantly reduced. When the user (i.e. subject) wearing a neural response device **620** of the type described in the discussion of FIGS. **1** and **2** above views the screen, only the object of focus will be vibrantly blinking whereas peripheral objects, which are also temporally modulated, will contribute far less noise (since their modulation is only exhibited in HSF components that are out of field for the user intent on the object of focus). That allows the system to determine both quickly and accurately which object the viewer is currently focusing on. Modulated HSF components, being close to invisible when not the object of focus, allow the stimuli to be barely visible to external viewers, especially when seen from a distance (e.g. a distance greater than twice the distance between a typical active user and the display device). This allows for a discreet (e.g. more private) interaction between the user and the object(s) of focus.

In certain alternative embodiments, target objects (or "screen objects") are distinct graphical elements presented on a display of a display device, and overlay objects are generated to correspond to one or more of the screen objects. It is the overlay objects, rather than the screen objects themselves, which are now filtered to produce HSF and LSF versions.

FIG. **7** is an exemplary illustration of another embodiment of the disclosed subject matter implementing such a scheme. As in FIG. **6**, the display device may include a processing unit (not shown), a modulator subsystem **605** and a display driver subsystem **606**: the display device of FIG. **7** is further provided with an overlay subsystem **704**.

Here, the screen objects **601** will have display signals conveyed to the overlay subsystem **704**.

In certain embodiments, each screen object will have associated with it an overlay object. Alternatively, as illustrated in FIG. **7**, only certain screen objects have an associated overlay object **701**. A graphical overlay object may, for example, be a geometric shape that surrounds a corresponding screen object.

In certain embodiments, such as that illustrated in FIG. **7**, the overlay objects **701**, rather than the screen objects themselves, are now filtered to produce HSF and LSF versions (again denoted **603** and **604** respectively). For each overlay object **701**, the processing unit of the display device operates to apply a spatial frequency filter **702** (or a spatial frequency transform) to generate HSF and LSF versions **603**, **604** of the overlay object **701**.

The modulator subsystem **605** separately modulates the HSF and LSF versions **603**, **604** of each overlay object. The modulator subsystem **605** then conveys the modulated HSF and LSF versions of each overlay object to the overlay superposition subsystem **704**. The modulator subsystem **605** may optionally convey the modulated HSF and LSF versions of each overlay object as a single superimposed overlay object or as separate versions.

The overlay superposition subsystem **704**, receiving processed graphical overlay objects, processes the screen objects **601** and the modulated overlay objects to generate a superposition display signal from the screen and overlay objects.

The superposition subsystem **704**, in turn, conveys the processed superposition display signals to the display driver subsystem **606** to drive the display.

The separate modulation may mirror the different processing of target object versions in FIG. **6**. The modulator subsystem **605** is configured to process the overlay objects **701** such that the LSF versions **604** are static (e.g. constantly displayed) whereas the HSF versions **603** are modulated to produce distinctive blinking patterns for differentiating the overlay objects. When the subject focuses on a screen object **601**, they see a blinking overlay object **701** quite distinctly whereas the peripheral screen objects and their blinking HSF overlay objects are naturally subdued by the human vision system. Again, the overlay object **701** associated with the target screen object **601** of focus is readily distinguished from the other overlay objects to enable the system to quickly and accurately determine which screen object the user is focusing on.

The above schemes for either processing the target objects themselves to apply a modulation to the HSF version of that object or processing overlay objects to be visually superposed over target objects to apply a modulation to the HSF version of the overlay object become less effective when the HSF component of the target object/overlay object provides an insufficient stimulation impact. For example, the target object may be visually smooth so that there are not enough sharp edges or patches of high contrast to generate a large HSF component. In such cases, no amount of modulation based on the HSF version of the object will be visually apparent to the viewing subject.

FIGS. **8**A, **8**B and **8**C illustrate the operation of the method of a further aspect of the present disclosure. In certain embodiments, a base image (e.g. a 2D pixel surface) including image data is processed for display in a graphical user interface of a display: the base image is processed to identify (and optionally classify) objects of interest within the base image. The base image and/or the portions of the base image including the identified objects of interest are logically associated with one or more control items (the control items being associated with user-selectable actions).

The image data for the base image and/or the portions of the base image including the identified objects of interest are processed to generate low spatial frequency map data and high spatial frequency map data. In certain embodiment, this processing is achieved through the application of spatial frequency filtering: features of a spatial frequency lower than a predetermined low spatial frequency threshold are preserved in the low spatial frequency map data, while features of a spatial frequency higher than a predetermined high spatial frequency threshold are preserved in the high spatial frequency map data. The predetermined high spatial frequency threshold and predetermined low spatial frequency threshold may be the same. Alternatively, the respective spatial frequency thresholds may differ from one another so that features with spatial frequencies intermediate between the two thresholds may be included in both sets of map data or excluded from both sets of map data.

In certain embodiments, the integral of distribution of the HSF components in the HSF map data is calculated for each of a plurality of patches spanning the HSF map data, the patches being dimensioned based on the foveal area of the retina (the area of the fovea setting a maximum area over which HSF components will have an impact). The integral for a given patch is compared to a predetermined spatial frequency threshold, T**1**. The threshold, T**1**, is a cut-off set to a value considered to indicate the presence of sufficient HSF components to provide a significant stimulation impact (i.e. in terms of the strength of the HSF components and/or their spatial distribution over the base image).

Where the integral for the given patch exceeds the predetermined spatial frequency threshold, T**1**, a temporal modulation is applied to the HSF component for that patch and the display is fed a first modified (i.e. blended) HSF and temporal signal with or without the LSF component. Examples of blending of signals include additive blending, multiplication, and subtraction as well as other convention signal multiplexing techniques.

In certain embodiments, the technique for blending is a technique analogous to the conventional overlay blend mode used in the fields of digital image editing and computer graphics. Conveniently, in an ON state of the modulation, a topmost image is superposed over a background image:

parts of the top image where the underlying background image is light are made lighter, while parts where the background image is dark are made darker.

Where the integral for the given patch does not exceed the predetermined spatial frequency threshold, T**1**, it is determined whether to blend in HSF noise, this operation is illustrated in FIGS. **8**B and **8**C. In certain embodiments, it is determined whether the mean luminosity (and/or contrast) of respective pixels of the base image falls within a predetermined range: for example, the luminosity range from (50–T**2**)% to (50+T**2**)%. The predetermined range is set to correspond to a range of luminosity and/or contrast for which HSF noise may be effective, i.e. maintaining a low ratio between luminosity for ON vs OFF states, while allowing for a low peripheral saliency and ensuring a good neural response.

