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(54) **METHOD AND SYSTEM FOR CLASSIFYING BANKNOTES BASED ON NEUROANALYSIS**

(57) The present invention relates to a system and a method for classifying banknotes based on neuroanalysis, comprising: providing a user with visual information of a banknote; acquiring, by means of sensors of an input module, biometric signals of the user; segmenting the acquired biometric signals into predetermined periods of time in a process module; identifying certain events as a result of the comparison of each of the segments with

pre-established patterns; obtaining at least one biometric variable based on the identified events; analysing the biometric variables according to previously known results stored in a database; establishing a neurometric indicator based on the preceding analysis; and classifying the banknote in an output module according to the established neurometric indicators.

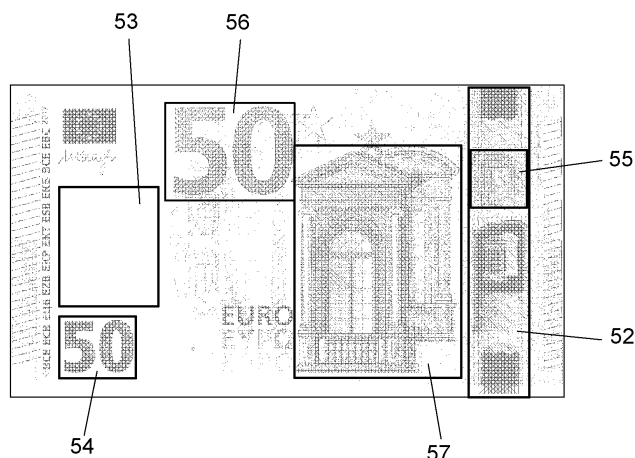


FIG. 5

Description**OBJECT OF THE INVENTION**

[0001] The present invention relates to the technical field of the neuroanalysis of objects through the processing of biometric signals of users exposed to said objects and, more specifically, to the characterization of banknotes and communication materials based on quantifiable information extracted from biometric signals, which allows banknotes and communication materials relating to banknotes to be classified according to an objective perception of the users of certain parameters concerning the design and security elements.

BACKGROUND OF THE INVENTION

[0002] The integrity of any banknote used as a means of payment is currently guaranteed by means of the combination of designs and security measures under constant development, by communicating said characteristics through communication materials (communication campaigns, brochures, educational material, etc.).

[0003] Furthermore, the creation of said banknotes must correspond to aesthetic and functional criteria providing for the easy recognition thereof, for detection of their authenticity detected or simplified handling, while at the same time meeting a number of technical requirements of the public, of manufacturers and of the issuing authorities. Given that the banknote is a communication medium by itself, whereby the message expressed in the design thereof is intended to be communicated, among the requirements of the public, the intellectual and emotional processes of the public relating to how they perceive said aesthetic and functional aspects must be taken into account so as to ensure that the message integrated in the design of the banknotes is received by the public in a manner that is true to the purpose of the communication of the design.

[0004] Likewise, the communication materials must also be produced considering the intellectual and emotional processes of the public so that they generate the greatest communicative impact possible therein, to thus maximize the guarantee that the public has received the educational message and, furthermore, has understood it as it was expected to. For that purpose, it is just as important to assess the content incorporated in the communication materials as in the materials themselves (brochures, images, videos, advertisements, etc.), and as in the distribution of said materials over the different channels of communication (web, radio, TV, written press, etc.).

[0005] Conventionally, the assessment of the human perception of said aspects of the banknote and communication materials relating to banknotes is justified in the decision-making theories which assume that humans can intentionally and precisely verbalize their attitudes, emotions and behaviours. Therefore, such theories are based on explicit responses obtained through questionnaires and interviews. However, such explicit measurements have been shown to be conditioned by "social desirability effects", which may lead to false accounts of behaviours, attitudes and beliefs. Furthermore, there may always be different interpretations, giving rise to less reliable and less valid results. Moreover, some questions rely on the self-assessment of a user which require people to have open knowledge of their dispositions, and this is not always the case.

[0006] In contrast, recent studies have demonstrated the considerable influence of implicit processes on psychological constructs and neurocognitive mechanisms of special relevance for humans, such as attitudes, stereotypes, self-confidence, personal relationships, decision-making and personal attachment.

[0007] Implicit measurements refer to the methods and techniques capable of capturing or tracking implicit mental processes or the results thereof, including brain images, behavioural monitoring and psychosomatic results. Neuroscience has shown that most of the brain processes that regulate human emotions, attitudes, behaviours and decisions do not involve human consciousness. That is, these implicit processes are brain functions that occur automatically and out of conscious control or awareness; in contrast, explicit processes occur through conscious executive control.

[0008] Neuroscience and, more specifically, measuring techniques based on the biometric response of human beings have improved a lot in recent years, allowing them to be used in studies evaluating products, digital contents and even in real spaces. Evidently, the contribution made by implicit measurements does not entirely invalidate the results and constructs modelled from explicit processes. On the contrary, they complement each other because any research activity regarding human decisions based on data coming solely and exclusively from explicit process measurements is incomplete and often inaccurate.

[0009] Based on the foregoing, if designers, central banks and issuing authorities were to be provided with a methodology based on implicit and explicit measurements of the perception of the public of banknotes and communication materials relating to banknotes, it would be extremely beneficial for designing families of efficient banknotes and communication material. Such efficiency is understood as the combination in the banknote of a design and effective security elements that draw the attention of the public, suitably communicate the message integrated in the design thereof and facilitate recognition of the banknote, therefore increasing the security thereof; and the production of communication material relating to banknotes capable of generating the greatest communicative impact possible such that it maximizes

communication to the public of recognition of the banknote, the design and security measures thereof.

DESCRIPTION OF THE INVENTION

[0010] In order to achieve the objectives and prevent the aforementioned drawbacks, in a first aspect, the present invention describes a method for classifying banknotes based on neuroanalysis, comprising the steps of: providing a user with visual information of a banknote; acquiring, by means of a sensor of an input module, at least one biometric signal of the user as a response to the visual information of the banknote; segmenting the acquired biometric signals into predetermined periods of time in a process module; comparing each of the segments with pre-established patterns; identifying certain events as a result of the comparison of each of the segments with the pre-established patterns; obtaining at least one biometric variable based on the identified events; analyzing the biometric variables in the process module according to previously known results stored in a database; establishing a neurometric indicator in the process module based on the preceding analysis; and classifying the banknote in an output module according to the established neurometric indicator.

[0011] According to one of the embodiments of the invention, the visual information of the banknote is provided physically, virtually or by means of a combination of the two in a tangible interface on which virtual elements added to a physical banknote by means of augmented reality technology are represented.

[0012] The biometric signal according to a particular embodiment of the invention comprises information of at least one implicit process of the user, to be selected from: gesture analysis for banknote-hand interaction, eye tracking and facial expression analysis.

[0013] The biometric signal according to a particular embodiment of the invention comprises information from a physiological response of the user, to be selected from: a brain response, heart rate variation and skin conductance.

[0014] The present invention contemplates the possibility of obtaining a biometric variable based on user eye tracking, wherein the identified events result from the comparison of the signal for eye tracking with a pattern that establishes a first user eye movement speed threshold determining the presence of a fixation event or a saccadic eye movement event. Additionally, once a saccadic eye movement has been detected, the possibility of determining if it corresponds to an ambient saccadic eye movement or a focal saccadic eye movement according to a second pre-established threshold of angular deviation of the eye of the user during said event is contemplated.

[0015] The biometric variables obtained by the present invention based on the identified events are contemplated to comprise quantifiable information of said identified events, to be selected from: amount of identified events, average duration of the identified events, frequency of each identified event in a pre-established time, sequence of the identified events and number of visits to one same predefined area.

[0016] Additionally, one of the embodiments of the invention contemplates defining at least one area of interest in the banknote and associating the biometric variable acquired from the user with said area of interest. Particularly, in one of the embodiments of the present invention wherein the visual information comprises a security element arranged in the banknote, it is contemplated that the area of interest is larger than or equal to the area of the banknote occupied by the security element, and wherein the area of interest includes the area of the banknote occupied by said security element. It is thus advantageously possible to assess each of the elements of the banknote separately.

[0017] According to an embodiment of the present invention, analyzing the biometric variables according to previously known results comprises training a supervised learning system of the process module according to the following steps:

- repeating the steps of: providing a user with visual information of a banknote; acquiring, by means of a sensor of an input module, at least one biometric signal of the user as a response to the visual information of the banknote; and segmenting the acquired biometric signals into predetermined periods of time in a process module; for a plurality of different banknotes and different users;
- for each banknote, grouping together the identified events of each user according to a previously established number of groups;
- assigning an initial value of the neurometric indicator to each banknote, wherein said value is based on an analysis of the groups of identified events by an expert user.

[0018] Additionally, the possibility of analyzing the biometric variables by means of the supervised learning module of the process module is contemplated, following the steps of: providing the initial value of the neurometric indicator assigned to each banknote in an input of the learning system; applying, through the supervised learning system, a predictive model to the biometric variables obtained by the process module and the assigned initial value; and validating the predictive model, by means of a cross-validation process, with a number of previously determined iterations.

[0019] The partial metrics of the present invention defined herein as neurometric indicators represent one or more of the following cognitive processes in the brain of the user: visual interest, attention, evoked emotions, motivation, mental load, stress and level of arousal.

[0020] Optionally, the user being provided with tactile and sound information of the banknote is contemplated in one of the embodiments of the invention.

