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DESCRIPTION

[0001] The present disclosure relates to a hearing device and related method, in particular a method for configuring hearing device parameters.

BACKGROUND

[0002] Hearing devices with user-selectable programs allowing the user to adjust hearing device programs/hearing device parameters to obtain a satisfactory listening experience are known.

[0003] US 2003/0133578 relates to hearing aids and methods and apparatus for audio fitting thereof. Method and apparatus for audio fitting a hearing aid are described in a hand-held configuration having paired comparisons (hearing selections) stored in and derivable from a memory therein. The paired comparisons are presented one at a time to a user and a preferred selection for each paired comparison is made by a select indicator after the user toggles back and forth between the selections for as many times necessary in determining their preferences. A genetic algorithm converges all the preferences upon a single solution. Crossover and mutation genetic algorithm operators operate on a linear range of indexes representative of parametric values of the pairs. A fully integrated hearing aid having all the above described features incorporated therein is also presented.

[0004] The paper 'A Probabilistic Modeling Approach to Hearing Loss Compensation' of Thijs van de Laar and Bert de Vries published in IEEE/ACM Transactions on Audio, Speech, and Language Processing, Vol. 24, No. 11, November 2016 teaches a probabilistic model for finding optimum hearing aid parameters.

[0005] The paper 'Perception-Based Personalization of Hearing Aids Using Gaussian Processes and Active Learning' by Jens Brehm Bagger Nielsen, Jakob Nielsen, and Jan Larsen published in IEEE/ACM Transactions on Audio, Speech, and Language Processing, Vol 23, No. 1, January 2015 teaches a stochastics framework with machine learning for finding optimum hearing aid parameter sets.

[0006] The paper 'Incremental Utility Elicitation for Adpative Personalisation' by Tom Heskes and Bart de Vries published in the Proceedings of the 17th Belgium-Netherlands Conference on Artificial Intelligence, 17-18 October 2005, Brussels, Belgium also teaches a stochastics framework for finding optimum parameter sets for medical devices.

SUMMARY

[0007] There is a desire to provide an improved listening experience to a hearing device user.

[0008] Further, there is a need for a simple and effective way to configure one or more hearing device parameters of a hearing device.

[0009] A hearing device is disclosed, the hearing device comprising a set of microphones comprising a first microphone for provision of a first microphone input signal; a processor for processing input signals according to one or more hearing device parameters and providing an electrical output signal based on input signals; a user interface; and a receiver for converting the electrical output signal to an audio output signal. The processor is configured to initialize a model comprising a parameterized objective function based on a first assumption and a second assumption on the objective function; obtain an initial test setting defined by one or more initial test hearing device parameters; assign the initial test setting as a primary test setting; obtain a secondary test setting based on the model, the secondary test setting defined by one or more secondary test hearing device parameters; output a primary test signal according to the primary test setting via the receiver; output a secondary test signal according to the secondary test setting via the receiver; detect a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting; update the model based on the primary test setting, the secondary test setting, and the preferred test setting; and in accordance with a determination that a tuning criterion is satisfied, update the hearing device parameters of the hearing device based on hearing device parameters of the preferred test setting, wherein the objective function $f_{\hat{X},\Lambda}(X)$ is given by:

$$f_{\hat{X},\Lambda}(X) = -\left(\left(X-\hat{X}\right)^{T}\Lambda\left(X-\hat{X}\right)\right)^{p},$$

where X is a D-dimensional vector in a hypercube $[0,1]^{D}$ that represents the (D) hearing device parameters of the device, $\hat{X}$ is a maximizing argument of $f_{\hat{X},\Lambda}$, Λ is a positive definite $D \times D$ scaling matrix, wherein D is an integer less than 20, and p is a real-valued exponent in the range from 0.01 to 0.99.

[0010] Further, a method for tuning hearing device parameters of a hearing device is disclosed, the method comprising initializing a model comprising a parameterized objective function based on a first assumption and a second assumption on the objective function; obtaining an initial test setting defined by one or more initial test hearing device parameters; assigning the initial test setting as a primary test setting; obtaining a secondary test setting based on the model, the secondary test setting defined by one or more secondary test hearing device parameters; outputting a primary test signal according to the primary test setting; outputting a secondary test signal according to the secondary test setting; detecting a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting; updating the model based on the primary test setting, the secondary test setting, and the preferred test setting; and in accordance with a determination that a tuning criterion is satisfied, updating the hearing device parameters of the hearing device based on hearing device parameters of the preferred test setting, wherein the objective function $f_{\hat{X},\Lambda}(X)$ is given by:

$$f_{\hat{X},\Lambda}(X) = -\left((X - X)^{\top} \Lambda (X - X)\right) ,$$

where X is a D-dimensional vector in a hypercube $[0,1]^D$ that represents the (D) hearing device parameters of the device, X is a maximizing argument of $f_{\hat{X},\Lambda}$, Λ is a positive definite $D \times D$ scaling matrix, wherein D is an integer less than 20, and p is a real-valued exponent in the range from 0.01 to 0.99. The method may be performed in a hearing device system comprising the hearing device and/or an accessory device.

[0011] It is an advantage of the present disclosure that hearing device parameters can be configured during a normal operating situation and/or with a small number of user inputs/interactions. Thus, a simple and smooth user experience of the hearing device is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The above and other features and advantages of the present invention will become readily apparent to those skilled in the art by the following detailed description of exemplary embodiments thereof with reference to the attached drawings, in which:

Fig. 1 schematically illustrates an exemplary hearing device and accessory device according to the disclosure,

Fig. 2 is a flow diagram of an exemplary method according to the disclosure,

Fig. 3 is a flow diagram of an exemplary method according to the disclosure,

Fig. 4 is a flow diagram of an exemplary method according to the disclosure,

Fig. 5 is a flow diagram of an exemplary method according to the disclosure, and

Fig. 6 illustrates results of optimization of different objective functions.

DETAILED DESCRIPTION

[0013] Various exemplary embodiments and details are described hereinafter, with reference to the figures when relevant. It should be noted that the figures may or may not be drawn to scale and that elements of similar structures or functions are represented by like reference numerals throughout the figures. It should also be noted that the figures are only intended to facilitate the description of the embodiments. They are not intended as an exhaustive description of the invention or as a limitation on the scope of the invention. In addition, an illustrated embodiment needs not have all the aspects or advantages shown. An aspect or an advantage described in conjunction with a particular embodiment is not necessarily limited to that embodiment and can be practiced in any other embodiments even if not so illustrated, or if not so explicitly described.

[0014] The present disclosure relates to hearing systems, user accessory device and hearing device thereof, and related methods. The user accessory device forms an accessory device to the hearing device. The user accessory device is typically paired or wirelessly coupled to the hearing device. The hearing device may be a hearing aid, e.g. of the behind-the-ear (BTE) type, in-the-ear (ITE) type, in-the-canal (ITC) type, receiver-in-canal (RIC) type or receiver-in-the-ear (RITE) type. Typically, the hearing device system is in possession of and controlled by the hearing device user. The user accessory device may be a hand-held device, such as smartphone, a smartwatch, a special purpose device, or a tablet computer.

[0015] The hearing system may comprise a server device and/or a fitting device. The fitting device is controlled by a dispenser and is configured to determine configuration data, such as fitting parameters. The server device may be controlled by the hearing device manufacturer.