If the mean luminosity of the pixels of the base image does fall within the predetermined range, the processor is configured to process image data for areas (i.e. patches) where the HSF is below the predetermined threshold, T**1**, to (at least partly) desaturate the local hue for pixels in that area, thereby generating a desaturated map, and to apply a high spatial frequency filtered noise patch or Gabor variant patch to the areas where the HSF is below the predetermined threshold, T**1**, to generate a HSF noise map for that area. Desaturation of the pixels is achieved by calculating the median of the R-G-B channels, which will statistically provide luminosity values closer to 50% gray. A temporal (and spatial) modulation is applied to the HSF noise patch (es) and the display is fed the desaturated map data and a second modified (i.e. blended) HSF and temporal modulation. Consequently, the luminosity for the areas will remain substantially the same after the application of the temporal modulation, while the stimulation caused by the temporal modulation is smooth (i.e. not visually disturbing) while facilitating improved decoding of attended/foveal targets.

If the mean luminosity of the pixels of the base image does not fall within the predetermined range (i.e. [50–T**2**: 50+T**2**]), an alternative approach is needed in that area/patch. The mean luminosity is either too great or insufficient to allow temporal modulation to be applied directly to the HSF portion of the base image. In certain embodiments (illustrated by option (A) in FIG. **8**C), pixels of high and low values are replaced by preset intermediate values (thus discarding certain original pixel information from the base image) to generate a gray overlay map. HSF noise is generated and a temporal modulation may then be applied to the HSF noise. The display is fed the combined gray overlay map and HSF noise with the temporal modulation. In certain examples, the generated HSF noise is arranged to have a luminosity "balanced" between "OFF" and "ON" state, being generated with 50% black and 50% white so that, for example, the HSF noise is also effectively "gray".

In an alternative approach to the pixels of the base image having out-of-range luminosity (illustrated by option (B) in FIG. **8**C), pixels of the area are directly overwritten by pixel values incorporating HSF noise. A temporal modulation may then be applied to the HSF noise. The display is fed the combined gray overlay map and HSF noise with the temporal modulation. In a further embodiment, a contrast change is applied to an LSF component so that the resulting visual stimuli are light-balanced when HSF and LSF components are blended with an additive blend.

It will be appreciated that spatial frequency and luminosity thresholds discussed above may conveniently depend on (and be set according to) many different factors, such as subject's own vision capacities, display device distance, display device pixel density, display device display size, etc.

FIG. **10** is a block diagram illustrating an example software architecture **1006**, which may be used in conjunction with various hardware architectures herein described. FIG. **10** is a non-limiting example of a software architecture and it will be appreciated that many other architectures may be implemented to facilitate the functionality described herein. The software architecture **1006** may execute on hardware such as machine **1100** of FIG. **11** that includes, among other things, processors **1104**, memory **1106**, and input/output (I/O) components **1118**. A representative hardware layer **1052** is illustrated and can represent, for example, the machine **1100** of FIG. **11**. The representative hardware layer **1052** includes a processing unit **1054** having associated executable instructions **1004**. The executable instructions **1004** represent the executable instructions of the software architecture **1006**, including implementation of the methods, modules and so forth described herein. The hardware layer **1052** also includes memory and/or storage modules shown as memory/storage **1056**, which also have the executable instructions **1004**. The hardware layer **1052** may also comprise other hardware **1058**, for example dedicated hardware for interfacing with EEG electrodes and/or for interfacing with display devices.

In the example architecture of FIG. **10**, the software architecture **1006** may be conceptualized as a stack of layers where each layer provides particular functionality. For example, the software architecture **1006** may include layers such as an operating system **1002**, libraries **1020**, frameworks or middleware **1018**, applications **1016** and a presentation layer **1014**. Operationally, the applications **1016** and/or other components within the layers may invoke application programming interface (API) calls **1008** through the software stack and receive a response as messages **1010**. The layers illustrated are representative in nature and not all software architectures have all layers. For example, some mobile or special purpose operating systems may not provide the frameworks/middleware **1018**, while others may provide such a layer. Other software architectures may include additional or different layers.

The operating system **1002** may manage hardware resources and provide common services. The operating system **1002** may include, for example, a kernel **1022**, services **1024**, and drivers **1026**. The kernel **1022** may act as an abstraction layer between the hardware and the other software layers. For example, the kernel **1022** may be responsible for memory management, processor management (e.g., scheduling), component management, networking, security settings, and so on. The services **1024** may provide other common services for the other software layers. The drivers **1026** may be responsible for controlling or interfacing with the underlying hardware. For instance, the drivers **1026** may include display drivers, EEG device drivers, camera drivers, Bluetooth® drivers, flash memory drivers, serial communication drivers (e.g., Universal Serial Bus (USB) drivers), Wi-Fi® drivers, audio drivers, power management drivers, and so forth depending on the hardware configuration.

The libraries **1020** may provide a common infrastructure that may be used by the applications **1016** and/or other components and/or layers. The libraries **1020** typically provide functionality that allows other software modules to perform tasks in an easier fashion than by interfacing directly with the underlying operating system **1002** functionality (e.g., kernel **1022**, services **1024**, and/or drivers **1026**). The libraries **1020** may include system libraries **1044** (e.g., C standard library) that may provide functions such as memory allocation functions, string manipulation functions, mathematic functions, and the like. In addition, the libraries **1020** may include API libraries **1046** such as media libraries (e.g., libraries to support presentation and manipulation of various media formats such as MPEG4, H.264, MP3, AAC, AMR, JPG, and PNG), graphics libraries (e.g., an OpenGL framework that may be used to render 2D and 3D graphic content on a display), database libraries (e.g., SQLite that may provide various relational database functions), web libraries (e.g., WebKit that may provide web browsing functionality), and the like. The libraries **1020** may also include a wide variety of other libraries **1048** to provide many other APIs to the applications **1016** and other software components/modules.

The frameworks **1018** (also sometimes referred to as middleware) provide a higher-level common infrastructure that may be used by the applications **1016** and/or other software components/modules. For example, the frameworks/middleware **1018** may provide various graphic user interface (GUI) functions, high-level resource management, high-level location services, and so forth. The frameworks/middleware **1018** may provide a broad spectrum of other APIs that may be used by the applications **1016** and/or other software components/modules, some of which may be specific to a particular operating system or platform.

The applications **1016** include built-in applications **1038** and/or third-party applications **1040**.

The applications **1016** may use built-in operating system functions (e.g., kernel **1022**, services **1024**, and/or drivers **1026**), libraries **1020**, or frameworks/middleware **1018** to create user interfaces to interact with users of the system. Alternatively, or additionally, in some systems interactions with a user may occur through a presentation layer, such as the presentation layer **1014**. In these systems, the application/module "logic" can be separated from the aspects of the application/module that interact with a user.