[0021] A second aspect of the invention relates to a system for classifying banknotes based on neuroanalysis, comprising the following elements:

- an input module comprising at least one sensor, configured to acquire a biometric signal of the user as a response to visual information of the banknote provided to said user;
- a process module, configured to segment the biometric signal into predetermined periods of time; comparing each of the segments with pre-established patterns; identifying certain events as a result of the comparison of each of the segments with the pre-established patterns; obtaining at least one biometric variable based on the identified events; analyzing the biometric variables according to previously known results stored in a database; and establishing a neurometric indicator based on the analysis; and
- an output module configured to classify the banknote according to the neurometric indicator.

[0022] Optionally, in one of the embodiments, the output module has display means configured to visually represent the neurometric indicators of the banknote and a final classification metric, based on the neurometric indicators, which is associated with the visual information of each banknote.

[0023] The present invention therefore involves a series of advantages over the state of the art. The neuroanalysis carried out by the present invention is highly advantageous for the design and incorporation of security elements in the banknotes, because unlike the known studies in the state of the art, the invention contemplates the integration of metrics which quantify the gestural behaviour in the interaction of the public with the banknote, integrates eye tracking techniques to map fixations on the banknote, brain measurement equipment synchronized with the assessment of each banknote, integrates the heart rate variability signal as an indicator of the impact on the level of valence and arousal of the design of the banknote and, definitively, produces the classification of banknotes based on a precise objective characterization of human perception. The classification of banknotes performed by the method and the system of the present invention follows a process which ensures the reproducibility thereof and comparison between studies that are conducted with the same equipment anywhere around the world.

[0024] The present invention contemplates the generation of a classifier with a neurobehavioural impact, taking into account metrics coming from the ocular analysis system, physiological metrics and voluntary responses, in order to provide design impact indicators which aid in the comparison of different design parameters for the purpose of determining the design and the security elements that will make up part of a banknote.

BRIEF DESCRIPTION OF THE FIGURES

[0025] To complete the description of the invention, and for the purpose of helping to make the characteristics thereof more readily understandable, according to a preferred exemplary embodiment thereof, a set of drawings is included where, by way of illustration and not limitation, the following figures have been represented:

- **Figure 1** shows a block diagram including the complete methodology followed in an embodiment of the invention.
- **Figure 2** schematically shows the process for identifying and quantifying the information extracted from a biometric signal from eye tracking acquired in one of the embodiments of the invention.
- **Figure 3** shows a block diagram including the process for generating and training the classifier used by the present invention.
- **Figure 4** graphically associates several examples of the measured signals with each user for calculating different neurometric indicators. Specifically, five different indicators are represented.
- **Figure 5** shows one of the possible displays provided at the output of a particular embodiment of the invention, wherein several areas of interest have been defined on the banknote associated with both security elements and design elements.
- **Figure 6** shows a schematic representation of the possibilities of presenting objects for neuro-assessment of the present invention, preferably banknotes, both in a real format and in a virtual format, with or without context.

DETAILED DESCRIPTION OF THE INVENTION

[0026] The present invention discloses a method and a system for classifying banknotes based on neuroanalysis techniques. It thus allows for determining which design and security elements must be integrated in the manufacture of a new banknote and its optimal configuration based on the monitoring of certain conscious and unconscious processes of the public exposed to such elements.

[0027] Similarly, the present invention may also be applied to the communication material relating to banknotes, which

allows the communication materials to be produced efficiently, emphasizing the main features of the banknotes in informative brochures that are both printed out and can be found on web pages from the issuing authorities (accessible through the web page of the Banco de España (Bank of Spain), for example). In these brochures, each of the security features of a banknote (such as, for example, relieves, watermarks, security threads, windows with a portrait, holograms, colours, infrared properties, microtexts or a standard or special response to ultraviolet light) is identified and highlighted both visually and by means of descriptive texts which indicate to the user how to recognize it; therefore, similarly to the case of evaluating a banknote, the application of the present invention relating to said communication material allows for determining the effectiveness thereof of communicating to the public the design and security features integrated in a banknote based on the monitoring of certain conscious and unconscious processes of the public exposed to such communication material.

[0028] The neurodesign of banknotes according to the present invention may be applied to only one or to all the elements currently integrated in a banknote or communication material. It is preferably applied to security elements because the security of any of the elements implemented in a banknote to ensure the authenticity thereof does not only come from the technical features that are typical of said elements, which prevent or hinder imitation, but also influences the level of security the public perceives.

[0029] Therefore, the perception of the public of a security element is essential in improving its efficacy because if a security element, such as a holographic sheet, for example, even in the hypothetical case that the imitation thereof was impossible, were to be integrated in a banknote such that it goes completely unobserved by the user, the effectiveness of said element in the overall integrity of the banknote would be zero.

[0030] The present invention, therefore, increases the efficiency of the elements making up a banknote and communication materials providing an assessment of such elements based on several implicit measurements of the user, which are obtained as a result of a quantification of detected events by means of comparison with certain pre-established patterns of the biometric signals of the user captured by the corresponding sensors arranged in the system. The quantification of conscious and unconscious responses is performed based on neuroscience and behavioural measurement techniques, which are used for inferring, from events detected in the biometric signals, various biometric variables which characterize said signals during the time of exposure of a user to a visual stimulus. These biometric variables are used to check for the existence of patterns in the unconscious responses and the correlations thereof with the assessment of the elements of the banknote under study, obtaining neurometric indicators which classify these elements based on cognitive responses, such as visual interest or workload.

[0031] The classification of the set of biometric variables into neurometric indicators is performed by supervised learning techniques such as neural networks. Each of these neurometrics is then weighted and fused in a single final metric, based on weights defined by a group of experts, which will allow the design or security element or the entire banknote or communication material being analyzed to be characterized on a general level, which thus enables it to be determined if said element is suitable for being integrated in the banknote, or for being put into circulation in the case of analyzing the entire banknote, or for being disclosed to the public if it is communication material.

[0032] **Figure 1** shows a block diagram including the methodology followed in a complete embodiment of the invention. According to said figure 1, the present invention contemplates an input **1** which may comprise one or more types of input

signals $x^i = [x_1^i, x_2^i, \dots, x_n^i]$, such as real banknote samples **11**, real banknote samples with altered security elements **12**, banknote test samples which are not in circulation **13** or training/educational/communication materials relating to banknotes **14**. These inputs are entered in a configurable neuro-assessment module **2** with a certain configuration which defines the context **21** to be extracted (context may not be provided **211**, a real context may be provided **212** or a virtual context may be provided **213**), the mode of presentation **22** of the banknote (which may be a physical mode of presentation **221** or a virtual mode of presentation **222**), users **23** who are going to be exposed to the samples and the modes **24** for obtaining responses (contemplating the human behaviour response **241**, the physiological response **242** and the voluntary responses **243**). Operating on the preceding inputs which are acquired according to the configuration established in the configurable neuro-assessment module **2**, there is a set of algorithms f_{ij} loaded in a neurometric process module **3** for extracting and offering at the output thereof a set of neurometric indicators **4** related to the neu-

roperception of the banknote $x^o = [x_1^o, x_2^o, \dots, x_m^o]$, which may be shown to the user directly in the output module **5** or be used as a basis for a final classification metric of the banknotes.

In matrix form, $x^o = A \cdot x^i$, where $A \in M_{m \times n}(\mathbb{R})$ is the neurometric matrix of the banknotes

$$A = \begin{bmatrix} f_{1,1} & \cdots & f_{1,n} \\ \vdots & \ddots & \vdots \\ f_{m,1} & \cdots & f_{m,n} \end{bmatrix}$$

that binds together the set of operations performed in the process module **3**.

[0033] Therefore, the metrics obtained at the output of the process module depend entirely on the selected techniques and modes of obtaining user responses. In one of the embodiments of the invention, the following responses are contemplated:

- Human behaviour response **241**:

- eye tracking **2411**: several infrared cameras are arranged to record the pupils of the eyes. After calibration, wherein the user focuses on a few specific points, the gaze of the user is determined by means of open access tracking algorithms, referenced in two-dimensional coordinates;
- facial expression analysis **2412**: a frontal camera is arranged for detecting the gestures in the face of the user, which will later be analyzed by applying facial expression analysis algorithms; and
- tracking the behaviour of the user with respect to the banknote **2413**: this comprises a compilation of the interactions which the user has with the banknote, which are obtained through a set of cameras that record the gestures of the user. For that purpose, several RGB-D cameras are arranged which, together with specific computer vision algorithms, allow the normal gestures of the users in the interaction with the banknote to be detected and quantified.

- Physiological response **242**:

- brain response **2421**: a wireless headset is arranged on the head of the user, in communication with the rest of the system for electroencephalographic measurement of the brain;
- heart rate variability **2422**, which can be measured, for example, by placing electrodes in the thoracic area or by means of a photoelectric sensor on the index finger; and
- skin conductance **2423**: this may optionally be measured by applying electrodes on the wrist, on the palm of the hand or on the middle phalanges of the index and ring fingers in order to measure the skin conductance.

- Voluntary response **243**:

The voluntary responses solicited from users are not further described because they correspond to explicit measurements commonly used in the state of the art, i.e., obtained by means of interviews, questionnaires or other normally contemplated routes.

[0034] According to the configuration of the module **2**, biometric signals are obtained for each of the users at the input **31** of the neurometric process module **3**. Therefore, the input of the neurometric process module groups together the synchronized signals obtained for each user by the corresponding sensors, the signals relating to human behaviour, the signals relating to their physiological response and the signals relating to their voluntary response.