[0016] The hearing system is configured to receive and detect a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting. Accordingly, the hearing system may comprise one or more user interfaces for receiving and/or detecting a user input. For example, the hearing device may comprise a user interface receiving a user input. The user interface of the hearing device may comprise one or more buttons, an accelerometer and/or a voice control unit. The accessory device may comprise a user interface. The user interface of the accessor device may comprise a touch sensitive surface, e.g. a touch display, and/or one or more buttons. The user interface of the accessory device may comprise a voice control unit. The user interface of the hearing device may comprise one or more physical sliders, knobs and/or push buttons. The user interface of the accessory device may comprise one or more physical or virtual (on-screen) sliders, knobs and/or push buttons.

[0017] A method for tuning hearing device parameters of a hearing device comprises the sequence of steps as defined in claim 1.

[0018] The first assumption may be that the objective function is a smooth function.

[0019] The second assumption may be that the objective function is unimodal.

[0020] The objective function is denoted $f_{\hat{X},\Lambda}(X)$, where X is a D-dimensional vector in the hypercube $[0,1]^D$ that represents the (D) hearing device parameters of the device, $\hat{X}$ is the maximizing argument of $f_{\hat{X},\Lambda}$, and A is a scaling matrix. The number D of hearing device parameters may be 1 and/or less than 20, such as in the range from 2 to 15.

[0021] According to the invention, the objective function $f_{\hat{X},\Lambda}(X)$ is given by:

$$f_{\hat{X},\Lambda}(X) = -\left(\alpha\left(X-\hat{X}\right)^T \Lambda\left(X-\hat{X}\right)\right)^p,$$

where X is a D-dimensional vector in the hypercube $[0,1]^D$ that represents the (D) hearing device parameters of the device, $\hat{X}$ is the maximizing argument of $f_{\hat{X},\Lambda}$, Λ is a positive definite $D \times D$ scaling matrix, wherein D is an integer less than 20, and p is a real-valued exponent in the range from 0.01 to 0.99. The real-valued exponent p may be in the range from 0.2 to 0.8. In an example, the real-valued exponent p may set to 1. α is a real-valued parameter, which according to the invention is equal to one. Other examples not falling under the scope of the claimed invention comprise values of α larger than one.

[0022] The objective function $f_{\hat{X},\Lambda}(X)$ may be given by:

$$f_{\hat{\mathrm{x}},\Lambda}(\mathrm{x}) = -\sqrt{(\mathrm{x}-\hat{\mathrm{x}})^T \Lambda (\mathrm{x}-\hat{\mathrm{x}})}.$$

[0023] In an example not falling under scope of the claimed invention, the objective function $f_{\hat{X},\Lambda}(X)$ may be given by:

$$f_{\hat{X},\Lambda}(X) = exp\left(-\left(X-\hat{X}\right)^T \Lambda \left(X-\hat{X}\right)\right)$$

[0024] The maximizing argument $\hat{X}$ may be constrained by one or more prior assumptions on the objective function $f_{\hat{X},\Lambda}$.

[0025] The maximizing argument $\hat{X}$ may be constrained by the following prior assumptions on the objective function $f_{\hat{X},\Lambda}$:

$$\hat{X} = \Phi\left(\hat{Z}\right),$$

where $\Phi(\hat{z})$ is a cumulative density function of a probability distribution, such as the standard normal distribution, and $\hat{Z}$ is a sample from another probability distribution. In one or more exemplary methods/hearing systems, the maximizing argument $\hat{X}$ may be constrained by the following prior assumptions on the objective function $f_{\hat{X},\Lambda}$:

$$\hat{X} = \Phi\left(\hat{Z}\right), \text{ with } \hat{Z} \sim \mathcal{N}(\mu, \Sigma),$$

where

$$\Phi(\hat{z}) = \int_{-\infty}^{\hat{z}} \mathcal{N}(x|0,1)\mathrm{d}x$$

is the cumulative density function of the standard normal distribution, and $\hat{Z}$ is a sample from the normal distribution with mean vector μ and covariance matrix Σ. Values of the mean and covariances are learned from the user responses.

[0026] The scaling matrix Λ is a positive-definite scaling matrix Λ, for example constrained by the following prior assumptions:

$$\Lambda = \mathtt{diagm}([\lambda_1, \ldots, \lambda_D]), \qquad \lambda_d \sim \mathtt{Gamma}(k_d, \theta_d),$$

where λ_d is a sample from the Gamma distribution with shape and scale parameters k_d and θ_d, respectively. Values for the shape and scale parameters are learned from the user responses.

[0027] The scaling matrix Λ has two functions. Firstly, the diagonal elements of Λ are scaling factors for the individual hearing device parameters, and secondly the off-diagonal values allow to model correlations between the hearing device parameters. In one or more exemplary methods/hearing devices, the correlations between the hearing device parameters are not modelled in the prior assumption (Λ is diagonal).

[0028] The scaling matrix Λ does not need to be a diagonal matrix. The scaling matrix Λ may be selected as A = $L' * L$, where L is a low-triangular matrix (also known as the Cholesky decomposition of Λ). Gaussian priors may be applied on each of the elements of L, e.g.,

$$L_{ij} \sim \mathcal{N}(\mu_{ij}, \sigma_{ij}^2)$$

.

[0029] In one or more exemplary methods/hearing systems, the maximizing argument $\hat{X}$ may be constrained by the prior assumption:

$$p(\hat{X}) = \prod_{d=1}^{D} \mathrm{Beta}(\hat{X} \mid a_d, b_d),$$

where Beta() is the Beta distribution with shape parameters *a* and *b*. Values for the shape parameters are learned from the user responses.

[0030] The method may comprise updating the primary test setting with the preferred test setting; updating the secondary test setting, e.g. based on the updated model, the secondary test setting defined by one or more secondary test hearing device parameters; outputting the primary test signal according to the primary test setting; outputting the secondary test signal according to the secondary test setting; detecting a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting; and updating the model based on the primary test setting, the secondary test setting, and the preferred test setting.

[0031] The method may comprise determining if a continue-optimization criterion is satisfied and optionally forgo outputting test signals and detecting user input of preferred test setting in accordance with the continue-optimization criterion not being satisfied (in other words in accordance with a stop criterion being satisfied). The continue-optimization criterion may be based on the primary test setting and the secondary test setting. An exemplary continue-optimization criterion may be satisfied or at least partly satisfied if the model updates seem to converge to fixed parameter settings. The continue-optimization criterion may be based on a count of the number of user inputs. An exemplary continue-optimization criterion may be satisfied or at least partly satisfies if the number of user inputs in a given optimization sequence is less than ten, such as in the range from two to eight.

[0032] The method may comprise in accordance with the continue-optimization criterion being satisfied, repeating: updating the primary test setting with the preferred test setting; updating the secondary test setting based on the updated model, the secondary test setting defined by one or more secondary test hearing device parameters; outputting the primary test signal according to the primary test setting; outputting the secondary test signal according to the secondary test setting; detecting a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting; and updating the model based on the primary test setting, the secondary test setting, and the preferred test setting.

[0033] Obtaining an initial test setting may comprise randomly selecting a first initial test hearing device parameter of the one or more initial test hearing device parameters and/or selecting one or more current hearing device parameters as the one or more initial test hearing device parameters.

[0034] Obtaining a secondary test setting based on the model may comprise obtaining the secondary test setting as a sampling from a posterior distribution also denoted $p(\hat{X}|data)$ over the maximizing argument of the objective function, e.g. by Thompson sampling. The posterior distribution may be conditioned on one or more, such as all, previously obtained user input. The present method and hearing device allows for explicitly describing a probability distribution over the maximizing argument, i.e. $p(\hat{X}|data)$, where *data* denotes the data that follows or is obtained from all interaction with the user.