FIG. **11** is a block diagram illustrating components of a machine **1100**, according to some example embodiments, able to read instructions from a machine-readable medium (e.g., a machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. **11** shows a diagrammatic representation of the machine **1100** in the example form of a computer system, within which instructions **1110** (e.g., software, a program, an application, an applet, an app, or other executable code) for causing the machine **1100** to perform any one or more of the methodologies discussed herein may be executed. As such, the instructions **1110** may be used to implement modules or components described herein. The instructions **1110** transform the general, non-programmed machine **1100** into a particular machine programmed to carry out the described and illustrated functions in the manner described. In alternative embodiments, the machine **1100** operates as a standalone device or may be coupled (e.g., networked) to other machines. In a networked deployment, the machine **1100** may operate in the capacity of a server machine or a client machine in a server-client network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. The machine **1100** may comprise, but not be limited to, a server computer, a client computer, a personal computer (PC), a tablet computer, a laptop computer, a netbook, a set-top box (STB), a personal digital assistant (PDA), an entertainment media system, a cellular telephone, a smart phone, a mobile device, a wearable device (e.g., a smart watch), a smart home device (e.g., a smart appliance), other smart devices, a web appliance, a network router, a network switch, a network bridge, or any machine capable of executing the instructions **1110**, sequentially or otherwise, that specify actions to be taken by the machine **1100**. Further, while only a single machine **1100** is illustrated, the term "machine" shall also be taken to include a collection of machines that individually or jointly execute the instructions **1110** to perform any one or more of the methodologies discussed herein.

The machine **1100** may include processors **1104**, memory **1106**, and input/output (I/O) components **1118**, which may be configured to communicate with each other such as via a bus **1102**. In an example embodiment, the processors **1104** (e.g., a Central Processing Unit (CPU), a Reduced Instruction Set Computing (RISC) processor, a Complex Instruction Set Computing (CISC) processor, a Graphics Processing Unit (GPU), a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Radio-Frequency Integrated Circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor **1108** and a processor **1112** that may execute the instructions **1110**. The term "processor" is intended to include multi-core processor that may comprise two or more independent processors (sometimes referred to as "cores") that may execute instructions contemporaneously. Although FIG. **11** shows multiple processors, the machine **1100** may include a single processor with a single core, a single processor with multiple cores (e.g., a multi-core processor), multiple processors with a single core, multiple processors with multiples cores, or any combination thereof.

The memory **1106** may include a memory **1114**, such as a main memory, a static memory, or other memory storage, and a storage unit **1116**, both accessible to the processors **1104** such as via the bus **1102**. The storage unit **1116** and memory **1114** store the instructions **1110** embodying any one or more of the methodologies or functions described herein. The instructions **1110** may also reside, completely or partially, within the memory **1114**, within the storage unit **1116**, within at least one of the processors **1104** (e.g., within the processor's cache memory), or any suitable combination thereof, during execution thereof by the machine **1100**. Accordingly, the memory **1114**, the storage unit **1116**, and the memory of processors **1104** are examples of machine-readable media.

As used herein, "machine-readable medium" means a device able to store instructions and data temporarily or permanently and may include, but is not limited to, random-access memory (RAM), read-only memory (ROM), buffer memory, flash memory, optical media, magnetic media, cache memory, other types of storage (e.g., Erasable Programmable Read-Only Memory (EEPROM)), and/or any suitable combination thereof. The term "machine-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) able to store the instructions **1110**. The term "machine-readable medium" shall also be taken to include any medium, or combination of multiple media, that is capable of storing instructions (e.g., instructions **1110**) for execution by a machine (e.g., machine **1100**), such that the instructions, when executed by one or more processors of the machine **1100** (e.g., processors **1104**), cause the machine **1100** to perform any one or more of the methodologies described herein. Accordingly, a "machine-readable medium" refers to a single storage apparatus or device, as well as "cloud-based" storage systems or storage networks that include multiple storage apparatus or devices. The term "machine-readable medium" excludes signals per se.

The input/output (I/O) components **1118** may include a wide variety of components to receive input, provide output, produce output, transmit information, exchange information, capture measurements, and so on. The specific input/output (I/O) components **1118** that are included in a particular machine will depend on the type of machine. For example, user interface machines and portable machines such as mobile phones will likely include a touch input device or other such input mechanisms, while a headless server machine will likely not include such a touch input device. It will be appreciated that the input/output (I/O) components **1118** may include many other components that are not shown in FIG. **11**.

The input/output (I/O) components **1118** are grouped according to functionality merely for simplifying the following discussion and the grouping is in no way limiting. In various example embodiments, the input/output (I/O) components **1118** may include output components **1126** and input components **1128**. The output components **1126** may include visual components (e.g., a display such as a plasma display panel (PDP), a light emitting diode (LED) display, a liquid crystal display (LCD), a projector, or a cathode ray tube (CRT)), acoustic components (e.g., speakers), haptic components (e.g., a vibratory motor, resistance mechanisms), other signal generators, and so forth. The input components **1128** may include alphanumeric input components (e.g., a keyboard, a touch screen configured to receive alphanumeric input, a photo-optical keyboard, or other alphanumeric input components), point-based input components (e.g., a mouse, a touchpad, a trackball, a joystick, a motion sensor, or other pointing instruments), tactile input components (e.g., a physical button, a touch screen that provides location and/or force of touches or touch gestures, or other tactile input components), audio input components (e.g., a microphone), and the like.

In further example embodiments, the input/output (I/O) components **1118** may include biometric components **1130**, motion components **1134**, environment components **1136**, or position components **1138** among a wide array of other components. For example, the biometric components **1130** may include components to detect expressions (e.g., hand expressions, facial expressions, vocal expressions, body gestures, or eye tracking), measure biosignals (e.g., blood pressure, heart rate, body temperature, perspiration, or brain waves, such as the output from an EEG device), identify a person (e.g., voice identification, retinal identification, facial identification, fingerprint identification, or electroencephalogram based identification), and the like. The motion components **1134** may include acceleration sensor components (e.g., accelerometer), gravitation sensor components, rotation sensor components (e.g., gyroscope), and so forth. The environmental environment components **1136** may include, for example, illumination sensor components (e.g., photometer), temperature sensor components (e.g., one or more thermometers that detect ambient temperature), humidity sensor components, pressure sensor components (e.g., barometer), acoustic sensor components (e.g., one or more microphones that detect background noise), proximity sensor components (e.g., infrared sensors that detect nearby objects), gas sensors (e.g., gas detection sensors to detect concentrations of hazardous gases for safety or to measure pollutants in the atmosphere), or other components that may provide indications, measurements, or signals corresponding to a surrounding physical environment. The position components **1138** may include location sensor components (e.g., a Global Position System (GPS) receiver component), altitude sensor components (e.g., altimeters or barometers that detect air pressure from which altitude may be derived), orientation sensor components (e.g., magnetometers), and the like.