[0035] These individual signals and measurements collected for each of the users are subjected in the neurometric process module **3** to a conditioning process **32** which may comprise techniques for eliminating noise that may have been generated during the measurement process (particularly relevant in physiological signals), techniques for discarding possible atypical values and techniques for normalising the signal if needed. Conditioning is a necessary process, except for the voluntary responses, prior to extracting relevant metrics from the signals. Each of the signals used receives a specific conditioning as described in detail below.

[0036] Thus, for example, it is necessary to eliminate excessive noise in the signal for **eye tracking 2411**. This noise will inevitably be recorded due to the inherent instability of the eye, and especially due to blinking, which generate strong signal disturbances, but these disturbances may be eliminated depending on the available eye tracking recording device. The device itself often has the capacity to filter out blinking, or it simply returns to a value of (0,0) when the eye tracker "loses sight of" the features necessary for recording eye movements. In practice, the eye tracking data, represented in two-dimensional coordinates, falling outside of a given rectangular range may be considered noise and will be discarded. The use of a rectangular region to eliminate noise from the signal (2D) also addresses another current limitation of eye tracking devices: the precision thereof is usually degraded in extreme peripheral regions. For this reason (as well as the elimination of blinking), it may be reasonable to simply ignore eye movement data that may fall outside of the "effective operating range" of the device. This range will often be specified in terms of visual angle.

[0037] In the case of signals relating to **facial expression 2412**, the conditioning comprises four sub-processes mainly consisting of detecting faces, identifying characteristics, identifying actions and identifying emotions. First, all the different frames making up the video obtained are analyzed so as to identify the face of the user by applying computer vision techniques, such as the "Viola Jones Cascaded Classifier" algorithm, for example. Once the face of the user has been detected in each of the instants of the test, a detection of the features of the face is performed using facial coding algorithms, for example the FACS ("Facial Action Coding System") system, which can identify features such as vectors

of the eyelids, corners of the mouth, tip of the nose, etc. A point mesh which represents the face of the user is thus created. From these features, the so-called "Action Units" are then identified by the FACS system, wherein the fundamental actions of the face are characterized (such as *"brow lowering"*, *"nose wrinkling"*, *"lip tightening"*, *"outer brow raising"*, etc.). Lastly, from the different Action Units identified, a classifier is applied providing the statistical probability in each instant that one of the basic emotions is being experienced, giving a signal of 0 to 1. The emotions that are comprised include *joy, anger, surprise, disgust, fear and sadness*. These signals are later corrected using an individualized baseline, using the response of the user to a neutral stimulus, thus minimizing individual biases. Therefore, the facial expression signal is finally made up of six independent signals, individually corrected with a baseline, wherein each of them represents the probability that the subject is experiencing each of the basic emotions in one instant of time.

[0038] For the measurements and signals relating to **human behaviour tracking 2413**, the conditioning is mainly concentrated on the detection of the gestures of the user in the video signal, wherein the hands and interaction of the user with the banknote or communication material are observed. First, the video is segmented for each of the banknotes or communication materials presented to each user. Then each video segment is analyzed so as to detect one or several events, for example: *"the user flips the banknote over"*, *"the user touches the banknote searching for a distinctive texture"*, *"the user turns the banknote"*, *"the user looks at the banknote against the light"*, *"the user moves the banknote in search of a distinctive sound"*, *"the user folds the banknote"*. The detection of these gestures is preferably performed by means of a semi-manual process which, supported in open source code libraries such as *"OpenPose"*, for characterizing the position of the hands and their phalanges and for performing an initial identification of the gestures described above, adds a manual review to confirm the correct identification of the gestures detected and processed by the algorithms.

[0039] These measurements and signals relating to human behaviour tracking also contemplate the possibility of the user receiving sound and tactile stimuli as a result of handling the banknote, because a banknote is normally made with different paper than what is used for writing or other activities. As a result, handling the banknote gives off a characteristic rattling sound that cannot be achieved with normal paper, which is one of the security measures that are the most well-known and recognizable by users.

[0040] Regarding the conditioning of the physiological responses **242**, the signals and measurements related to the **brain response 2421** of the user are based on an electroencephalogram (EEG) signal made up of one power signal for each of the electrodes making up the data acquisition hardware. First, the data from each channel is analyzed so as to identify damaged channels using the fourth standardized moment (kurtosis) of the signal of each electrode. Furthermore, the channel is also considered damaged if the signal is flatter than 10 % of the total duration thereof. If a channel is considered to be damaged, it can be interpolated from the neighboring electrodes thereof. According to one of the particular embodiments, the baseline of the electroencephalogram signal is eliminated by subtracting it from the mean and setting a bandpass filter between 0.5 and 40 Hz. The resulting signal is then segmented into periods with duration of one second. An automatic detection is applied to reject periods wherein more than two channels contain samples exceeding an absolute threshold, for example, of 100.00 μV and a gradient of 70.00 μV between the samples. Furthermore, an independent component analysis (ICA) is performed in order to identify and eliminate components due to blinking, eye movements and/or muscle movements. Said components are analyzed by means of visual inspection by a trained expert in order to confirm the effectiveness of the algorithms used.

[0041] For **heart rate variability (HRV) 2422**, conditioning of the signal comprises analyzing an electrocardiogram (ECG) signal, for example through the Pan-Tompkins algorithm for the detection of the QRS interval. This detection allows a new time series to be obtained which characterizes the electrocardiogram with the time that passes between beats. For a good-quality signal, the detection performed by the Pan-Tompkins algorithm is revised so as to detect ectopic beats and artifacts, and, finally, obtains a series of RR pulsations which include the time difference between two consecutive pulsations and allows the heart rate variability analysis to be performed.

[0042] For **skin conductance 2423**, the conditioning consists of a visual inspection for the diagnosis and correction of artifacts that may be incorporated in the signal. These artifacts are corrected by first- or second-order linear interpolations. Then the phase component of the clean signal is extracted the signal, which is what is affected by unconscious changes derived from occasional stimuli and is not affected by other changes such as temperature, for example. Lastly, this signal with the phase component is standardized using Venables and Christie formulas in order to eliminate inter-subject differences.

[0043] Once the signals have gone through the conditioning process **32**, the neurometric process module **3** applies, signal by signal, algorithms for the extraction of numerical biometric variables of interest **33** in each of the conditioned signals. The individual biometric variables of each user are obtained and synchronized with the phases of the neuro-assessment of the stimuli considered. This process is repeated by each of the users of the complete sample and by each of the signals recorded in the test analyzed in each case. The values of the biometric variables obtained in this phase generate a metrics database which is the one used in the following phase to extract the neurometric indicators resulting from the neuro-assessment of the banknote. Some examples of the mathematical techniques applied, according to one of the embodiments of the invention, in each of the signals for obtaining the biometric variables that will make up the database used to calculate the neurometric indicators are described in detail below.

[0044] In the case of the signal for **eye tracking 2411** the process follows the diagram of **Figure 2**. Thus, in a first step, basic parameters for eye tracking **70** are extracted. By means of a series of algorithms, the main parameters for the eye tracking, which are distinguished between *fixations* and *saccadic eye movements*, are extracted. *Fixations* are understood as the instants wherein the eye is focusing on the visual scene to cause the visual information to reach the brain. *Saccadic eye movements* are understood as the movement of the eyes with the aim of refocusing on another new point of visual interest.

[0045] For that purpose, an algorithm for detecting the raw signal is applied in order to extrapolate if the analyzed sample is part of a fixation or a saccadic eye movement. The most widely-used algorithm is based on eye speed. By applying a filter to the eye movement with a window of, for example, 0.05 seconds, each piece of raw data of the present embodiment is classified as one of the following two states:

$$\begin{cases} \dot{\theta} \geq 100 \text{ (}^\circ/\text{sec)} \rightarrow \text{the piece of data is part of a saccadic eye mov.} \\ \dot{\theta} < 100 \text{ (}^\circ/\text{sec)} \rightarrow \text{the piece of data is part of a fixation} \end{cases}$$

[0046] The corrections are calculated through the groups of samples defined by the fixation, provided that the duration reaches a minimum established, for example, 100 ms. The fixation position is defined by the average position of the samples associated with that fixation. The lengths of the saccadic eye movements are defined by the distance between continuous fixations.

[0047] Additionally, a division of the saccadic eye movements is contemplated, which is applicable to the viewing of the banknote or communication material which divides these movements of the eye into ambient saccadic eye movements (which scan the banknote entirely) or focal saccadic eye movements (which move around a specific area of the banknote of interest). In this specific case, the following thresholds are applied for differences between ambient and focal movements:

$$\begin{cases} \theta \geq 4.8^\circ \rightarrow \text{ambient saccadic eye mov.} \\ \theta < 4.8^\circ \rightarrow \text{focal saccadic eye mov.} \end{cases}$$

[0048] Once the basic parameters for eye tracking **70** have been extracted in accordance with the foregoing, then, transferring **71** of the parameters for eye tracking in three dimensions to the design of the banknote in two dimensions is performed. With the exception of the case in which the banknote design is presented on a digital monitor, wherein the virtual banknote is already located from the start by the graphics engine programming; in the remaining situations, the parameters are set to a three-dimensional coordinate system, which must be transferred to a two-dimensional model of the banknote in order to facilitate the subsequent calculation of metrics relative to the entire banknote and to internal areas of interest. For that purpose, a semi-automatic method is generated which helps transfer the coordinate system for fixations and saccadic eye movements from a 3D system to a 2D system, particularly centring on the banknote being assessed in each instant of the test. Said method applies algorithms for segmenting and identifying objects by image analysis in order to identify the banknote under study in space, such that the position of the banknote in the 3D coordinate system is known at all times. At the same time and in a synchronized manner, the position of the eye of the user is monitored in that same 3D coordinate system, whereby it is possible to perform the pairing of both values in a 2D space wherein the banknote can be represented as an image on both faces onto which the obtained fixations and saccadic eye movements can be projected.