[0035] Detecting a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting may comprise prompting the user for the user input. Detecting a user input may be performed on the hearing device, e.g. by a user activating a button and/or an accelerometer (e.g. single or double tapping the hearing device housing) in the hearing device. Detecting a user input may be performed on the accessory device, e.g. by a user selecting a user interface element representative of the preferred test setting. Detecting a user input may be performed on the accessory device, e.g. by a user selecting a user interface element representative of the preferred test setting on a touch-sensitive display.

[0036] Updating the model may be based on a Bayesian inference method. Updating the model may comprise updating one or more of the parameters of the model. In one or more exemplary methods/hearing devices/accessory devices, updating the model may comprise updating one or more, e.g. all, of the mean vector μ, the covariance matrix $\sum$, and the shape and scale parameters k_d and θ_d. Updating the model, or parameters thereof may be based on variational optimization, Laplace approximation or Monte Carlo sampling.

[0037] Updating the hearing device parameters of the hearing device is based on hearing device parameters of the preferred test setting. For example, the hearing device parameters of the hearing device may be set to the maximizing argument $\hat{X}$ of the objective function. In one or more exemplary methods/hearing devices, the hearing device parameters of the hearing device may be updated after each test cycle, i.e. after each user input, however, in order to not confuse the user and/or save power, the hearing device parameters of the hearing device may be updated in accordance with a tuning criterion being satisfied. In one or more exemplary methods/hearing devices, the tuning criterion is satisfied when the continue-optimization criterion is not satisfied, i.e. when tuning of the hearing device parameters is done.

[0038] The hearing device comprises the set of features defined in claim 14.

[0039] Fig. 1 shows an exemplary hearing system. The hearing system 1 comprises a hearing device 2 and an accessory device 4. The hearing device 2 optionally comprises a transceiver module 6 for (wireless) communication with the accessory device 4 and optionally a contralateral hearing device (not shown in Fig. 1). The transceiver module 6 comprises antenna 8 and transceiver 10, and is configured for receipt and/or transmission of wireless signals via wireless connection 11 to the accessory device 4.

[0040] The hearing device 2 comprises a set of microphones comprising a first microphone 12 for provision of a first microphone input signal 14; a processor 16 for processing input signals including the first microphone input signal 14 according to one or more hearing device parameters and providing an electrical output signal 18 based on input signals; a user interface 20 connected to the processor 16; and a receiver 22 for converting the electrical output signal 18 to an audio output signal.

[0041] The accessory device 4 is a smartphone and comprises a user interface 24 comprising a touch display 26, and a processor (not shown). The accessory device 4 is in a setting adjustment mode for adjusting a setting, i.e. one or more hearing device parameters, of the hearing device 2.

[0042] The hearing device 2 (processor 16) or the accessory device 4 is configured to initialize a model comprising a parameterized objective function based on a first assumption and a second assumption on the objective function, e.g. in accordance a determination that a start criterion is satisfied. The start criterion may be satisfied if a user input on user interface 20 or user interface 24 indicative of a user desire to start optimization has been detected, e.g. by activation of virtual start button 28 on the accessory device 4.

[0043] The hearing device 2 or the accessory device 4 is configured to obtain an initial test setting defined by one or more initial test hearing device parameters; assign the initial test setting as a primary test setting; and obtain a secondary test setting based on the model, the secondary test setting defined by one or more secondary test hearing device parameters.

[0044] In an implementation including accessory device 4, the accessory device 4 may be configured to send a control signal 30 to the hearing device 2, the control signal 30 being indicative of the primary test setting and the secondary test setting, thus enabling the hearing device 2 to output test signals accordingly.

[0045] The hearing device 2 (processor 16) is configured to output a primary test signal according to the primary test setting via the receiver 22 and a secondary test signal according to the secondary test setting via the receiver 22.

[0046] The hearing device 2 (processor 16) or the accessory device 4 is configured to detect a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting, e.g. by detecting a user input on user interface 20 or by detecting a user selection of one of a primary virtual button 32 and a secondary virtual button 34 on the user interface 26 of accessory device 4.

[0047] The hearing device 2 (processor 16) and/or the accessory device 4 is configured to update the model based on the primary test setting, the secondary test setting, and the preferred test setting; and in accordance with a determination that a tuning criterion is satisfied, update the hearing device parameters of the hearing device based on hearing device parameters of the preferred test setting. The tuning criterion may be satisfied when a user provides a user input indicative of a desire to stop optimization, e.g. by detecting a user selection of a stop virtual button (not shown) on the user interface 26 of accessory device 4 and/or when a pre-set number of user inputs of preferred test setting(s).

[0048] In an implementation including accessory device 4, the accessory device 4 may be configured to send a control signal 32 to the hearing device 2, the control signal 38 being indicative of the hearing device parameters of the preferred test setting, thus enabling the hearing device to update the hearing device parameters of the hearing device.

[0049] Fig. 2 is a flow diagram of an exemplary method for tuning hearing device parameters of a hearing device. The method 100 comprises initializing 102 a model comprising a parameterized objective function based on a first assumption and a second assumption on the objective function. The objective function $f_{\hat{X},\Lambda}(X)$ is given by:

$$f_{\hat{X},\Lambda}(X) = -\left(\left(X - \hat{X}\right)^T \Lambda \left(X - \hat{X}\right)\right)^p,$$

where X is a D-dimensional vector in the hypercube $[0,1]^D$ that represents the (D) hearing device parameters of the device, X is the maximizing argument of $f_{\hat{X},\Lambda}$, Λ is a positive definite $D{\times}D$ scaling matrix, wherein D is an integer less than 20, and p is 0.5. The maximizing argument $\hat{X}$ is constrained by the following prior assumptions on the objective function $f_{\hat{X},\Lambda}$:

$\hat{X} = \Phi(\hat{Z})$, with $\hat{Z} \sim \mathcal{N}(\mu, \Sigma)$,

where

$\Phi(\hat{z}) = \int_{-\infty}^{\hat{z}} \mathcal{N}(x|0,1)\mathrm{d}x$

is the cumulative density function of the standard normal distribution, and Z is a sample from the normal distribution with mean vector μ and covariance matrix Σ. The positive-definite scaling matrix Λ is constrained by the following prior assumptions:

$$\Lambda = \mathtt{diagm}([\lambda_1, \ldots, \lambda_D]), \qquad \lambda_d \sim \mathtt{Gamma}(k_d, \theta_d),$$

where λ_d is a sample from the Gamma distribution with shape and scale parameters k_d and θ_d, respectively.

[0050] The method 100 comprises obtaining 104 an initial test setting defined by one or more initial test hearing device parameters and assigning 106 the initial test setting as a primary test setting. The method 100 comprises obtaining 108 a secondary test setting based on the model by sampling from a posterior distribution also denoted $p(\hat{X}|data)$ over the maximizing argument of the objective function, the secondary test setting defined by one or more secondary test hearing device parameters.

[0051] The method 100 proceeds to outputting, with the hearing device, 110 a primary test signal according to the primary test setting and outputting, with the hearing device, a secondary test signal 112 according to the secondary test setting.

[0052] The method 100 comprises detecting 114 a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting; and updating 116 the model based on the primary test setting, the secondary test setting, and the preferred test setting, wherein updating the model comprises updating the mean vector μ, the covariance matrix $\sum$, and the shape and scale parameters k_d and θ_d based on variational optimization.