Communication may be implemented using a wide variety of technologies. The input/output (I/O) components **1118** may include communication components **1140** operable to couple the machine **1100** to a network **1132** or devices **1120** via a coupling **1124** and a coupling **1122** respectively. For example, the communication components **1140** may include a network interface component or other suitable device to interface with the network **1132**. In further examples, communication components **1140** may include wired communication components, wireless communication components, cellular communication components, Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components to provide communication via other modalities. The devices **1120** may be another machine or any of a wide variety of peripheral devices (e.g., a peripheral device coupled via a Universal Serial Bus (USB)). Where an EEG device or display device is not integral with the machine **1100**, the device **1120** may be an EEG device and/or a display device.

FIG. **12** illustrates the main functional blocks in the method of operation of a processing device (for example, processing device **208** in FIG. **2**) in accordance with the present disclosure. In block **1202**, the processing device obtains a base image. In block **1204**, the processing device generates at least one visual stimulus, each stimulus having a characteristic modulation, the characteristic modulation being applied to high spatial frequency, HSF, components of the visual stimulus. In block **1206**, the processing device controls the display of the or each visual stimulus via a graphical user interface, GUI, of a display. In block **1208**, the processing device receives neural signals of a user from a neural signal capture device. In block **1210**, when the user views the or each visual stimulus, the processing device determines a point of focus of the user in the viewed image based on the neural signals, the neural signals including information associated with the characteristic modulation of a visual stimulus to which the user's visual attention is directed.

FIG. **13** illustrates the processing of a base image to generate a visual stimulus as described above in relation to FIG. **6**. The base image **1320** is subjected to image recognition **1310** (using for example a convolutional neural network) and the image is segmented **1308** to recognize boundaries between the object(s) of interest (i.e. target objects, **601**) and background.

For the object of interest in FIG. **6**, the image data for the object are processed to derive HSF components **1306** and LSF components **1304**. The processing of the image data comprises the application of a spatial frequency filter or transform.

The resulting HSF components are then modulated to encode an optical characteristic to which a user's brain responds (when the object is viewed) in a detectable and decodable manner. The modulated HSF components are blended with the LSF components to generate a hybrid image object **1302**. User attention on the hybrid image object **1302** can then be detected (through capture and decoding of neural responses).

Once it becomes possible to identify an object of interest through the use of overlay image objects, use cases such as 'zooming' on specific objects/faces in a surveillance video simply by focusing attention on that face/object and making real objects actionable (to draw down additional information associated with that object say) in AR scenarios, where the stimulus overlay is presented to the user in a headset (smart glasses, say) on top of the user's view of the real objects.

The positive neurosynchrony feedback loop described in relation to the BCI in FIG. **2** may be employed to confirm the intent of the user for example to initiate an action such as a zoom, information request, the browsing/navigation of virtual UI elements, annotation of objects, activation/selection of objects (e.g., through a virtual appliance interface on a real wall) in mixed reality settings.

Although described through a number of detailed exemplary embodiments, the portable devices for the acquisition of electroencephalographic signals according to the present disclosure comprise various variants, modifications and improvements which will be obvious to those skilled in the art, it being understood that these various variants, modifications and improvements fall within the scope of the subject of the present disclosure, as defined by the following claims.

Although an overview of the inventive subject matter has been described with reference to specific example embodiments, various modifications and changes may be made to these embodiments without departing from the broader scope of embodiments of the present disclosure. Such embodiments of the inventive subject matter may be referred to herein, individually or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single disclosure or inventive concept if more than one is, in fact, disclosed.

The embodiments illustrated herein are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed. Other embodiments may be used and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. The Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

As used herein, the term "or" may be construed in either an inclusive or exclusive sense. Moreover, plural instances may be provided for resources, operations, or structures described herein as a single instance. Additionally, boundaries between various resources, operations, modules, engines, and data stores are somewhat arbitrary, and particular operations are illustrated in a context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within a scope of various embodiments of the present disclosure. In general, structures and functionality presented as separate resources in the example configurations may be implemented as a combined structure or resource. Similarly, structures and functionality presented as a single resource may be implemented as separate resources. These and other variations, modifications, additions, and improvements fall within a scope of embodiments of the present disclosure as represented by the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

Thus, the present disclosure describes a system and method for improving the accuracy, speed performance and visual comfort of BCIs.

In accordance with an aspect of the present disclosure the system is a closed-loop system comprising: a display subsystem operative to display one or more object images; a display-driver subsystem operative to convey a display signal to said display subsystem; an HSF/LSF discriminating, filtering and processing subsystem operative to essentially separate said object images into HSF and LSF versions that evoke essentially HSF neural responses and essentially LSF neural responses, respectively; said HSF/LSF discriminating, filtering and processing subsystem operative to process said HSF versions so as to blink on and off, and said LSF versions so as to be non-blinking; and an electrode helmet operative to detect neural brain activity, produce an electrical signal representing said neural brain activity, and to convey said electrical signal to said HSF/LSF discriminating, filtering and processing subsystem wherein said electrical signal is compared to concurrent display signals in said HSF/LSF discriminating, filtering and processing subsystem so as to associate said electrical signal with a corresponding said concurrent display signal.

The system may further comprise said display signal being used to modulate screen objects.

Alternatively or additionally, the system may further comprise said display signal being used to modulate screen object overlays.

In accordance with a further aspect of the present disclosure there is provided a method for improving the accuracy, speed performance and visual comfort of BCIs, the method comprising: detecting neural signals from helmet electrodes when worn on a user's head and while said user gazes at objects on a display screen; correlating said detected neural signals with display signals used to modulate said objects; comparing said neural signals with said display signals; and identifying an object of focus wherein said neural signal and said display signals correlate.

The method may further comprise identifying said object of focus wherein said object of focus is a screen object.

Alternatively or additionally, the method may further comprise identifying said object of focus wherein said object of focus is a screen-object overlay.

EXAMPLES

To better illustrate the system and methods disclosed herein, a non-limiting list of examples is provided here:

1. A method comprising:
   - filtering graphical data for one or more screen objects, to generate a high spatial frequency, HSF, version of the or each screen object;
   - for each HSF version of the screen object, applying a characteristic modulation;
   - generating display signals including visual stimuli corresponding to said modulated versions of the screen objects;
   - displaying the display signals on a display screen;
   - receiving neural signals of a user from a neural signal capture device while said user gazes at the display screen;
   - for each visual stimulus, determining whether the neural signals received when the user gazes at the display screen include a neural signature of said visual stimulus; and
   - identifying an object of focus of the user in the display signals displayed on the display screen when it is determined that the neural signals include the neural signature of the visual stimulus, the object of focus being a display object on the display screen that coincides with the visual stimulus.
2. The method of example 1, wherein the neural signals correspond to neural oscillations measured in a visual cortex of the user's brain.