[0049] Reference to a "semi-automatic" process is due to the fact that with the preceding steps, wherein processes are carried out in a first instance by executing the algorithm automatically, manual revision by qualified personnel is advisable which allows the results obtained automatically to be confirmed, making corrections where needed and contributing to fine-tuning the algorithms for successive analyses.

[0050] Following the diagram represented in **Figure 2** for the extraction of metrics of interest from the signal for **eye tracking 2411**, wherein the visual interest of the user in certain areas of the banknote or communication material is considered relevant, the latter must be segmented into all the desired areas of interest. A step for predefining the areas of interest of the banknote **72** is thus contemplated. Each of these areas may comprise design elements, security elements or communication elements of the banknote about which it is of interest to know the perception of the users. It will only be necessary to mark with a software tool, on each of the faces, the coordinates of the vertices of the areas of interest.

[0051] Regardless of whether areas of interest are defined in the banknote, the method for extracting metrics from the signal for eye tracking contemplates an extraction **73** of metrics relative to the visual attention of the user on the entire banknote or communication material in general. These metrics will take one or more of the following events into account: "*fixations on the whole banknote (on both faces)*", "*saccadic eye movements over the banknote*", "*blinking*"

when viewing the banknote (measurement usually provided by the eye tracking equipment)", "size of the pupil (measurement usually provided by the eye tracking equipment)". The identification of events in the signal for eye tracking promotes the application of a series of mathematical operations to translate those events into quantifiable information, comprising for example: counting the amount of events (fixations, saccadic eye movements, blinking) taking place within the entire banknote (on both faces); counting the average time each event lasts; counting the frequency of these events in a defined period of time; or obtaining the sequence of these events.

[0052] Moreover, if some specific areas of the banknote or communication material are of special interest and these areas have been predefined in step 72 of figure 2, the method for extracting metrics from the signal for eye tracking contemplates an extraction 74 of metrics relative to the visual attention of the user on said predefined areas of interest. In this case, an additional basic parameter associated with the areas of interest, which is the term "visit", is previously calculated. "Visit" is understood as a type of event which includes more than one continuous fixation and that the time between fixations does not exceed a pre-established time threshold, for example one second. The metrics obtained by "visit"-type events, such as detecting, in the case of visits, if a visit to the same area occurs again, or in other words if and how many "revisits" occur, are now added to the metrics with quantifiable information described above.

[0053] The extraction of numerical biometric variables of interest 33 for the specific case of the signal for **facial expression 2412** comprises characterizing the response of each user to each of the banknotes shown from several independent identified and processed emotions. For that purpose, the signals are segmented according to the presentation time of the stimuli, extracting several independent signals which characterize each banknote. Three types of variables are obtained from these signals: the first ones are general metrics, computing the mean of the signal in the stimulus (e.g. the average probability of "joy"); the second ones are metrics based on thresholds, wherein there a function is applied to each signal which analyses if the probability of feeling a particular emotion is greater than X, in order to subsequently calculate the percentage of time that the subject has been above said threshold, wherein said threshold can be defined in two levels, for example 0.5 to detect the percentage of time that the subject has been experiencing that emotion, regardless of the intensity, and 0.8 to calculate the percentage of time that the subject has been intensely experiencing that emotion; finally, the third type of metrics are *ratio* metrics, such as the ratio between positive and negative emotions, for example.

[0054] For the biometric variables of **human behaviour tracking 2413**, the number of times a gesture is made during the viewing of a banknote, and the percentage it represents with respect to the total number of gestures is counted from the conditioned signal. Out of the signals associated with the **brain response 2421**, the extraction of numerical biometric variables of interest comprises, from the conditioned signals after the conditioning process 32, a spectral analysis of the encephalogram signal to estimate the spectral power in each second, in the conventional frequency band: θ (4-8 Hz), α (8-12 Hz), β (13-25 Hz), γ (25-40 Hz). According to one of the embodiments, it is performed using Welch's method with a 50 % overlap, from which metrics are derived which characterize the power of each of the bands in each second, and, from them, other metrics are derived such as frontal asymmetry, which can be interpreted as the amount of motivation towards (approach) or away from a stimulus. It is defined as:

$$\text{Index of Frontal Asymmetry} = \ln\left(\frac{\text{Alpha power right F4}}{\text{Alpha power left F3}}\right),$$

F4 and F3 being the electrodes placed in that

position according to the international 10-20 system.

[0055] In addition to the metrics derived from the spectral power, in one of the embodiments of the invention, those metrics which characterize cognitive states are also calculated. These variables use previously trained classifiers which, from the initial tasks the user must perform to calibrate the classifier, allow the level of "engagement" and of "workload" to be predicted. "Engagement" reflects the general level of engagement, commitment, attention and concentration during the visual scanning of the user to gather information, whereas "workload" is understood as any cognitive process involving an executive process, such as analytical reasoning, problem-solving or working memory, for example.

[0056] The extraction of numerical biometric variables of interest 33 for the specific case of the signal for **heart rate variability 2422** comprises three types of variables: variables derived from the time domain, variables derived from the frequency domain and variables which quantify non-linear dynamics.

[0057] The analysis in the time domain includes the following characteristics: mean and standard deviation of RR intervals, the root mean square of the sum of squares of the differences between adjacent RR intervals (RMSSD), the number of successive differences of intervals differing by more than 50 ms (pNN50), the triangular interpolation of the heart rate variability (HRV) histogram and the baseline width of the RR histogram assessed by means of triangular interpolation (TINN).

[0058] Frequency domain characteristics are calculated using the power spectral density (PSD), applying the fast Fourier transform. The analysis is performed in three bands: VLF (very low frequency, <0.04 Hz), LF (low frequency, 0.04-0.15 Hz) and HF (high frequency, 0.12-0.4 Hz). For each of the three frequency bands, the maximum value (corresponding to the frequency having the maximum magnitude) is calculated and the power of each frequency band is

calculated in absolute and percentage terms. The normalized power (n.u.) is calculated for the LF and HF bands and the percentage of total power is calculated by previously subtracting the VLF power from the total power. The LF/HF ratio is calculated to quantify sympathovagal balance and to reflect sympathetic modulations. Furthermore, total power is calculated.

[0059] Lastly, several features are also extracted using non-linear analyses, because they have proven to be important quantifiers of cardiovascular control dynamics. First, a Poincare plot analysis is applied, which is a visual and quantitative technique in which the shape of a frame is classified into functional classes, providing summarized information about the behaviour of the heart. A transverse axis (SD1) is associated with a rapid, beat-to-beat variability and a longitudinal axis (SD2) analyses long-term R-R variability. An entropy analysis is further included, using methods existing in the state of the art such as "Sample entropy" (SampEn), "Approximate entropy" (ApEn) and DFA correlations.

[0060] For **skin conductivity 2423**, two types of biometric variables which characterize the level of activation of the user upon viewing a banknote or communication material will be generated from the clean signal which represents the EDA (electrodermal activity) phase component. The first type is made up of the average of the signal in the segment of each stimulus, whereas the second type of variable analyses the peaks experienced by the user during the viewing of the banknote. These peaks will be characterized by the number of peaks per minute and the average amplitude thereof.

[0061] In regard to the extraction of biometric variables from the **voluntary responses 243** of the user, if tasks such as recognition of the banknote, reading or viewing of communication material are incorporated, these responses are quantified with the hit-miss percentage. Furthermore, the average response time in each of the tasks is calculated. Examples of interviews and questionnaires that are conducted include following: after the user views each banknote (front and back) on the monitor, there are questions about certain semantic axes such as aesthetics, quality, design, durability, pleasure or emotional aspects, in addition to an assessment and unconscious association of open attributes for each of the banknotes; after the user views all the banknotes, a questionnaire is completed comprising questions to know which banknotes and security elements are remembered, in which part of the banknote a certain security element is located, or what content the communication material incorporates, and recognition questions showing images of banknotes, asking the user whether or not they were shown during the test; after the user physically interacts with each banknote, a questionnaire is completed to assess the medium of the banknote (paper, plastic or variants thereof) or of the communication material and attributes similar to the previous phase, but adding attributes related to the feel of the banknote such as the geometry, texture, sound and/or relief.

[0062] After the complete step for the extraction of biometric variables of interest **33** with quantifiable information of the conditioned signals **32** previously obtained by means of different biometric sensors, according to the configuration established in the configurable neuro-assessment module **2**, and presented at the input **31** of the neurometric process module, the neurometric process module **3** of the present invention applies a classification algorithm in a predictive module **34** in order to obtain at the output a set of neurometric indicators **4** of the neuro-assessment of the user.

[0063] The classification algorithm, which will subsequently be applied to each of the responses of the users in the banknotes, must be previously calibrated. **Figure 3** comprises a block diagram which represents the two parts into which the calibration is divided: first the generation of a *ground truth* **300**, and then the creation of the predictive model **310**. Thus, to generate the ground truth, the biometric variables **33** obtained for a set of banknotes, for example one hundred banknotes, will be used. Preferably the set of banknotes comprises the broadest possible range of responses on a cognitive, emotional and behavioural level. This set is preferably chosen by a multidisciplinary team of experts selected from different fields/sectors (such as banking, psychology or neuroscience) and contains both real banknotes and ad-hoc designs which guarantee a wide range of responses. The group of experts only selects **301** the biometric variables related to the neurometric indicator, from the set of neurometric indicators **4**, being generated at all times (some examples of the relationship between the selected biometric variables and the different neuro-assessment indicators are included below). With the values of the metrics selected in the set of banknotes or communication material assessed by each of the users, an unsupervised clustering-type (k-means) machine learning algorithm is applied for grouping together **302** the banknotes based on their responses. The one hundred banknotes are thereby divided into different groups according to the response thereof in the different metrics forming the indicators. The mean of each group which represents the average response in each group is then calculated. The team of experts validates **308** the groups and analyses **303** the responses of each group in depth from the mean thereof and assigns a value **304** of the indicator to this group of banknotes, for example following a Likert scale from 1 to 5.