[0053] The method 100 comprises updating 118 the hearing device parameters of the hearing device based on hearing device parameters of the preferred test setting.

[0054] Updating 118 the hearing device parameters and updating 120 the primary test setting may be integrated in a single operation, e.g. updating 120 the primary test setting may be performed as an integrated part of updating 118 the hearing device parameters.

[0055] Updating 116 the model and updating 120 the primary test setting may be integrated in a single operation, e.g. updating 120 the primary test setting may be performed as an integrated part of updating 116 the model.

[0056] The method 100 may be a continuous method and may comprise updating 120 the primary test setting with the preferred test setting; and optionally, as part of obtaining 108 the secondary test setting, updating 122 the secondary test setting based on the updated model.

[0057] Fig. 3 is a flow diagram of an exemplary method for tuning hearing device parameters of a hearing device. The method 100A implements a conditioned updating of hearing device parameters of the hearing device. This may be advantageous, e.g. if acts 102, 104, 106, 108, 114, 116 of the method are implemented at least partly in an accessory device, since receipt/transmission in/from the hearing device required in connection with update 118 can be reduced. The method 100A comprises determining if a tuning criterion is satisfied and in accordance with a determination that the tuning criterion is satisfied 130, updating 118 the hearing device parameters of the hearing device based on hearing device parameters of the preferred test setting. Further, normal operation of the hearing device is not affected until a preferred setting is obtained. The method 100A may comprise, in accordance with a determination that the tuning criterion is not satisfied 130, updating 120 the primary test setting with the preferred test setting; and updating 122, as part of obtaining 108 secondary test setting, the secondary test setting based on the updated model.

[0058] Fig. 4 is a flow diagram of an exemplary method for tuning hearing device parameters of a hearing device. The method 100B comprises determining if a continue-optimization criterion is satisfied and in accordance with the continue-optimization criterion being satisfied 140, repeating updating 120 the primary test setting with the preferred test setting; updating 122 the secondary test setting based on the updated model, the secondary test setting defined by one or more secondary test hearing device parameters; outputting 110 the primary test signal according to the primary test setting; outputting 112 the secondary test signal according to the secondary test setting; and detecting 114 a user input of a preferred test setting indicative of a preference for either the primary test setting or the secondary test setting. When the continue-optimization criterion is satisfied, the method 100B proceeds to updating 118 hearing device parameters of the hearing device.

[0059] Fig. 5 is a flow diagram of an exemplary method for tuning hearing device parameters of a hearing device. In the method 100C, the hearing device parameters are updated 118 in each optimization cycle.

[0060] Fig. 6 illustrates results of optimization of a hearing device parameter with different objective functions. The first objective function f_1 is a 1-dimensional cone depicted in Fig. 6a. The second objective function f_2 is bell-shaped, shown in Fig. 6c. The cone variant of the parametric model (Cone-Thompson) is compared to a GP model with a squared exponential kernel (GP-Thompson).

[0061] Since the parametric model assumes the objective function to have the analytical form of a cone, there is a model mismatch in the second experiment, allowing us to test the robustness under mismatch. Priors $p(\hat{X})$ and $p(\Lambda)$ are chosen to be uninformative. User inputs $x'_1, \ldots, x'_{40}$ are selected through Thompson sampling under both models. The hyperparameters of the GP model are fitted in every iteration by marginal log-likelihood optimization. The results in Figs. 6b and 6d show that the present method consistently and significantly outperforms GP-Thompson on both objective functions. Figs. 6b and 6d depict the so-called "cumulative value" curves, which are the cumulative sums of the objective function values at the inputs $x'_1, \ldots, x'_{40}$. Larger cumulative values correspond to inputs $x'_1, \ldots, x'_{40}$ that are closer to the optimal parameter value. The fact that the Cone-Thompson curves are consistently above the GP-Thompson curves indicates that the Cone-Thompson algorithm select better inputs than the GP-Thompson algorithm.

[0062] The use of the terms "first", "second", "third" and "fourth", "primary", "secondary", "tertiary" etc. does not imply any particular order, but are included to identify individual elements. Moreover, the use of the terms "first", "second", "third" and "fourth", "primary", "secondary", "tertiary" etc. does not denote any order or importance, but rather the terms "first", "second", "third" and "fourth", "primary", "secondary", "tertiary" etc. are used to distinguish one element from another. Note that the words "first", "second", "third" and "fourth", "primary", "secondary", "tertiary" etc. are used here and elsewhere for labelling purposes only and are not intended to denote any specific spatial or temporal ordering. Furthermore, the labelling of a first element does not imply the presence of a second element and vice versa.

[0063] Although particular features have been shown and described, it will be understood that they are not intended to limit the claimed invention, and it will be made obvious to those skilled in the art that various changes and modifications may be made without departing from the scope of the claimed invention. The specification and drawings are, accordingly to be regarded in an illustrative rather than restrictive sense. The claimed invention is defined by the scope of the appended claims.

LIST OF REFERENCES

[0064]

1
: hearing system

2
: hearing device

4
: accessory device

6
: transceiver module

8
: antenna

10
: transceiver

11
: wireless connection 11 between hearing device and accessory device

12
: first microphone

14
: first microphone input signal

16
: processor

18
: electrical output signal

20
: user interface

22
: receiver

24
: user interface of accessory device

26
: touch display

28
: start button 28

30
: control signal indicative of primary and secondary test setting

32
: primary virtual button

34
: secondary virtual button

38
: control signal indicative of the hearing device parameters of the preferred test setting

100, 100A, 100B, 100C
: method for tuning hearing device parameters

102
: initializing a model

104
: obtaining an initial test setting

106
: assigning the initial test setting as a primary test setting

108
: obtaining a secondary test setting

110
: outputting a primary test signal according to the primary test setting

112
: outputting a secondary test signal according to the secondary test setting

114
: detecting a user input of a preferred test setting

116
: updating the model

118
: updating the hearing device parameters of the hearing device

120
: updating the primary test setting

122
: updating the secondary test setting

130
: in accordance with a determination that the tuning criterion is satisfied

140
: in accordance with a continue-optimization criterion being satisfied

200
: first objective function

202
: second objective function

REFERENCES CITED IN THE DESCRIPTION

Cited references

Patent documents cited in the description

- US20030133578A [0003]

Non-patent literature cited in the description

- **THIJS VAN DE LAARBERT DE VRIES**A Probabilistic Modeling Approach to Hearing Loss CompensationIEEE/ACM Transactions on Audio, Speech, and Language Processing, 2016, vol. 24, 11 [0004]
- **JENS BREHM BAGGER NIELSENJAKOB NIELSENJAN LARSEN**Perception-Based Personalization of Hearing Aids Using Gaussian Processes and Active LearningIEEE/ACM Transactions on Audio, Speech, and Language Processing, 2015, vol. 23, 1 [0005]
- **TOM HESKESBART DE VRIES**Incremental Utility Elicitation for Adpative PersonalisationProceedings of the 17th Belgium-Netherlands Conference on Artificial Intelligence, 2005, [0006]