3. The method of example 1 or 2, wherein the neural signature comprises information associated with the characteristic modulation of the visual stimulus.
4. The method of any one of examples 1, 2 or 3, further comprising filtering graphical data for one or more screen objects, to generate a low spatial frequency, LSF, version of the or each screen object; and, for each LSF version of the screen object, encoding a static display signal.
5. The method of any one of examples 1-4, wherein the graphical data for the one or more screen objects is filtered using at least one of a spatial frequency filter or a spatial frequency transform.
6. The method of any one of examples 1-5, wherein the characteristic modulation is a characteristic temporal modulation.
7. The method of any one of examples 1-6, wherein determining whether the received neural signals include the digital signature of the visual stimulus includes: performing spectral analysis on the received neural signals, and determining whether the spectral characteristics of the received neural signals correspond to the spectrum associated with the characteristic modulation of the visual stimulus.
8. The method of any one of examples 1-7, wherein the neural signal capture device includes an EEG helmet comprising electrodes, the EEG helmet being configured to be worn on a user's head.
9. The method of any one of examples 1-8, wherein said object of focus is the screen object itself.
10. The method of any one of examples 1-9, wherein said object of focus is a display object displayed on the display screen and the visual stimulus is an overlay object different from the display object and displayed over the display object.
11. A brain computer interface system, comprising:
    - a display subsystem configured to present a display screen to a user;
    - a neural signal capture device configured to capture neural signals associated with the user;
    - an interfacing device operatively coupled to the display subsystem and the neural signal capture device, the interfacing device including:
    - a memory; and
    - a processor operatively coupled to the memory and configured:
        - to filter graphical data for one or more screen objects, to generate a high spatial frequency, HSF, version of the or each screen object;
        - for each HSF version of the screen object, to apply a characteristic modulation;
        - to generate display signals including visual stimuli corresponding to said modulated versions of the screen objects;
        - to convey the display signals to the display subsystem for display on the display screen;
        - to receive neural signals of the user from the neural signal capture device while said user gazes at the display screen;
        - for each visual stimulus, to determine whether the neural signals received when the user gazes at the display screen include a neural signature of said visual stimulus; and
        - to identify an object of focus of the user in the display signals displayed on the display screen when it is determined that the neural signals include the neural signature of the visual stimulus, the object of focus being a display object on the display screen that coincides with the visual stimulus.
12. The brain computer interface system of example 11, wherein the processor is further configured:
    - to associate the object of focus with at least one control item from a set of control items;
    - to determine, based on the object of focus and the at least one control item, an action intended by the user; and
    - to implement the action intended by the user.
13. The brain computer interface system of example 11 or example 12, wherein the processor further comprises:
    - a display-driver subsystem operative to convey a display signal to said display subsystem.
14. The brain computer interface system of any one of examples 11 to 13, wherein the neural signal capture device comprises an electrode helmet operative to detect neural brain activity, produce an electrical signal representing said neural brain activity, and to convey said electrical signal to the interfacing device.
15. The brain computer interface system of any one of examples 11 to 14, wherein the object of focus is the screen object itself.
16. The brain computer interface system of any one of examples 11 to 14, wherein said object of focus is a display object displayed on the display screen and the visual stimulus is an overlay object different from the display object and displayed over the display object.
17. The brain computer interface system of any one of examples 11 to 16, wherein the processor is further configured: to filter graphical data for one or more screen objects to generate a low spatial frequency, LSF, version of the or each screen object; and, for each LSF version of the screen object, to encode a static display signal.
18. A computer-readable storage medium, the computer-readable storage medium carrying instructions that, when executed by a computer, cause the computer to perform operations comprising:
    - filtering graphical data for one or more screen objects, to generate a high spatial frequency, HSF, version of the or each screen object;
    - for each HSF version of the screen object, applying a characteristic modulation;
    - generating display signals including visual stimuli corresponding to said modulated versions of the screen objects;
    - displaying the display signals on a display screen;
    - receiving neural signals of a user from a neural signal capture device while said user gazes at the display screen;
    - for each visual stimulus, determining whether the neural signals received when the user gazes at the display screen include a neural signature of said visual stimulus; and
    - identifying an object of focus of the user in the display signals displayed on the display screen when it is determined that the neural signals include the neural signature of the visual stimulus, the object of focus being a display object on the display screen that coincides with the visual stimulus.
19. The computer-readable storage medium of example 18, wherein the neural signals correspond to neural oscillations measured in a visual cortex of the user's brain.

20. The computer-readable storage medium of example 18 or example 19, wherein the neural signature comprises information associated with the characteristic modulation of the visual stimulus.
21. The computer-readable storage medium of any one of examples 18, 19 or 20, wherein the instructions further cause the computer to perform operations comprising: filtering graphical data for one or more screen objects, to generate a low spatial frequency, LSF, version of the or each screen object; and, for each LSF version of the screen object, encoding a static display signal.
22. The computer-readable storage medium of any one of examples 18 to 21, wherein the graphical data for the one or more screen objects is filtered using at least one of a spatial frequency filter or a spatial frequency transform.
23. The computer-readable storage medium of any one of examples 18 to 22, wherein the characteristic modulation is a characteristic temporal modulation.
24. The computer-readable storage medium of any one of examples 18 to 23, wherein determining whether the received neural signals include the digital signature of the visual stimulus includes: performing spectral analysis on the received neural signals, and determining whether the spectral characteristics of the received neural signals correspond to the spectrum associated with the characteristic modulation of the visual stimulus.
25. A method of tracking visual attention, the method comprising:

obtaining a base image;

generating at least one visual stimulus, each stimulus having a characteristic modulation, the characteristic modulation being applied to high spatial frequency, HSF, components of the visual stimulus;

displaying the or each visual stimulus via a graphical user interface, GUI, of a display; receiving neural signals of a user from a neural signal capture device; and

when the user views the or each visual stimulus, determining a point of focus of the user in the viewed image based on the neural signals, the neural signals including information associated with the characteristic modulation of a visual stimulus to which the user's visual attention is directed.
26. The method of example 25, wherein generating the stimulus includes:

processing at least a portion of the base image to generate low spatial frequency (LSF) map data and HSF map data; and

determining whether the HSF map data fulfils a predetermined spatial frequency threshold, T**1**.
27. The method of example 26, wherein processing at least a portion of the base image comprises:

applying at least one of a spatial frequency filter or a spatial frequency transform;

storing features of said at least a portion of the base image having a spatial frequency lower than a predetermined low spatial frequency threshold in the low spatial frequency map data; and

storing features of said at least a portion of the base image having a spatial frequency higher than a predetermined high spatial frequency threshold in the high spatial frequency map data.
28. The method of example 26, wherein the HSF map data does not fulfil the predetermined spatial frequency threshold, T**1**, and

wherein generating the stimulus further includes:

generating enhanced HSF map data, thereby introducing additional HSF stimulation in the visual stimulus; and