[0064] Once the ground truth of the one hundred banknotes of the example has been generated **300**, wherein each has been assigned **304** a value in each of the indicators, the classification model is created **310**. For that purpose, a dataset is created in which the inputs are the biometric variables selected **301** and the output is the value already assigned **304** to the corresponding neurometric indicator. The predictive model **306** is designed with this dataset based on artificial neural networks. The training **305** of the neural network, which is fed with the selected metrics **301** and the assigned values **304**, is validated **307** by applying a cross-validation algorithm of k-iterations with a k of 10, and the model is then tested with 15 % of the sample, which was previously extracted from the validation process. Once the predictive model is validated and tested **306**, it may be applied to the biometric variables of any banknote, providing an

assessment in each of the neurometric indicators.

[0065] The output of the predictive module 34 comprises the indicators generated according to the obtained predictive models which are applied to the numerical biometric variables of interest 33 and produce as a result a value for each of the indicators of the neuro-assessment of each banknote for each user.

[0066] Figure 4 shows a diagram with the measured signals of each user to be taken into account for the calculation of certain indicators. According to one of the embodiments of the invention wherein five indicators are contemplated, for the calculation of a first **visual interest indicator 41** (BVIS), the human behaviour responses 241 represented by the eye tracking signals 2411 and facial expression analysis 2412 are considered relevant; none of the physiological responses 242 is necessary, and voluntary responses in the form of an interview 2433, questionnaires 2434 and response to tasks 2431 are indeed taken into account; for the calculation of a second **engagement indicator 42** (BEI), the human behaviour response 241 represented by the eye tracking signals 2411, the physiological responses 242 represented by the brain response 2421 and the heart rate variability 2422, as well as the voluntary responses in the form of questionnaires 2434 are considered relevant; for the calculation of a third **workload indicator of 43** (BWI), the human behaviour responses 241 represented by the eye tracking signals 2411, for facial expression analysis 2412 and for user behaviour tracking 2413, the physiological responses 242 represented by the brain response 2421 and the voluntary responses in the form of response to tasks 2431 and reaction time 2432 are considered relevant; for the calculation of a fourth **emotional indicator 44** (BEI), the human behaviour responses 241 represented by facial expression analysis 2412, the physiological responses 242 represented by the heart rate variability 2422 and the skin conductance 2423, and the voluntary responses in the form of an interview 2433 and questionnaires 2434 are considered relevant; for the calculation of a fifth **security indicator 45** (BSCI), human behaviour responses 241 represented by the eye tracking signals 2411 and user behaviour tracking 2413, the physiological responses 242 represented by the skin conductance 2423 and the voluntary responses in the form of an interview 2433, questionnaire 2434, response to tasks 2431 and reaction time 2432 are considered relevant.

[0067] The visual interest indicator 41, BVIS ("*Banknote Visual Interest Score*"), is a metric related to the visual interest the design of the banknote arouses. This high level metric is centred on a non-linear model establishing a visual interest score which the perception of the design of the banknote generates and which allows for comparison between different design types. For that purpose, the indicator is calculated through supervised learning techniques applied to the biometric variables of interest 33, extracted from the selected conditioned signals which contain quantifiable information specifically comprising in this embodiment:

- metrics relative to the viewing time of the areas of interest relative to the design of the banknote or communication material vs. the viewing time of the security areas or other area of interest relative to the content of the communication materials;
- metrics relative to the total time allocated for viewing the banknote or communication material in comparison to visual navigation outside the banknote or communication material;
- metrics relative to how the eye scans the banknote or communication material and the ratio between scanning (ambient saccadic eye movements) and focusing (focal saccadic eye movements);
- metrics relative to the gaze sequence in viewing the design elements of the banknote or communication material vs. the security elements or other area of interest relative to the content of the communication materials;
- ratio of quadrants per second of the banknote that the eye of the user navigates, dividing the banknote into a specific number of quadrants;
- percentage of banknote scanned; and
- ratio between the number of broad movements vs. short movements of the eye within the banknote.

[0068] Additionally, in this visual interest indicator, some values relative to the voluntary response are contemplated as a global assessment of the design of the assessed banknotes; recall of the banknotes and of areas of interest of the banknote; and times allocated for performing the tasks of assessing the banknote.

[0069] One of the cognitive indicators, the engagement indicator 42, BEI ("*Banknote Engagement Index*"), refers to the level of functional sustained attention being applied by the person to the perception of the banknote or communication material. This indicator is of great interest because it reflects if the banknote or communication material arouses interest sufficient for focusing on it. Furthermore, it allows it to be discerned if the subject is concentrated on the task, and therefore if the remaining metrics obtained in that instant are of value.

[0070] One of the cognitive indicators used in one of the embodiments of the present invention, the workload indicator 43, BWI ("*Banknote Workload Index*"), refers to the cognitive load or mental effort involved for the subject in the process of perceiving and assessing certain attributes of the banknote or communication material. It is very important because a high cognitive load may mean that there is a saturation of information, which leads to rejection, but at the same time a low value may indicate boredom of the subject, which is also negative.

[0071] In one of the embodiments of the invention, a cognitive indicator combining the two aforementioned indicators, i.e., engagement indicator **42** BEI and workload indicator **43** BWI, is contemplated.

[0072] The emotional indicator **44**, BEII ("*Banknote Emotional Induction Index*"), used in one of the embodiments of the invention is a metric relative to the capacity of emotional induction of the banknote or communication material. Namely, the indicator BEI is based on the calculation and representation of a point on a two-dimensional spatial axis in which the capacity of emotional excitation (*arousal*) and the capacity to generate a positive or negative emotion (valence) is extracted. To calculate these two dimensions that support indicator BEII, the processing of the signal from behavioural measurements (micro facial expressions during banknote viewing) and the physiological response (cerebral hemisphere asymmetry, cardiac variability and skin conductance) is performed.

[0073] The security indicator **45**, BSCI ("*Banknote Security Capacity Index*"), used in one of the embodiments of the invention is a metric relative to banknote security. Namely, this indicator reflects the capacity of the design and security elements of the banknote for being authenticated by the public. The calculation thereof is based on several parameters relative to the behavioural signal (e.g. eye tracking of the security elements of the banknote, automatic tracking of the gestures of the participant interacting with the banknote) and voluntary response values of the subject. Through the modelling of these parameters, an absolute index can be obtained that allows for the comparison of new security elements and designs in a single banknote or the comparison of current security elements and designs of different types of banknotes.

[0074] Once the predictive models **306** have been applied to the selected biometric variables, which contain numerical metrics of interest with quantifiable information, and once the neuro-assessment indicators have been obtained for each banknote or communication materials, these indicators are processed in an output module **5** equipped with different functionalities. In this output module **5**, the neurometric indicators **4** are statistically treated in order to satisfactorily characterize a banknote or communication materials. On one hand, the general response of the banknote or communication materials is measured using data aggregation techniques (for example the arithmetic mean or standard deviation), and on the other hand, based on specific conditions and cases, different additional analyses are carried out in order to determine if there are significant differences that may allow final conclusions to be inferred relative to the objective of the neuro-assessment study. For example, in addition to mean comparison techniques, correlation techniques and clustering techniques can be used. All this statistical analysis is implemented automatically, ensuring reproducibility and the comparison of the same studies contemplated on several dates and in several locations. Therefore, the statistical inference analysis extracts the significant differences in the biometric variables with numerical metrics of interest **33**. By contrasting different models, such as analysis of variance or the Kruskal-Wallis test, for example, the indicators calculated according to different clusters are compared. These analyses are applied in order to analyze the differences in the neurometric indicators between different banknotes presented and/or the differences with different designs of a single banknote (due to changes in the design, size or position of design elements of the banknote), which can be weighted by additional factors such as the sex, age or familiarity with handling cash of the user.

[0075] After calculating the indicators, in one of the embodiments of the invention the output module **5** calculates a final metric which encompasses all the calculated indicators and offers a snapshot of the performance of the banknote or communication material, allowing for a rapid assessment, comparison and classification compared to other assessed banknotes. This final metric is based on a score of 1 to 10 through a mathematical equation in which each of the calculated neurometric indicators has an influence with a specific weight.

[0076] The higher the score, the better the performance of the assessed design. If in any case any indicator is to be dispensed with, the model recalculates the value by cancelling out the impact of the value of that neurometric indicator. The indicator is thereby dynamic and only reflects the indicators that are of interest in each specific case (for example, the preceding final score may be recalculated so that it only reflects the impact of the visual and cognitive indicators or even just one of them).

