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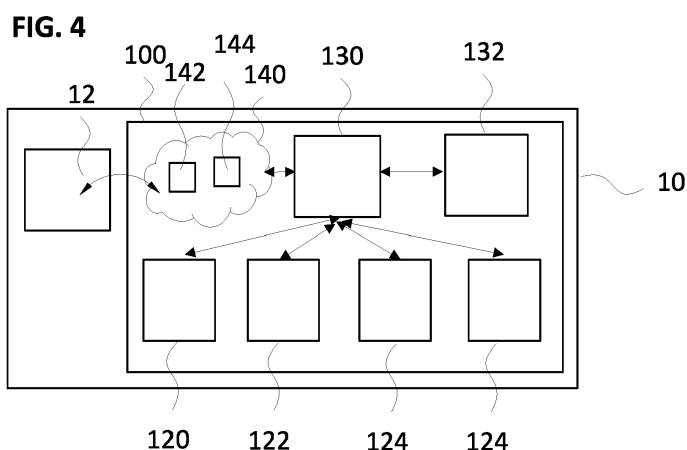
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(54) **HEARING SYSTEM**

(57) The invention relates to a hearing system (10) including a hearing device (12), the hearing system (10) implementing a hierarchical control system with at least two control levels (110, 112, 114, 116), wherein at least one control entity (120, 122, 124, 126) is assigned to each of the control levels (110, 112, 114, 116), the hearing system (10) including a memory (130) storing instructions, and a processor (132) communicatively coupled to the memory and configured to execute the control system (100) and the following instructions: determining and monitoring a hearing situation of a user of the hearing system (10) based on a status of the hearing system (10) and user related data stored in the memory (130); and determining, based on the hearing situation of the user,

an updated hearing device setting (144), associating the updated hearing device setting (144) with one of the at least two control levels,

wherein the control system (100) is configured to query the control entity (120, 122, 124, 126) assigned to the control level (110, 112, 114, 116) associated with the updated hearing device setting (144) for approval of the updated hearing device setting (144) upon approval, allow the hearing system (10) to apply the updated hearing device setting (144); and, subsequently notify at least the control entity (120, 122, 124, 126) assigned to the next higher control level about the application of the updated hearing device setting (144) if the control system (100) comprises a next higher control level.



Description

FIELD OF THE INVENTION

- 5 **[0001]** The invention relates to a hearing system with a hearing device. The invention further relates to a method, a computer program and a computer readable medium for controlling the hearing system.

BACKGROUND OF THE INVENTION

- 10 **[0002]** Hearing devices are generally small and complex devices. Hearing devices can include a processor, microphone, speaker, memory, housing, and other electrical and mechanical components. Some example hearing devices are Behind-The-Ear (BTE), Receiver-In-Canal (RIC), In-The-Ear (ITE), Completely-In-Canal (CIC), and Invisible-In-The-Canal (IIC) devices. A user can prefer one of these hearing devices compared to another device based on hearing loss, aesthetic preferences, lifestyle needs, and budget.
- 15 **[0003]** Today's hearing devices mainly work based on the settings that the user receives from user's audiologist or hearing care professional (HCP). Such first settings have typically to be optimized at least during an initial period, where the hearing device is worn.
- [0004]** There are several ways to improve this configuration such as follow up fittings with the HCP or by the user who can adjust settings either at the hearing device directly or e. g. based on apps running on a smartphone.
- 20 **[0005]** Furthermore, some hearing devices are configured for automatic adjustments. In case of automatic adjustments based on sensors or user feedbacks, the user just gets adjusted settings for the hearing devices without interactions with the user. Thus, the user may not be aware of what has caused the change, may not even perceive any change and cannot control this change. The user thus can also not reject the change when he would prefer the previous setting.