applying a temporal modulation to the enhanced HSF map data.
29. The method of example 28, wherein generating enhanced HSF map data includes:

determining whether the luminosity of said at least a portion of the base image falls within a predetermined range; and

when the luminosity of said at least a portion of the base image falls within the predetermined range, generating a HSF noise map for use as the enhanced HSF map data.
30. The method of example 29, wherein generating enhanced HSF map data when the luminosity of said at least a portion of the base image does not fall within the predetermined range includes:

generating a gray overlay map; and

generating an HSF noise map for use as the enhanced HSF map data, and

wherein displaying the or each visual stimulus includes:

merging the enhanced HSF map data with the gray overlay map to provide a blended image; and

displaying the blended image via the GUI.
31. The method of example 29, wherein generating enhanced HSF map data when the luminosity of said at least a portion of the base image does not fall within the predetermined range includes:

generating a gray overlay map;

generating a hard noise map; and

replacing the HSF map data with data from the hard noise map for use as the enhanced HSF map data, and

wherein displaying the or each visual stimulus includes:

merging the enhanced HSF map data with the gray overlay map to provide a blended image; and

displaying the blended image via the GUI.
32. The method of example 25, wherein generating the stimulus includes:

processing the base image into segmented display objects;

for each segmented display object, filtering the segmented display objects into high spatial frequency, HSF, components and low spatial frequency, LSF, components; and

applying a temporal modulation in the HSF components of the segmented display objects.
33. The method of example 25, wherein generating the stimulus includes:

processing the base image into segmented display objects;

for each segmented display object, generating an overlay object;

for each overlay object, generating an HSF overlay object component and an LSF overlay object component; and

applying a temporal modulation in the HSF overlay object components of the overlay objects.
34. The method of example 33, wherein generating an HSF overlay object component and an LSF overlay object component comprises filtering the overlay object HSF components and LSF components respectively.
35. The method of example 25, wherein determining the point of focus includes correlating said received neural signals with display signals used to modulate said objects.
36. The method of example 25, wherein at least one visual stimulus corresponds to at least one control item, the or each control item being associated with one or more user-selectable actions.

37. The method of example 36, further comprising:
determining, based on the point of focus and the at least one control item, an action intended by the user; and
implementing the action intended by the user.
38. The method of example 25, wherein obtaining a base image includes:
operating an image capture device to capture the base image.
39. The method of example 25, wherein obtaining a base image includes:
receiving image data generated by an application executing in a processing device and using the received data as the base image.
40. The method of example 25, wherein displaying the or each visual stimulus comprises:
merging the or each visual stimulus with the base image to provide a blended image; and displaying the blended image via the GUI.
41. The method of example 38, wherein the display is a transparent display through which a user is presented a field of view aligned with that of the image capture device and wherein displaying the or each visual stimulus comprises displaying the or each visual stimulus over the field of view.
42. An apparatus, comprising:
a display configured to present a control interface to a user;
a neural signal capture device configured to capture neural signals associated with the user;
an interfacing device operatively coupled to the display and the neural signal capture device, the interfacing device including:
a memory; and
a processor operatively coupled to the memory and configured to:
receive the neural signals from the neural signal capture device;
generate and present a stimulus, via the control interface and to the user, the stimulus including a set of control items associated with a set of actions;
determine a point of focus of the user based on the neural signals, the point of focus being associated with at least one control item from the set of control items;
determine, based on the point of focus and the at least one control item, an action intended by the user; and
implement the action intended by the user.
43. A computing apparatus, the computing apparatus comprising:
a processor; and
a memory storing instructions that, when executed by the processor, configure the apparatus to:
obtain a base image;
generate at least one visual stimulus, each stimulus having a characteristic modulation, the characteristic modulation being applied to high spatial frequency, HSF, components of the visual stimulus;
display the or each visual stimulus via a graphical user interface, GUI, of a display; receive neural signals of a user from a neural signal capture device; and
when the user views the or each visual stimulus, determine a point of focus of the user in the viewed image based on the neural signals, the neural signals including information associated with the characteristic modulation of a visual stimulus to which the user's visual attention is directed.
44. The computing apparatus of example 43, wherein generating the stimulus includes:
processing at least a portion of the base image to generate low spatial frequency (LSF) map data and HSF map data; and
determining whether the HSF map data fulfils a predetermined spatial frequency threshold, T**1**.
45. The computing apparatus of example 43, wherein processing at least a portion of the base image comprises:
applying at least one of a spatial frequency filter or a spatial frequency transform;
storing features of said at least a portion of the base image having a spatial frequency lower than a predetermined low spatial frequency threshold in the low spatial frequency map data; and
storing features of said at least a portion of the base image having a spatial frequency higher than a predetermined high spatial frequency threshold in the high spatial frequency map data.
46. The computing apparatus of example 43, wherein the HSF map data does not fulfil the predetermined spatial frequency threshold, T**1**, and
wherein generating the stimulus further includes:
generating enhanced HSF map data, thereby introducing additional HSF stimulation in the visual stimulus; and
applying a temporal modulation to the enhanced HSF map data.
47. The computing apparatus of example 46, wherein generating enhanced HSF map data includes:
determining whether the luminosity of said at least a portion of the base image falls within a predetermined range; and
when the luminosity of said at least a portion of the base image falls within the predetermined range, generating a HSF noise map for use as the enhanced HSF map data.
48. The computing apparatus of example 47, wherein generating enhanced HSF map data when the luminosity of said at least a portion of the base image does not fall within the predetermined range includes:
generating a gray overlay map; and
generating an HSF noise map for use as the enhanced HSF map data, and
wherein displaying the or each visual stimulus includes:
merging the enhanced HSF map data with the gray overlay map to provide a blended image; and
displaying the blended image via the GUI.
49. The computing apparatus of example 47, wherein generating enhanced HSF map data when the luminosity of said at least a portion of the base image does not fall within the predetermined range includes:
generating a gray overlay map;
generating a hard noise map; and
replacing the HSF map data with data from the hard noise map for use as the enhanced HSF map data, and
wherein displaying the or each visual stimulus includes:
merging the enhanced HSF map data with the gray overlay map to provide a blended image; and
displaying the blended image via the GUI.
50. The computing apparatus of example 43, wherein generating the stimulus includes:
processing the base image into segmented display objects;
for each segmented display object, filtering the segmented display objects into high spatial frequency, HSF, components and low spatial frequency, LSF, components; and
applying a temporal modulation in the HSF components of the segmented display objects.