[0077] One of the embodiments contemplates graphic representation, for example by means of heat maps, two-dimensional axes, curves or percentages, of all the biometric variables, neurometric indicators and statistical inferences obtained during the process carried out by each of the modules of the invention. **Figure 5** represents one of these particular views, wherein a face of a banknote is represented, and associated with each of the defined areas of interest, the values of the indicators (not shown in the figure) obtained for said areas of interest are represented. For example, for a defined area of interest to comprise a security element incorporated in the banknote, such as a hologram **52**, a watermark **53**, a special printing ink **54** or a window **55**, the represented indicators code the neuro-assessment obtained from the perception of the users of that security element. In one embodiment, each of the areas of interest is associated with a percentage score of the visit time, visitors and revisits, which is furthermore complemented by a heat map and the sequence of visits of the different areas of interest. For example, after the analysis of the area of interest including the hologram **52**, a visit time of 14.92 % of the total time spent on inspecting the banknote, 86.53 % of users who have observed it and 78.72 % of users who have revisited it is obtained. This type of measurements are what make it possible to construct the indicators for comparison between banknotes, comparison of elements and classification.

[0078] In one of the embodiments, the present invention classifies in the output module **5** a complete sample of

banknotes according to the obtained indicators associated with the areas of interest comprising the security elements. The security level of the security elements is determined by the perception of the public and is a determining factor for assessing the incorporation thereof in future legal banknotes. The classification of banknotes based on the perception of the users of the security elements allows security elements to be selected that are acceptable and unacceptable for being incorporated in legal currency, establishing a minimum threshold in the indicators for determining that the perception of the public of the security element is sufficient for it to be incorporated in the banknote. These minimum thresholds may be calibrated using modified security elements and analyzing how the perception of the users varies with respect to the modifications of different security elements. In this manner, the modified security elements that obtain a better classification in the perception of the users will thus be the security elements that are most suitable for being incorporated in legal banknotes. Considering the eye tracking signals, for example, the number of revisits of the user to the security element or the time used in viewing said element with respect to the rest of the banknote is a determining factor.

[0079] Besides the comparison between elements of the same type, in one of the embodiments of the invention it is particularly advantageous to monitor the influence of some parameters over others, and mainly the influence of the variation of one parameter over another. For example, the colour of the banknote with respect to the perceived security of a certain security element. If the objective is to determine the colour of the banknote providing the most security, the set of banknotes that will be subjected to neuroanalysis will differ only in the colour of the design thereof, but the security elements will be kept intact. The neuroanalysis of the perception of the users will allow it to be determined if colour variations have an influence on the perception of the security elements, characterizing the different banknotes based on the perception of the users and finally classifying them in an orderly and objective manner, with the best classified banknote being the banknote corresponding to the colour that is most suitable for security of the banknote. For example, a grey colour for the banknote could largely cancel out the security of a hologram element or a security thread element with a metallic appearance, which would be virtually camouflaged and go unnoticed for a user. In other words, according to the consideration raised by the example, the classification will indicate how each of the test colours disturbs the perception of the security elements integrated in the banknote, whereby the final classification determines the colour to be included in the banknote to be manufactured.

[0080] According to other objectives which seek the design of other parameters of the banknote other than colour, such as the size of the banknote, the size of a certain element, the position of a certain element or the use of different materials, the banknote samples and the areas of interest are selected so that precisely those parameters are what vary from one banknote to another, and similarly to the preceding case, the characterization of the perception of the users indicates in an objective manner the influence that said parameters have on the banknote. For example, by defining an area of interest **56** including the value of the banknote (50 Euros for example), it is interesting to compare the influence that different sizes and positions have compared to the perception of the design and security elements of the banknote. In this specific case, the perceived security of the watermark **53** may be affected starting from a certain size of the representation of the value of the banknote, or a position that is too close, because it attracts the visual attention of the user in excess or would cancel out or reduce the perception of the watermark, which reduces the security of the banknote in the opinion of the user. Even other elements of the banknote which, outwardly, have no more than a merely aesthetic function, such as the decoration included in the area of interest **57**, are also important in the global assessment of the banknote, and the colour, size or position thereof may influence the security it has, for which reason in one of the embodiments the analysis of absolutely all the elements of the banknote is contemplated.

[0081] In addition to the graphic representation shown in figure 5, other comparative results that can be graphically shown are contemplated. These mainly contemplate the comparison of the viewing times of the areas of interest associated with design elements of the banknote, normalized in reference to the physical space they occupy; curves of the effect of the position vs. the visual interest indicator BVIS (useful for the case of presenting positional variants of a single element of the banknote to be neuro-assessed); and curves of the effect of the size vs. visual interest indicator BVIS (useful for the case of presenting size variants of a single element of the banknote to be neuro-assessed).

[0082] **Figure 6** schematically shows of the possibilities of presenting objects for the neuro-assessment of the present invention, preferably banknotes or communication materials, both in a real format and in a virtual format. The samples of banknotes or communication materials to be analyzed comprise different security features, design features or contents of the communication materials according to, among others, different materials, designs, sizes and positions, which influence the perception which the public has of the banknote. The context of the samples of banknotes can be presented to the user by means of different techniques **21**, which include not providing any context **211**, adding real context **212** or adding a virtual context **213** wherein, by using computer and digital graphics techniques, different scenarios are reproduced, among which the following are contemplated: a virtual reality scenario, wherein the assessment configuration is used in laboratory conditions under a virtual replica of the real world, which may consist of two-dimensional (2D) models of the real context; an augmented reality scenario, wherein the configuration of the assessment is used in real life conditions, but completed with some virtual elements in 3D; and an augmented reality scenario, wherein the configuration of the assessment is used in laboratory conditions, but an augmented virtual replica of the real context is presented to the user. Moreover, depending on the human sensory channel to be used, the context may be provided by means of

one or a combination of the following immersive interfaces: visual devices (such as conventional monitors, vertically positioned monitors with stereoscopic 3D vision and 3D tracking of the position of the main user ("*fish tank*" interface), horizontally positioned monitor with stereoscopic 3D vision and 3D tracking of the position of the main user ("*workbench*" interface), surround displays made up of large displays based on projection and/or large monitors, hemispherical exhibits, or virtual reality headsets (HMD-Head Mounted Displays) and/or augmented reality and/or mixed reality); audio displays (wherein, for example, contextual sounds are reproduced using 3D sound generation techniques with headphones and/or external speakers); olfactory displays (wherein aromas are delivered through electronic noses and/or any commercial olfactory display); or haptic displays (where tactile and kinesthetic signals are provided through a tactile haptic display device, such as land references, body references, tactile references or a combination thereof, for example).

[0083] In regard to the presentation of the banknotes 22, laying aside context, the present invention also contemplates several alternatives shown in **Figure 6**. Mainly, two techniques are used based on the reliability thereof for reproducing real-life situations: using a physical banknote 221, wherein a real physical model of the banknote is presented to the user; or using a digital banknote 222, wherein a digital replica of the banknote is presented using a virtual banknote model which reproduces, in two or 3 dimensions, a digital image of the real banknote, or in a virtual banknote model based on a tangible interface which the user can feel with his or her hands. This tangible interface may represent in three dimensions the graphic elements in the physical paper using spatial augmented reality techniques. The final result of the overlay techniques can be presented to the user by means of a virtual reality headset or devices of this type may alternatively be dispensed with and digital projectors showing the information directly on the physical banknote may be chosen.

[0084] The present invention should not be limited by the embodiments herein described. Other arrangements may be carried out by those skilled in the art based on the present description. Accordingly, the scope of the invention is defined by the following claims.

Claims

1. A method for classifying banknotes based on neuroanalysis, **characterized by** comprising the following steps:

- a) providing a user with visual information of a banknote;
- b) acquiring, by means of a sensor of an input module (2), at least one biometric signal of the user as a response to the visual information of the banknote;
- c) segmenting the acquired biometric signals into predetermined periods of time in a process module (3);
- d) comparing each of the segments with pre-established patterns;
- e) identifying certain events as a result of the comparison of each of the segments with the pre-established patterns;
- f) obtaining at least one biometric variable based on the identified events;
- g) analyzing the biometric variables in the process module according to previously known results stored in a database;
- h) establishing a neurometric indicator in the process module based on the analysis of the previous step; and
- i) classifying the banknote in an output module (5) according to the established neurometric indicator.

2. The method according to claim 1, wherein the visual information of the banknote is provided physically, virtually or by means of a combination of the two in a tangible interface on which virtual elements added to a physical banknote by means of augmented reality technology are represented.

3. The method according to any of the preceding claims, wherein the biometric signal comprises information from at least one implicit process of the user, to be selected from: gesture analysis for banknote-hand interaction, eye tracking and facial expression analysis.

4. The method according to any of the preceding claims, wherein the biometric signal comprises information from a physiological response of the user, to be selected from: a brain response, heart rate variation and skin conductance.

5. The method according to claim 3, comprising obtaining a biometric variable based on user eye tracking, wherein the identified events result from the comparison of the signal for eye tracking with a pattern that establishes a first user eye movement speed threshold determining a fixation event or a saccadic eye movement event.

6. The method according to claim 5 wherein a saccadic eye movement has been detected, further comprises the possibility of determining if it corresponds to an ambient saccadic eye movement or a focal saccadic eye movement

according to a second pre-established threshold of angular deviation of the eye of the user during said event is contemplated.

7. The method according to any of the preceding claims, wherein the at least one biometric variable comprises quantifiable information about the identified events to be selected from: amount of identified events, average duration of the identified events, frequency of each identified event in a pre-established time, sequence of the identified events and number of visits to one same predefined area.

8. The method according to any of the preceding claims further comprising defining at least one area of interest in the banknote and associating the biometric variable acquired from the user with said area of interest.

9. The method according to claim 8, wherein the visual information comprises a security element arranged in the banknote, further comprising defining an area of interest larger than or equal to the area of the banknote occupied by the security element, and wherein the area of interest includes the area of the banknote occupied by said security element.