25 DESCRIPTION OF THE INVENTION

- [0006]** It is an objective of the invention to provide a hearing system which provides an improved user experience. It is a further objective to provide an enhanced safety for the user.
- [0007]** These objectives are achieved by the subject-matter of the independent claim. Further exemplary embodiments are evident from the dependent claims and the following description.
- 30 **[0008]** A first aspect of the invention relates to a hearing system including a hearing device, the hearing system implementing a hierarchical control system with at least two control levels, wherein at least one control entity is assigned to each of the control levels. The hearing system includes a memory storing instructions, and a processor communicatively coupled to the memory and configured to execute the control system. The processor is further configured to execute the following instructions: determining and monitoring a hearing situation of a user of the hearing system based on a status of the hearing system and user related data stored in the memory; and determining, based on the hearing situation of the user, an updated hearing device setting. The updated hearing device setting also may be associated with one of the at least two control levels.
- 35 **[0009]** The hearing device according to the present invention may be in particular one of Behind-The-Ear (BTE), Receiver-In-Canal (RIC), In-The-Ear (ITE), Completely-In-Canal (CIC), and Invisible-In-The-Canal (IIC) devices. Such a hearing device typically comprises a housing, a microphone or sound detector, and an output device including e.g. a speaker (also "receiver") for delivering an acoustic signal, i.e. sound into an ear canal of a user. The output device can also be configured, alternatively or in addition, to deliver other types of signals to the user which are representative of audio content and which are suited to evoke a hearing sensation. The output device can in particular be configured to deliver an electric signal for driving an implanted electrode for directly stimulating hearing receptors of the user as it is e.g. the case in a cochlea-implant. Output devices of other types of hearing devices are configured to transmit an acoustic signal directly via bone conduction as it is e.g. the case with so called BAHA devices (Bone Anchored Hearing Aid - BAHA) which transmit the acoustic signal via a pin implanted into the skull of a user. The hearing device may comprise the processor and the memory. The hearing device may further include other electrical and mechanical components,
- 40 **[0010]** like an input unit or a transmitter and/or one or more sensors. The hearing system may further include a mobile device being a user device, for example a smart phone or other connectable device, which can be connected to the hearing device over a network or by a direct, in particular wireless, connection. In such a case, sensors included in the mobile device may be used to collect sensor data to be send to the processor of the hearing system.
- 45 **[0011]** The hearing system is configured to determine and monitor a hearing situation of the user. A hearing situation of the user is to be understood to include factors, which change the personal hearing experience of the user such as acoustic of the environment, background and foreground noise and sound as well as medical conditions of the user. The hearing system may take into account measurements from one or more sensors to determine the hearing status.
- 50 **[0011]** The processor for determining, based on the hearing situation of the user, an updated hearing device setting,
- 55

may be a processor internal to the hearing device or a processor of a connected device or a connected network e.g. accessible through internet. The updated hearing device setting may be obtained from a database of available hearing device settings or can be procedurally generated at runtime based e.g. on the current hearing situation and user preferences. For example, based on the hearing situation of the user, an updated hearing device setting may be selected from a database of available hearing device settings, each available hearing device setting being associated with one of the at least two control levels. The hearing device settings may include settings for a single parameter as e.g. volume, or settings for a set of several parameters, like filter settings, loudness, balances, etc.

[0012] The available hearing device settings stored in the database may include a control level associated with the respective hearing device setting in which case the step of associating the updated hearing device setting with a control level simply requires obtaining and utilizing the corresponding information of the database. In case the updated hearing device setting is generated at runtime, the step of associating the updated hearing device setting with a control level may include e.g. associating the control level procedurally according to a predefined set of rules or may include obtaining an associated control level e.g. from a lookup table in which control levels are assigned to certain hearing device settings. The hearing system may implement one or more machine learning algorithms, like a trained neuronal network, which perform the determination and monitoring of the hearing situation and/or the selection of the updated hearing device setting. The algorithm may be executed in the hearing device, in a user or mobile device such as user's smartphone or in the cloud i.e. on one or several remote server or a combination thereof.

[0013] The database may be provided only for one user or may be provided for several users with several hearing devices. Such a database may comprise hearing device settings and their changes for a plurality of users. The device settings may be stored in the database, together with information, in which hearing situation the settings should be applied and for which users, in particular depending on user profiles and medical conditions like the hearing loss type, the amount of hearing loss, i.e. the user related data.

[0014] The control system is further configured to query the control entity assigned to the control level associated with the updated hearing device setting for approval of the updated hearing device setting and, upon approval, allow the hearing system to apply the updated hearing device setting; and subsequently notify at least the control entity assigned to the next higher control level about the application of the updated hearing device setting if the control system comprises a next higher control level. In such a way, the user can be protected by changes in the hearing device setting, which may be not beneficial, i.e. may not help the user to compensate his or her hearing loss and/or which may be dangerous for him. For example, the volume of a hearing device may not be turned up as high for a user with a mild hearing loss compared to a user with a severe hearing loss.