51. The computing apparatus of example 43, wherein generating the stimulus includes:
processing the base image into segmented display objects;
for each segmented display object, generating an overlay object;
for each overlay object, generating an HSF overlay object component and an LSF overlay object component; and
applying a temporal modulation in the HSF overlay object components of the overlay objects.
52. The computing apparatus of example 51, wherein generating an HSF overlay object component and an LSF overlay object component comprises filtering the overlay object HSF components and LSF components respectively.
53. The computing apparatus of example 43, wherein determining the point of focus includes correlating said received neural signals with display signals used to modulate said objects.
54. The computing apparatus of example 43, wherein at least one visual stimulus corresponds to at least one control item, the or each control item being associated with one or more user-selectable actions.
55. The computing apparatus of example 54, wherein the instructions further configure the apparatus to:
determine, based on the point of focus and the at least one control item, an action intended by the user; and
implement the action intended by the user.
56. The computing apparatus of example 43, wherein obtaining a base image includes:
operating an image capture device to capture the base image.
57. The computing apparatus of example 43, wherein obtaining a base image includes:
receiving image data generated by an application executing in a processing device and using the received data as the base image.
58. The computing apparatus of example 43, wherein displaying the or each visual stimulus comprises:
merging the or each visual stimulus with the base image to provide a blended image; and displaying the blended image via the GUI.
59. The computing apparatus of example 56, wherein the display is a transparent display through which a user is presented a field of view aligned with that of the image capture device and wherein displaying the or each visual stimulus comprises displaying the or each visual stimulus over the field of view.
60. A non-transitory computer-readable storage medium, the computer-readable storage medium including instructions that when executed by a computer, cause the computer to:
obtain a base image;
generate at least one visual stimulus, each stimulus having a characteristic modulation, the characteristic modulation being applied to high spatial frequency, HSF, components of the visual stimulus;
display the or each visual stimulus via a graphical user interface, GUI, of a display;
receive neural signals of a user from a neural signal capture device; and
when the user views the or each visual stimulus, determine a point of focus of the user in the viewed image based on the neural signals, the neural signals including information associated with the characteristic modulation of a visual stimulus to which the user's visual attention is directed.
61. The computer-readable storage medium of example 60, wherein generating the stimulus includes:
processing at least a portion of the base image to generate low spatial frequency (LSF) map data and HSF map data; and
determining whether the HSF map data fulfils a predetermined spatial frequency threshold, T**1**.
62. The computer-readable storage medium of example 60, wherein processing at least a portion of the base image comprises:
applying at least one of a spatial frequency filter or a spatial frequency transform;
storing features of said at least a portion of the base image having a spatial frequency lower than a predetermined low spatial frequency threshold in the low spatial frequency map data; and
storing features of said at least a portion of the base image having a spatial frequency higher than a predetermined high spatial frequency threshold in the high spatial frequency map data.
63. The computer-readable storage medium of example 60, wherein the HSF map data does not fulfil the predetermined spatial frequency threshold, T**1**, and
wherein generating the stimulus further includes:
generating enhanced HSF map data, thereby introducing additional HSF stimulation in the visual stimulus; and
applying a temporal modulation to the enhanced HSF map data.
64. The computer-readable storage medium of example 63, wherein generating enhanced HSF map data includes:
determining whether the luminosity of said at least a portion of the base image falls within a predetermined range; and
when the luminosity of said at least a portion of the base image falls within the predetermined range, generating a HSF noise map for use as the enhanced HSF map data.
65. The computer-readable storage medium of example 64, wherein generating enhanced HSF map data when the luminosity of said at least a portion of the base image does not fall within the predetermined range includes:
generating a gray overlay map; and
generating an HSF noise map for use as the enhanced HSF map data, and wherein displaying the or each visual stimulus includes:
merging the enhanced HSF map data with the gray overlay map to provide a blended image; and
displaying the blended image via the GUI.
66. The computer-readable storage medium of example 64, wherein generating enhanced HSF map data when the luminosity of said at least a portion of the base image does not fall within the predetermined range includes:
generating a gray overlay map;
generating a hard noise map; and
replacing the HSF map data with data from the hard noise map for use as the enhanced HSF map data, and
wherein displaying the or each visual stimulus includes:
merging the enhanced HSF map data with the gray overlay map to provide a blended image; and
displaying the blended image via the GUI.
67. The computer-readable storage medium of example 60, wherein generating the stimulus includes:
processing the base image into segmented display objects;

for each segmented display object, filtering the segmented display objects into high spatial frequency, HSF, components and low spatial frequency, LSF, components; and

applying a temporal modulation in the HSF components of the segmented display objects.

68. The computer-readable storage medium of example 60, wherein generating the stimulus includes:

processing the base image into segmented display objects;

for each segmented display object, generating an overlay object;

for each overlay object, generating an HSF overlay object component and an LSF overlay object component; and

applying a temporal modulation in the HSF overlay object components of the overlay objects.

69. The computer-readable storage medium of example 68, wherein generating an HSF overlay object component and an LSF overlay object component comprises filtering the overlay object HSF components and LSF components respectively.

70. The computer-readable storage medium of example 60, wherein determining the point of focus includes correlating said received neural signals with display signals used to modulate said objects.

71. The computer-readable storage medium of example 60, wherein at least one visual stimulus corresponds to at least one control item, the or each control item being associated with one or more user-selectable actions.

72. The computer-readable storage medium of example 71, wherein the instructions further configure the computer to:

determine, based on the point of focus and the at least one control item, an action intended by the user; and

implement the action intended by the user.

73. The computer-readable storage medium of example 60, wherein obtaining a base image includes:

operating an image capture device to capture the base image.

74. The computer-readable storage medium of example 60, wherein obtaining a base image includes:

receiving image data generated by an application executing in a processing device and using the received data as the base image.

75. The computer-readable storage medium of example 60, wherein displaying the or each visual stimulus comprises:

merging the or each visual stimulus with the base image to provide a blended image; and

displaying the blended image via the GUI.

76. The computer-readable storage medium of example 73, wherein the display is a transparent display through which a user is presented a field of view aligned with that of the image capture device and wherein display the or each visual stimulus comprises displaying the or each visual stimulus over the field of view.

Further particular and preferred aspects of the present disclosure are set out in the accompanying independent and dependent claims. It will be appreciated that features of the dependent claims may be combined with features of the independent claims in combinations other than those explicitly set out in the claims.

What is claimed is:

1. A method of tracking visual attention, the method comprising: obtaining a base image; generating a visual stimulus by performing operations comprising: processing a portion of the base image to extract high spatial frequency (HSF) components of the base image, the visual stimulus having a characteristic modulation, the characteristic modulation being applied to the HSF components of the base image, the HSF components having a spatial frequency higher than a predetermined high spatial frequency threshold; processing the portion of the base image to generate low spatial frequency (LSF) components of the base image, the LSF components having a spatial frequency lower than a predetermined low spatial frequency threshold; applying at least one of a spatial frequency filter or a spatial frequency transform to the portion of the base image; and storing the LSF components and the HSF components as LSF map data and HSF map data respectively; displaying the visual stimulus via a graphical user interface (GUI) of a display; receiving neural signals of a user from a neural signal capture device; and on the basis of detecting information associated with the characteristic modulation of the visual stimulus in the neural signals, determining a point of focus of the user in the viewed image, wherein generating the stimulus further comprises: on the basis of determining the HSF map data does not fulfil a predetermined spatial frequency threshold, performing operations comprising: generating enhanced HSF map data, thereby introducing additional HSF stimulation in the visual stimulus; and applying a temporal modulation to the enhanced HSF map data.