10. The method according to any of the preceding claims, wherein analyzing the biometric variables according to previously known results further comprises training a supervised learning system of the process module according to the following steps:

- repeating steps a)-c) of claim 1 for a plurality of different banknotes and different users;
- for each banknote, grouping together the identified events of each user according to a previously established number of groups;
- assigning an initial value of the neurometric indicator to each banknote, wherein said value is based on an analysis of the groups of identified events by an expert user.

11. The method according to claim 10, wherein analyzing the biometric variables by means of the supervised learning system further comprises the steps of:

- providing the initial value of the neurometric indicator assigned to each banknote in an input of the learning system;
- applying, through the supervised learning system, a predictive model to the biometric variables obtained by the process module and the assigned initial value; and
- validating the predictive model, by means of a cross-validation process, with a number of previously determined iterations.

12. The method according to any of the preceding claims, wherein the neurometric indicators represent one or more of the following cognitive processes in the brain of the user: visual interest, attention, evoked emotions, motivation, mental load, stress and level of arousal.

13. The method according to any of the preceding claims, wherein acquiring the biometric signal of the user further comprises a physical interaction of the user with the banknote, wherein said physical interaction provides tactile and sound information of the banknote to the user.

14. A system for classifying banknotes based on neuroanalysis, **characterized by** comprising:

- an input module (2) comprising at least one sensor, configured to acquire a biometric signal of the user as a response to visual information of the banknote provided to said user;
- a process module (3) configured to segment the biometric signal into predetermined periods of time; comparing each of the segments with pre-established patterns; identifying certain events as a result of the comparison of each of the segments with the pre-established patterns; obtaining at least one biometric variable based on the identified events; analyzing the biometric variables according to previously known results stored in a database; and establishing a neurometric indicator based on the analysis; and
- an output module (5) configured to classify the banknote according to the neurometric indicator.

15. The system according to claim 14, wherein the output module comprises display means configured to visually represent the neurometric indicators of the banknote and a final classification metric based on the neurometric indicators resulting from the neuroanalysis of each banknote.