PATENTKRAV

1. Fremgangsmåde (100, 100A, 100B, 100C) til tuning af høreapparatparametre for et høreapparat, hvilken fremgangsmåde omfatter:

initialisering (102) af en model omfattende en parametriseret objektivfunktion baseret på en første antagelse og en anden antagelse på den objektive funktion;

opnåelse (104) af en indledende testindstilling defineret af en eller flere indledende testhøreapparatparametre;

at tildele (106) den indledende testindstilling som en primær testindstilling;

opnåelse (108) af en sekundær testindstilling baseret på modellen, den sekundære testindstilling defineret af en eller flere sekundære testhøreapparatparametre;

udlæsning (110) af et primært testsignal ifølge den primære testindstilling;

udlæsning (112) af et sekundært testsignal ifølge den sekundære testindstilling;

detektering (114) af et brugerinput af en foretrukken testindstilling, der indikerer en præference for enten den primære testindstilling eller den sekundære testindstilling;

opdatering (116) af modellen baseret på den primære testindstilling, den sekundære testindstilling og den foretrukne testindstilling; og

i overensstemmelse med en bestemmelse om, at et justeringskriterium er opfyldt (130), opdatering (118) af høreapparatets høreapparatparametre baseret på høreapparatparametrene for den foretrukne testindstilling,

kendetegnet ved, at objektivfunktionen $f_{\hat{X},\Lambda(}X)$ er givet ved:

$$f_{\hat{X},\Lambda}(X) = -\left(\left(X-\hat{X}\right)^T \Lambda\left(X-\hat{X}\right)\right)^p,$$

hvor X er en D-dimensional vektor i en hyperkube $[0,1]^D$, der repræsenterer (D) høreapparatparametrene for enheden, $\hat{X}$ er et maksimerende argument for $f_{\hat{X},\Lambda}$, Λ er en positiv bestemt D × D skaleringsmatrix, hvor D er et heltal mindre end 20, og p er en eksponent med reel værdi i området fra 0,01 til 0,99.

2. Fremgangsmåde ifølge krav 1, hvor fremgangsmåden omfatter:

opdatering (120) af den primære testindstilling med den foretrukne testindstilling;

opdatering (122) af den sekundære testindstilling baseret på den opdaterede model, den sekundære testindstilling defineret af en eller flere sekundære testhøreapparatparametre;

udlæsning (110) af det primære testsignal ifølge den primære testindstilling;

udlæsning (112) af det sekundære testsignal ifølge den sekundære testindstilling;

detektering (114) af et brugerinput af en foretrukken testindstilling, der indikerer en præference for enten den primære testindstilling eller den sekundære testindstilling; og

opdatering (116) af modellen baseret på den primære testindstilling, den sekundære testindstilling og den foretrukne testindstilling.

3. Fremgangsmåde ifølge krav 1, hvor fremgangsmåden omfatter at man bestemmer (140), om et fortsat optimeringskriterium er opfyldt.

4. Fremgangsmåde ifølge krav 3, hvor fremgangsmåden omfatter:

i overensstemmelse med, at kriteriet om fortsat optimering er opfyldt (140), gentages:

opdatering (120) af den primære testindstilling med den foretrukne testindstilling;

opdatering (122) af den sekundære testindstilling baseret på den opdaterede model, den sekundære testindstilling defineret af en eller flere sekundære testhøreapparatparametre;

udlæsning (110) af det primære testsignal ifølge den primære testindstilling;

udlæsning (112) af det sekundære testsignal ifølge den sekundære testindstilling;

detektering (114) af et brugerinput af en foretrukken testindstilling, der indikerer en præference for enten den primære testindstilling eller den sekundære testindstilling; og opdatering (116) af modellen baseret på den primære testindstilling, den sekundære testindstilling og den foretrukne testindstilling.

5. Fremgangsmåde ifølge et hvilket som helst af kravene 1-4, hvor den første antagelse er, at den objektive funktion er en glat funktion.

6. Fremgangsmåde ifølge et hvilket som helst af kravene 1-5, hvor den anden antagelse er, at den objektive funktion er unimodal.

7. Fremgangsmåde ifølge krav 1, hvor objektivfunktionen $f_{\hat{X},\Lambda}(X)$ er givet ved:

$$f_{\hat{\mathbf{x}},\Lambda}(\mathbf{x}) = -\sqrt{(\mathbf{x}-\hat{\mathbf{x}})^T \Lambda (\mathbf{x}-\hat{\mathbf{x}})}.$$

8. Fremgangsmåde ifølge krav 7, hvor maksimeringsargumentet X er begrænset af følgende forudgående antagelser om objektivfunktionen $f_{\hat{X},\Lambda}$:

$$\hat{X} = \Phi(\hat{Z}), \text{ with } \hat{Z} \sim \mathcal{N}(\mu, \Sigma) \ ,$$

hvor $\Phi(\hat{z}) = \int_{-\infty}^{\hat{z}} \mathcal{N}(x|0,1)\mathrm{d}x$ er en kumulativ fordelingsfunktion af standardnormalfordelingen, og $\hat{Z}$ er en stikprøve fra normalfordelingen med middelvektor μ og kovariansmatrix ∑.

9. Fremgangsmåde ifølge et hvilket som helst af kravene 1, 7 eller 8, hvor den positive-definite skaleringsmatrix Λ er begrænset af følgende forudgående antagelser:

$$\Lambda = \mathtt{diagm}([\lambda_1, \ldots, \lambda_D]), \qquad \lambda_d \sim \mathtt{Gamma}(k_d, \theta_d) \ ,$$

hvor λ_d er en prøve fra en gamma-fordeling med henholdsvis form- og skalaparametre k_d og θ_d.

10. Fremgangsmåde ifølge et hvilket som helst af kravene 1-9, hvor opnåelse (104) af en indledende testindstilling omfatter tilfældig udvælgelse af en første indledende testhøreapparatparameter af den ene eller flere indledende testhøreapparatparametre eller valg af en eller flere aktuelle høreapparatparametre som en eller flere indledende test høreapparatparametre.

11. Fremgangsmåde ifølge et hvilket som helst af kravene 1-10, hvor opnåelse (108) af en sekundær testindstilling baseret på modellen omfatter opnåelse af den sekundære testindstilling som en prøveudtagning fra en posterior fordeling $p(\hat{X}|data)$ over maksimeringsargumentet for objektiv funktion, hvor den posteriore fordeling er betinget af alle tidligere opnåede brugerinput.

12. Fremgangsmåde ifølge et hvilket som helst af kravene 1-11, hvor detektering (114) af et brugerinput af en foretrukken testindstilling, der indikerer en præference for enten den primære testindstilling eller den sekundære testindstilling, omfatter at bede brugeren om brugerinputtet.

13. Fremgangsmåde ifølge et hvilket som helst af kravene 1-12, hvor opdatering af modellen er baseret på en Bayes eller omtrentlig Bayes inferensmetode.