2. The method of claim **1**, wherein generating enhanced HSF map data further comprises:

on the basis of determining the luminosity of the portion of the base image falls within a predetermined range, generating an HSF noise map for use as the enhanced HSF map data.

3. The method of claim **1**, wherein generating enhanced HSF map data further comprises:

on a basis of determining the luminosity of the portion of the base image does not fall within a predetermined range, performing operations comprising:

generating a gray overlay map; and

generating an HSF noise map for use as the enhanced HSF map data, and

wherein displaying the visual stimulus further comprises:

merging the enhanced HSF map data with the gray overlay map to provide a blended image; and

displaying the blended image via the GUI.

4. The method of claim **3**, wherein the HSF noise map comprises a hard noise map.

5. The method of claim **1**, wherein displaying the visual stimulus further comprises:

merging the visual stimulus with the base image to provide a blended image; and

displaying the blended image via the GUI.

6. A computing apparatus comprising: one or more processors; and a memory storing instructions that, when executed by the one or more processors, cause the computing apparatus to perform operations comprising: obtaining a base image; generating a visual stimulus by performing operations comprising: processing a portion of the base image to extract high spatial frequency (HSF) components of the base image, the visual stimulus having a characteristic modulation, the characteristic modulation being applied to the HSF components of the base image, the HSF components having a spatial frequency higher than a predetermined high spatial frequency threshold; processing the portion of the base image to generate low spatial frequency (LSF) components of the base image, the LSF components having a spatial frequency lower than a predetermined low spatial frequency threshold; applying at least one of a spatial frequency filter or a spatial frequency transform to the portion of the base image; and storing the LSF components and the HSF components as LSF map data and HSF map data respectively; displaying the visual stimulus via a graphical user interface (GUI) of a display; receiving neural signals of a user from a neural signal capture device; and on the basis of detecting information associated with the characteristic modulation of the visual stimulus in the neural signals, determining a point of focus of the user in the viewed image, wherein the instructions that, when executed by the one or more processors, cause the computing apparatus to perform operations comprising generating the stimulus further cause the computing apparatus to perform operations comprising: on the basis of determining the HSF map data does not fulfil a predetermined spatial frequency threshold, performing operations comprising: generating enhanced HSF map data, thereby introducing additional HSF stimulation in the visual stimulus; and applying a temporal modulation to the enhanced HSF map data.

7. The computing apparatus of claim **6** wherein the instructions that, when executed by the one or more processors, cause the computing apparatus to perform operations comprising enhanced HSF map data further cause the computer to perform operations comprising: on the basis of determining the luminosity of the portion of the base image falls within a predetermined range, generating an HSF noise map for use as the enhanced HSF map data.

8. The computing apparatus of claim **6**, wherein the instructions that, when executed by the one or more processors, cause the computing apparatus to perform operations comprising generating enhanced HSF map further cause the computing apparatus to perform operations comprising:

on a basis of determining the luminosity of the portion of the base image does not fall within a predetermined range, performing operations comprising:

generating a gray overlay map; and

generating an HSF noise map for use as the enhanced HSF map data, and wherein displaying the visual stimulus further comprises:

merging the enhanced HSF map data with the gray overlay map to provide a blended image; and

displaying the blended image via the GUI.

9. The computing apparatus of claim **8**, wherein the HSF noise map comprises a hard noise map.

10. The computing apparatus of claim **6**, wherein the instructions that, when executed by the one or more processors, cause the computing apparatus to perform operations comprisng displaying the or each visual stimulus further cause the computing apparatus to perform operations comprising:

merging the visual stimulus with the base image to provide a blended image; and

displaying the blended image via the GUI.

11. A non-transitory computer-readable storage medium, the non-statutory computer-readable storage medium including instructions that when executed by one or more processors of a computer, cause the computer to perform operations comprising: obtaining a base image; generating a visual stimulus by performing operations comprising: processing a portion of the base image to extract high spatial frequency (HSF) components of the base image, the visual stimulus having a characteristic modulation, the characteristic modulation being applied to the HSF components of the base image, the HSF components having a spatial frequency higher than a predetermined high spatial frequency threshold; processing the portion of the base image to generate low spatial frequency (LSF) components of the base image, the LSF components having a spatial frequency lower than a predetermined low spatial frequency threshold; applying at least one of a spatial frequency filter or a spatial frequency transform to the portion of the base image; and storing the LSF components and the HSF components as LSF map data and HSF map data respectively; displaying the visual stimulus via a graphical user interface (GUI) of a display; receiving neural signals of a user from a neural signal capture device; and on the basis of detecting information associated with the characteristic modulation of the visual stimulus in the neural signals, determining a point of focus of the user in the viewed image, wherein the instructions that, when executed by the one or more processors, cause the computer to perform operations comprising generating the stimulus further cause the computer to perform operations comprising: on the basis of determining the HSF map data does not fulfil a predetermined spatial frequency threshold, performing operations comprising: generating enhanced HSF map data, thereby introducing additional HSF stimulation in the visual stimulus; and applying a temporal modulation to the enhanced HSF map data.

12. The non-statutory computer-readable storage medium of claim **11**, wherein the instructions that, when executed by the one or more processors, cause the computer to perform operations comprising generating enhanced HSF map data further cause the computer to perform operations comprising:

on the basis of determining the luminosity of the portion of the base image falls within a predetermined range, generating an HSF noise map for use as the enhanced HSF map data.

13. The non-statutory computer-readable storage medium of claim **11**, wherein the computer instructions that, when executed by the one or more processors cause the computer to perform operations comprising generating enhanced HSF map data further cause the computer to perform operations comprising:

on a basis of determining the luminosity of the portion of the base image does not fall within a predetermined range, performing operations comprising:

generating a gray overlay map; and

generating an HSF noise map for use as the enhanced HSF map data, and

wherein displaying the visual stimulus further comprises:

merging the enhanced HSF map data with the gray overlay map to provide a blended image; and

displaying the blended image via the GUI.

14. The non-statutory computer-readable storage medium of claim **13**, wherein the HSF noise map comprises a hard noise map.

15. The non-statutory computer-readable storage medium of claim **11**, wherein the instructions that, when executed by the one or more processors, cause the computer to perform operations comprising displaying the visual stimulus further cause the computer to perform operations comprising:

merging the visual stimulus with the base image to provide a blended image; and

displaying the blended image via the GUI.

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