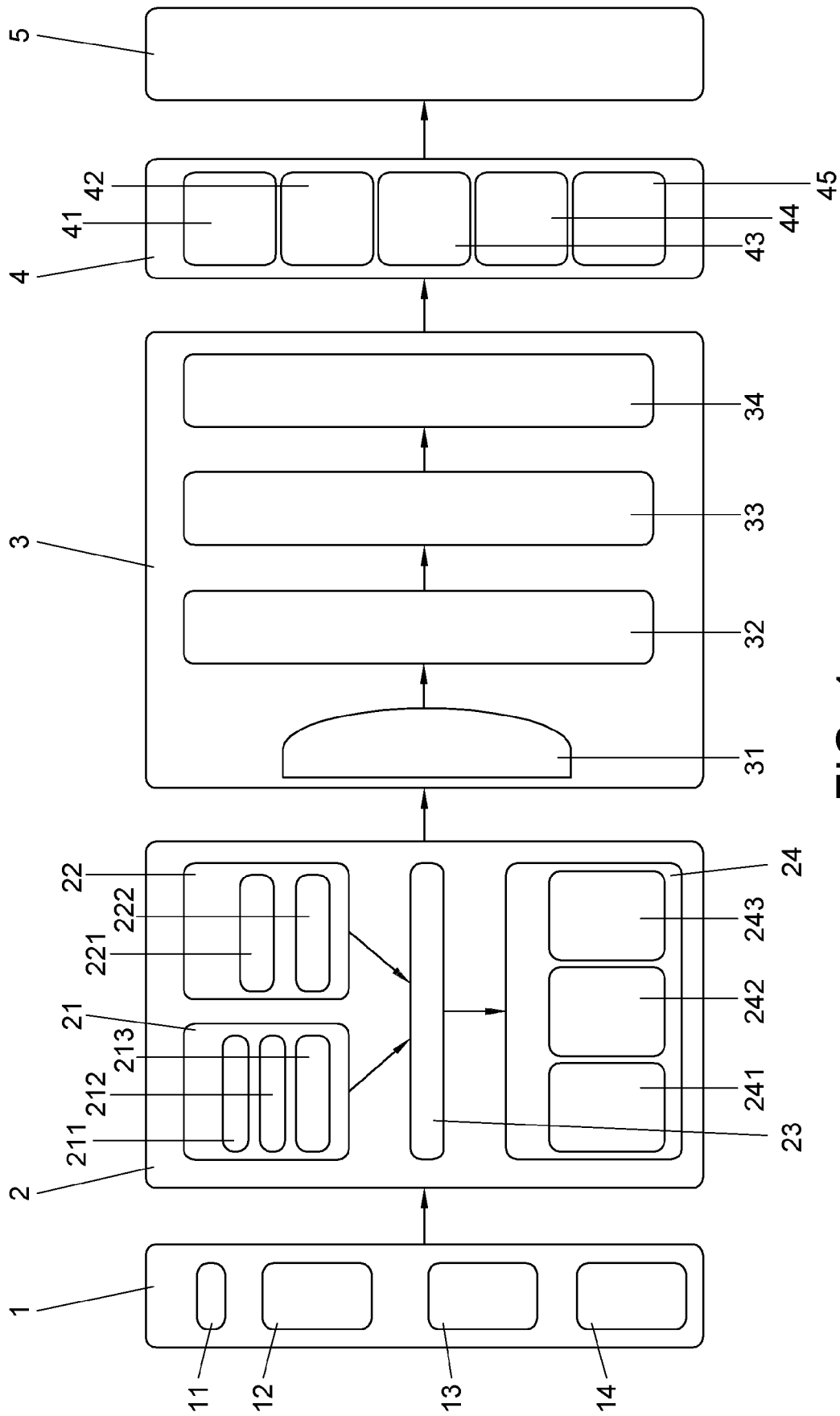


FIG. 1

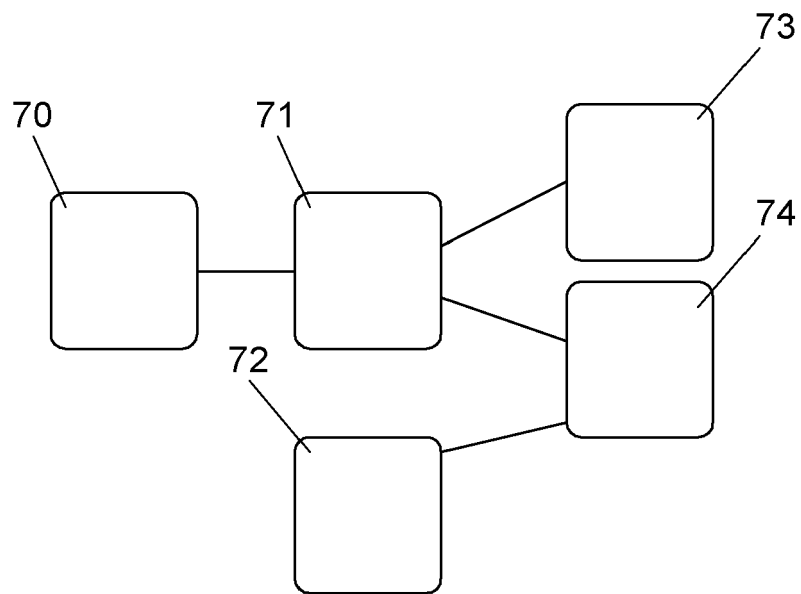


FIG. 2

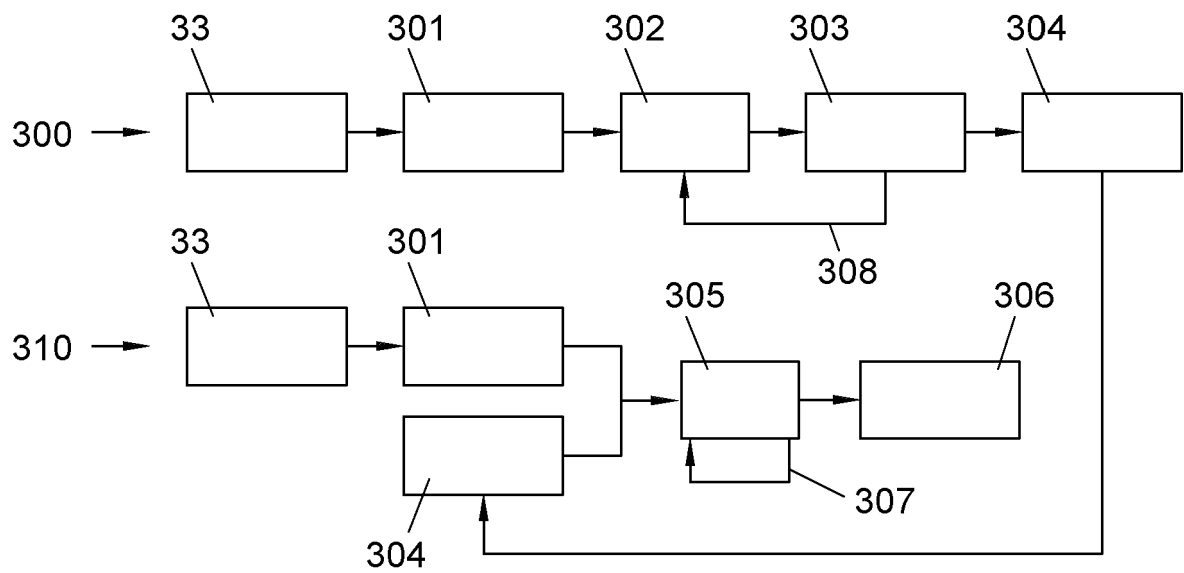


FIG. 3

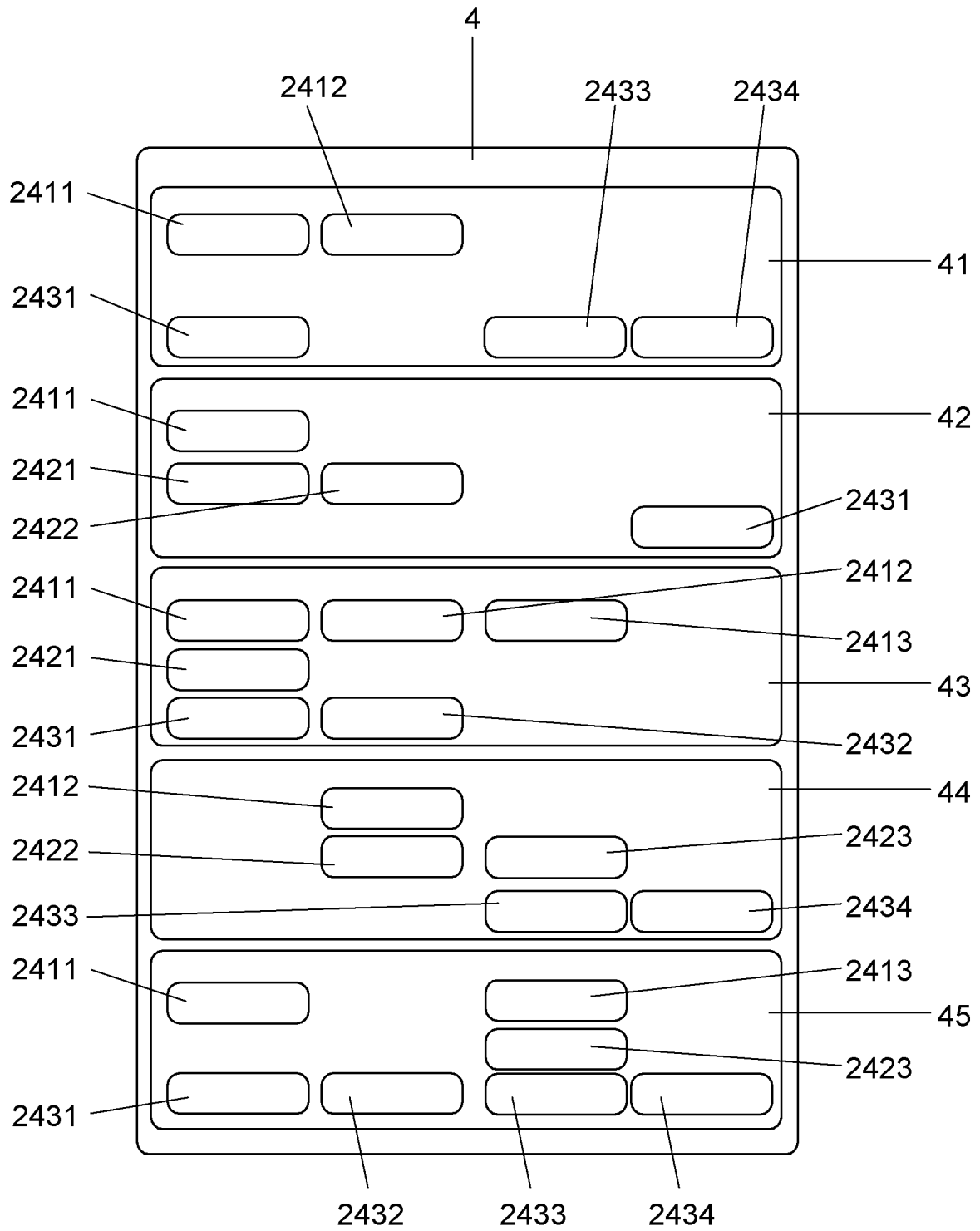


FIG. 4

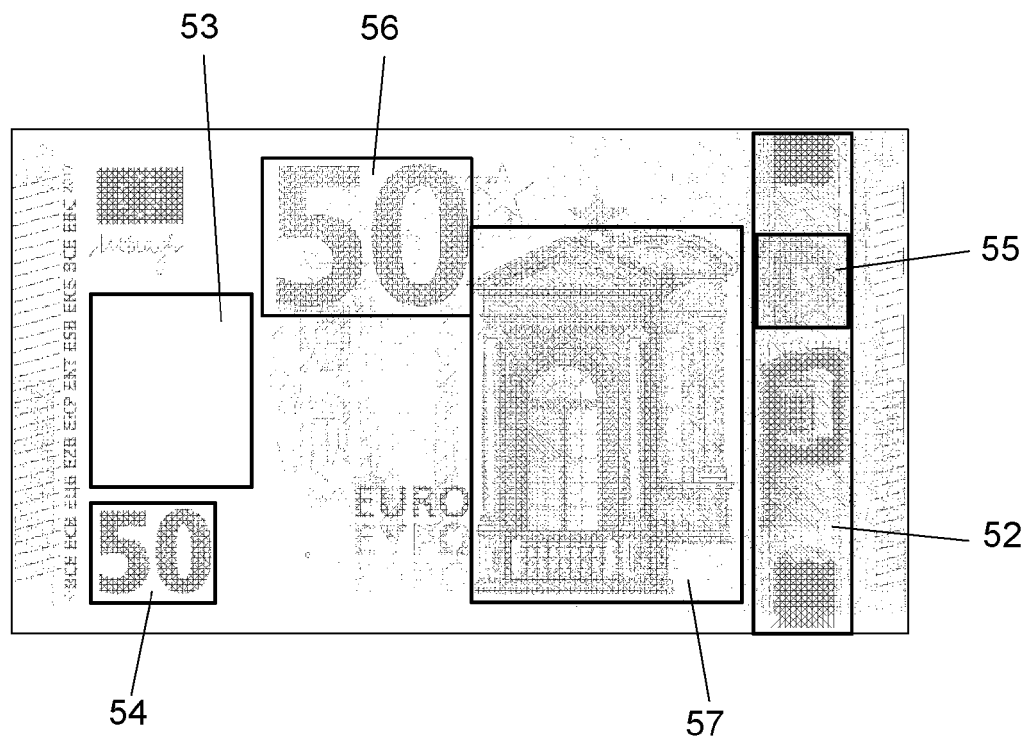


FIG. 5

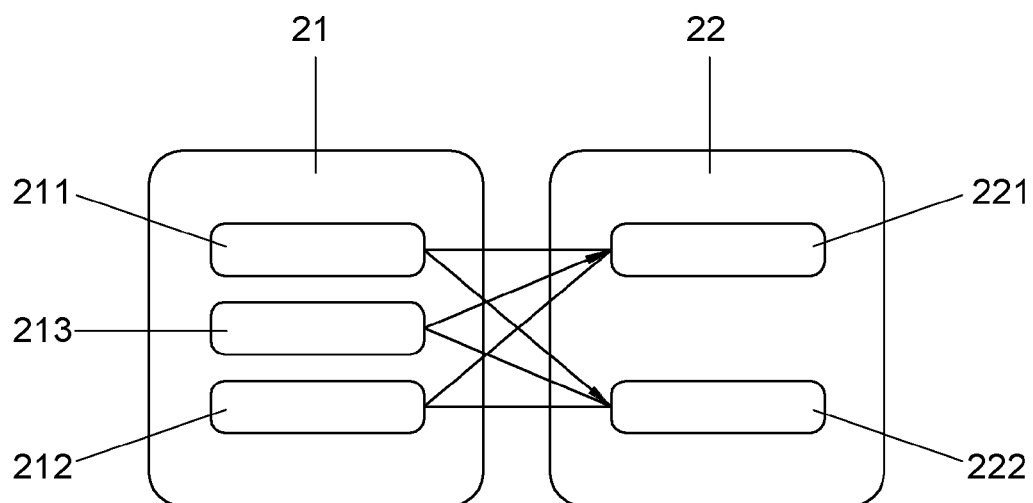


FIG. 6



EUROPEAN SEARCH REPORT

 Application Number
 EP 20 18 1632

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	KAI KUNZE ET AL: "I know what you are reading", PROCEEDINGS OF THE 17TH ANNUAL INTERNATIONAL SYMPOSIUM ON WEARABLE COMPUTERS, ISWC '13, 8 September 2013 (2013-09-08), pages 113-116, XP055742564, New York, New York, USA DOI: 10.1145/2493988.2494354 ISBN: 978-1-4503-2127-3 * page 2, column 1, line 8 - page 4, column 1, line 60 *	1-15	INV. G07D7/00
A	ANDREAS BULLING ET AL: "Recognition of visual memory recall processes using eye movement analysis", PROCEEDINGS OF THE 13TH INTERNATIONAL CONFERENCE ON UBIQUITOUS COMPUTING, UBIComp '11, 17 September 2011 (2011-09-17), page 455, XP055742919, New York, New York, USA DOI: 10.1145/2030112.2030172 ISBN: 978-1-4503-0630-0 * page 2, column 2, paragraph 4 - page 6, column 1, paragraph 2 *	1-15	TECHNICAL FIELDS SEARCHED (IPC) G07D
A	US 2011/256520 A1 (SIEFERT CALEB J [US]) 20 October 2011 (2011-10-20) * paragraph [0003] * * paragraph [0006] - paragraph [0010] *	1-15	
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 22 October 2020	Examiner Seifi, Mozhdeh
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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