14. Høreapparat (2) omfattende:

- et sæt mikrofoner omfattende en første mikrofon (12) til tilvejebringelse af et første mikrofonindgangssignal (14);

- en processor (16) til behandling af inputsignaler i overensstemmelse med en eller flere høreapparatparametre og tilvejebringelse af et elektrisk udgangssignal (18) baseret på inputsignaler;

- en brugergrænseflade (20); og

- en modtager (22) til at konvertere det elektriske udgangssignal (18) til et lydudgangssignal,

hvor processoren (16) er konfigureret til

initialisere en model omfattende en parametriseret objektivfunktion baseret på en første antagelse og en anden antagelse på den objektive funktion;

opnå en indledende testindstilling defineret af en eller flere indledende test høreapparatparametre;

tildele den indledende testindstilling som en primær testindstilling;

opnå en sekundær testindstilling baseret på modellen, den sekundære testindstilling defineret af en eller flere sekundære høreapparatparametre;

udsende et primært testsignal i henhold til den primære testindstilling via modtageren;

udsende et sekundært testsignal i henhold til den sekundære testindstilling via modtageren;

detektere et brugerinput af en foretrukken testindstilling, der indikerer en præference for enten den primære testindstilling eller den sekundære testindstilling;

opdatere modellen baseret på den primære testindstilling, den sekundære testindstilling og den foretrukne testindstilling; og

i overensstemmelse med en bestemmelse om, at et justeringskriterium er opfyldt, opdatere høreapparatets høreapparatparametre baseret på høreapparatets parametre for den foretrukne testindstilling,

kendetegnet ved, at objektivfunktionen $f_{\hat{X},\Lambda}(X)$ er givet af:

$$f_{\hat{X},\Lambda}(X) = -\left(\left(X - \hat{X}\right)^T \Lambda \left(X - \hat{X}\right)\right)^p,$$

hvor X er en D-dimensional vektor i en hyperkube $[0,1]^D$, der repræsenterer (D) høreapparatparametrene for enheden, $\hat{X}$ er et maksimerende argument for $f_{\hat{X},\Lambda}$, Λ er en positiv bestemt D × D skaleringsmatrix, hvor D er et heltal mindre end 20, og p er en eksponent med reel værdi i området fra 0,01 til 0,99.

DRAWINGS

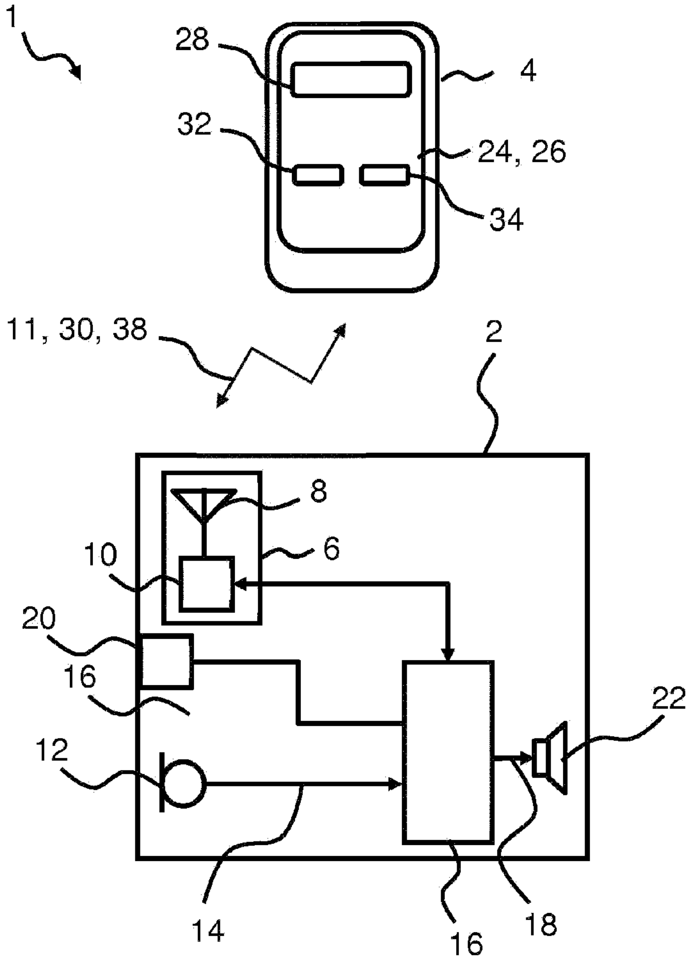


Fig. 1

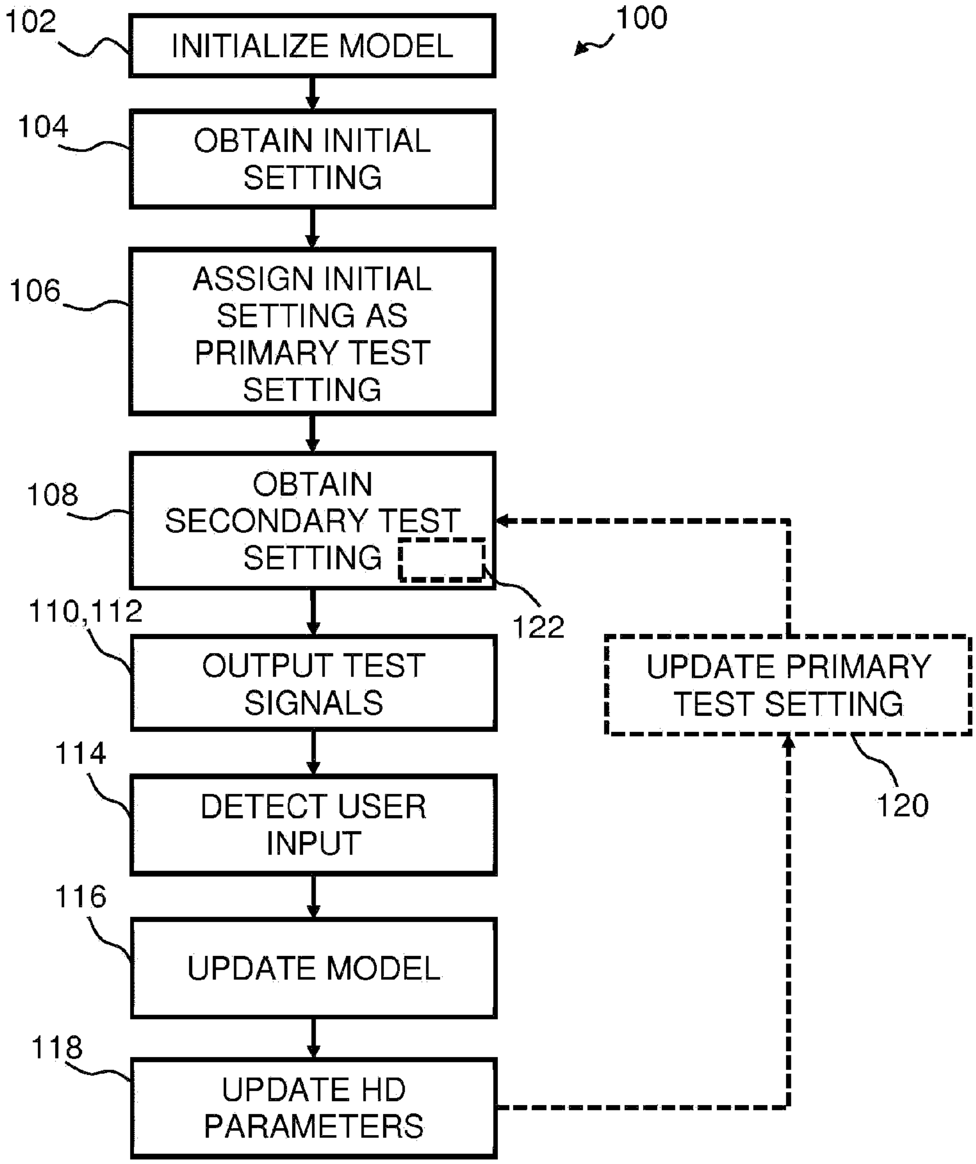

102
INITIALIZE MODEL
100
104
OBTAIN INITIAL SETTING
106
ASSIGN INITIAL SETTING AS PRIMARY TEST SETTING
108
OBTAIN SECONDARY TEST SETTING
122
110,112
OUTPUT TEST SIGNALS
UPDATE PRIMARY TEST SETTING
120
114
DETECT USER INPUT
116
UPDATE MODEL
118
UPDATE HD PARAMETERS

Fig. 2

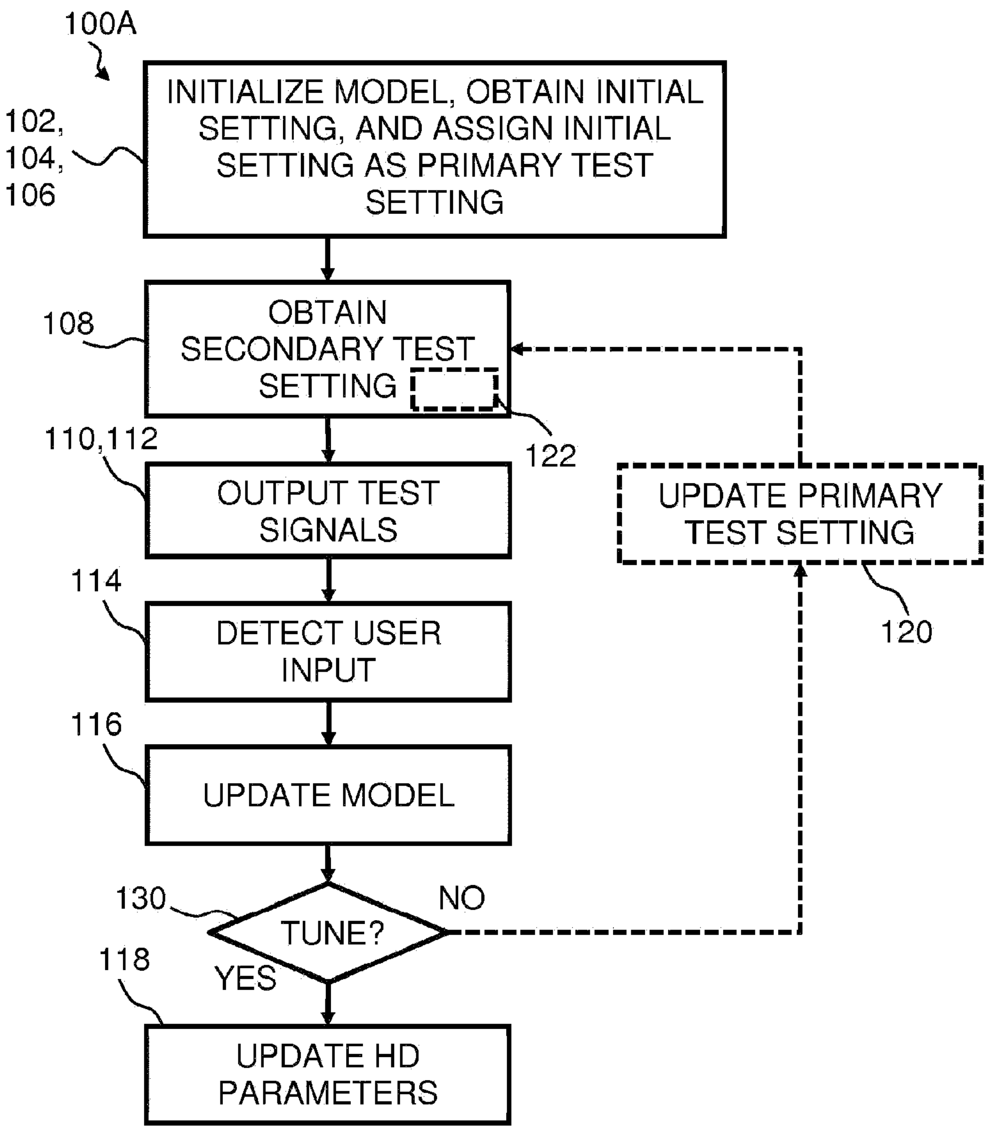

100A
102,
104,
106
INITIALIZE MODEL, OBTAIN INITIAL SETTING, AND ASSIGN INITIAL SETTING AS PRIMARY TEST SETTING
108
OBTAIN SECONDARY TEST SETTING
122
110,112
OUTPUT TEST SIGNALS
UPDATE PRIMARY TEST SETTING
120
114
DETECT USER INPUT
116
UPDATE MODEL
130
TUNE?
NO
YES
118
UPDATE HD PARAMETERS

Fig. 3

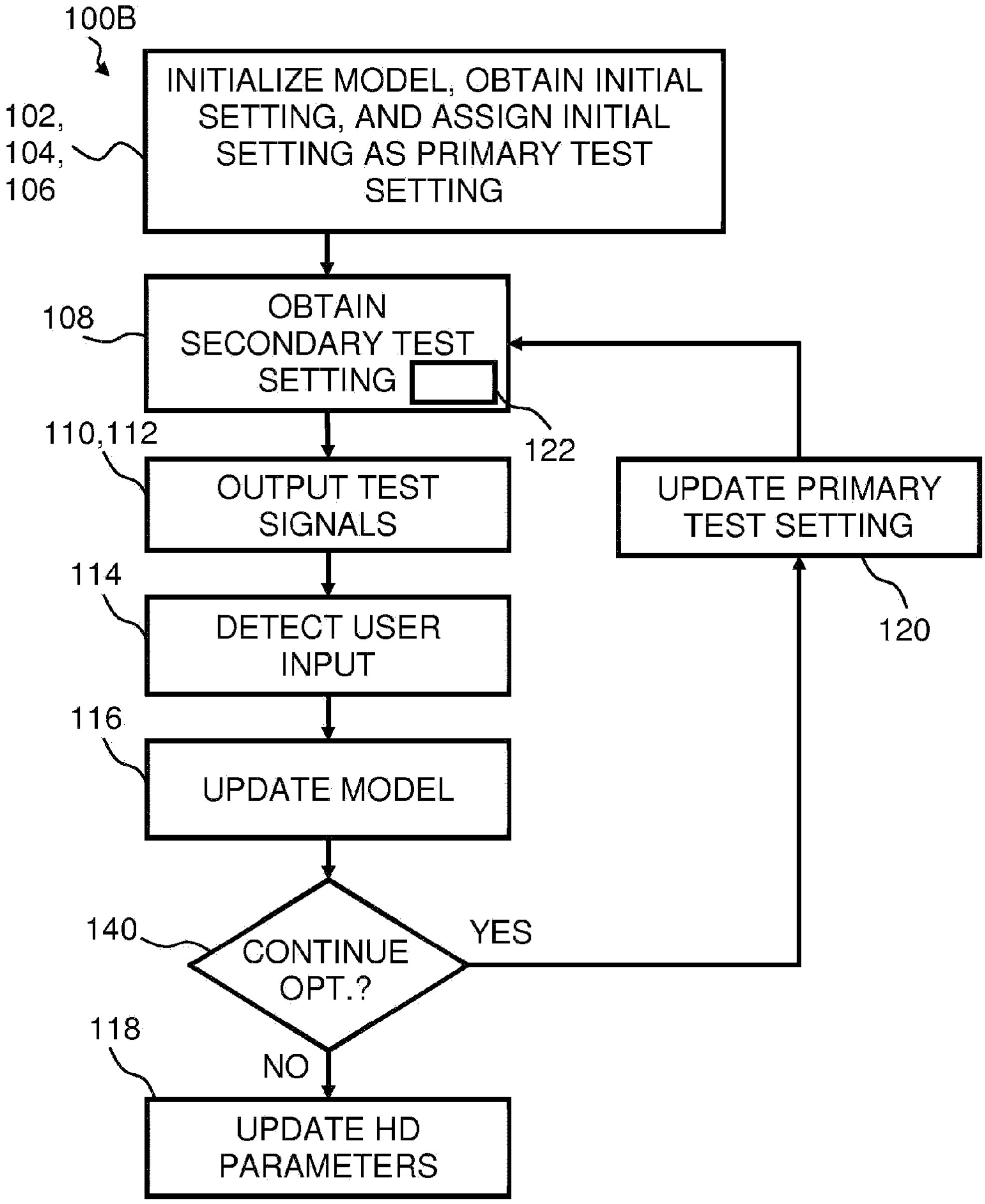

100B
102,
104,
106
INITIALIZE MODEL, OBTAIN INITIAL SETTING, AND ASSIGN INITIAL SETTING AS PRIMARY TEST SETTING
108
OBTAIN SECONDARY TEST SETTING
122
110,112
OUTPUT TEST SIGNALS
UPDATE PRIMARY TEST SETTING
120
114
DETECT USER INPUT
116
UPDATE MODEL
140
CONTINUE OPT.?
YES
118
NO
UPDATE HD PARAMETERS

Fig. 4

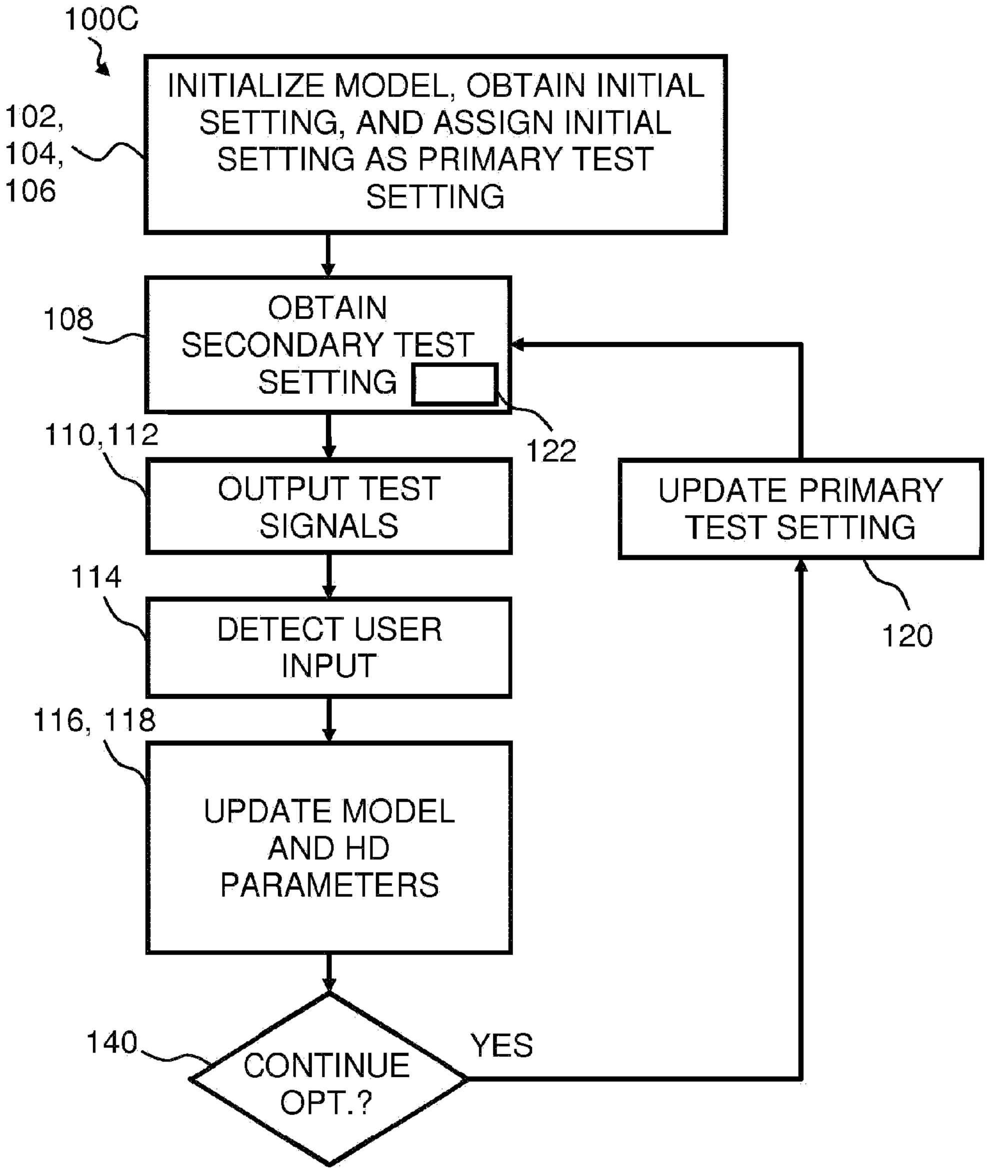
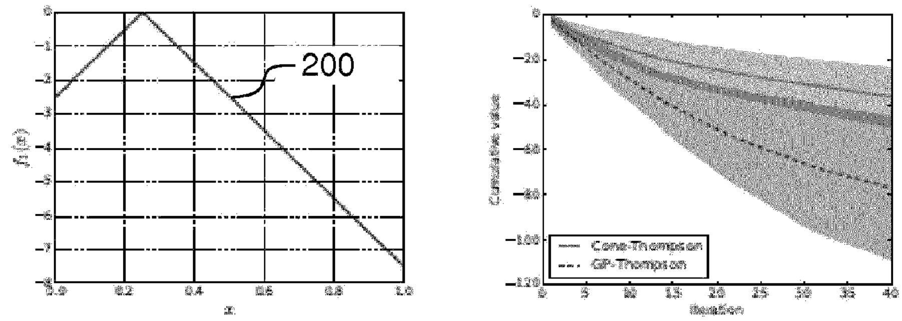
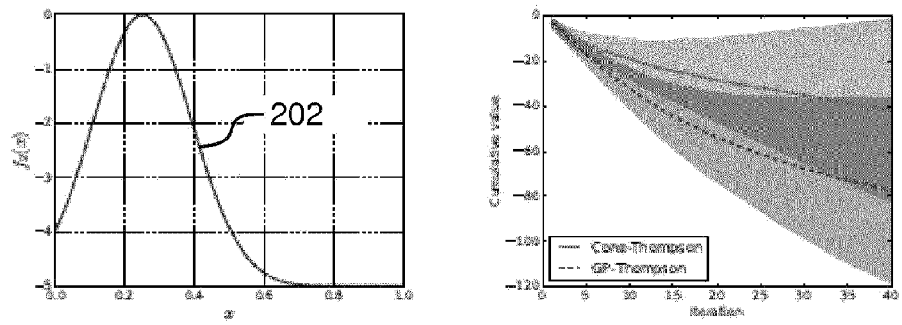

100C
102,
104,
106
INITIALIZE MODEL, OBTAIN INITIAL SETTING, AND ASSIGN INITIAL SETTING AS PRIMARY TEST SETTING
108
OBTAIN SECONDARY TEST SETTING
122
110,112
OUTPUT TEST SIGNALS
114
DETECT USER INPUT
116, 118
UPDATE MODEL AND HD PARAMETERS
140
CONTINUE OPT.?
YES
UPDATE PRIMARY TEST SETTING
120

Fig. 5



(a) $f_1(x) = -\sqrt{100(x-0.25)^2}$

(b) Results of optimization of f_1.



(c) $f_2(x) = 5\exp(-25(x-0.25)^2) - 5$

(d) Results of optimization of f_2.

Fig. 6