[0015] Control entities assigned to a control level can be algorithms, for instance machine learning algorithms, in particular algorithms implementing an artificial intelligence, or persons as e.g. a user, a designated caretaker or an HCP. Control entities can also be collective entities as e.g. a manufacturer or a regulating body. Algorithms particularly may be control entities assigned to the lowest available control level whereas a regulatory body and/or manufacturer may be the control entity assigned to the highest available control level.

[0016] There may be several hierarchically ordered control levels with different assigned control entities. "Hierarchical ordering" herein refers to a well-defined ordering of the control levels such that each control level - besides a highest control level - has exactly one next higher control level. The hierarchical ordering can be defined by an authorization that is required to apply a setting associated with the respective control level. Typically, higher control levels are authorized to apply settings of a lower control level whereas lower control levels are not authorized to apply settings associated with a higher control level. For instance, a user may be authorized to apply personalized settings of the hearing device whereas the HCP may be authorized to change personalized settings as well as fitting parameters related to the hearing loss of the user (which the user is not authorized to change). The regulatory body or manufacturer may e.g. be authorized to change hearing device related properties as e.g. a maximum allowable or achievable gain which the HCP is not authorized to change.

[0017] If a certain control level does not have sufficient authority to apply specific settings, such settings may be proposed to a control entity assigned to a higher control level which can approve and apply such settings by way of its higher authority.

[0018] For safety reasons, the control level associated with a particular setting for one or more parameters may be related to the required deviation from the actual settings in some embodiments. For example, the volume may be increased solely within a specific margin by the user, but within a wider margin by the HCP, etc. The same may apply to other parameters. As such, the control level assigned to a particular setting may be determined at runtime, based on the required deviation from the actual settings. The associated control level can be procedurally determined or can be read e.g. from a lookup table stored in the memory of the hearing system. This enhances the safety of the hearing device by avoiding to increase a hearing loss of the user by harmful settings or settings that may be harmful due to too big or sudden a change. Furthermore, when the selection of the settings is done automatically, the control entity of the next higher control level receives a corresponding notification and may check, whether the applied selection is beneficial. Alternatively, the selection of setting can be proposed to the control entity of the next higher control level and may be

approved by this control entity.

[0019] The machine learning algorithm may be trained as to which settings to propose or to apply in a given hearing situation and/or for a given condition of the user. The machine learning algorithm may be trained with historical data of the user of the hearing device and/or with data from a plurality of users obtained via a data sharing network. For example, the machine learning algorithm may be trained to propose a specific setting with a higher probability when the respective setting is satisfactory for a lot of users in the same or a comparable hearing situations.

[0020] New hearing device settings, which may be made by the user or the HCP, etc. can be included into the database and/or optional additional database and the machine learning algorithm can evaluate, whether these settings are satisfactory in specific situations or not. The new settings also can be included into the training process of the machine learning algorithm.

[0021] The improvements of the hearing device settings can either be audiological improvements or usability improvements.

[0022] Audiological improvements may comprise preferences of user in specific environments based on sensor measurements (microphone, accelerometer, GPS location, biometry sensors, ...), for example when working, travelling, listen to music, doing sports.

[0023] Usability improvements may comprise: e.g. adapting /changing timing of user interactions (responsivity, etc.) based on an user interaction history (e.g., many corrective adjustments) and/or emotion/health (e.g., shaking/trembling) measured by a biometry sensor.

[0024] According to an embodiment the control system comprises a control unit, the control unit being one control entity or being associated with a control entity. Thus, there may be for example a first lower-level control entity being a control unit associated with or included in the hearing device and a second, next higher level control entity may be the user. A control unit may be associated with the user, which is in particular a control entity assigned to a second control level. The control unit may implement an algorithm, in particular a machine learning algorithm, which provides for the functionality of a control entity.

[0025] The user may receive a notification with a suggestion for new possible settings for the hearing device based on the machine learning algorithm and sensor measurement. The user feedbacks, whether he applies the new setting(s) and whether also keeps them on the long run will then be used as well to improve future recommendation(s). This information may be included into the training of the machine learning algorithm.

[0026] The notification(s) can be provided to the user either on an app, or directly by the hearing device (e.g. as a voice message) or by a message sent to the user, for example a notification sent to the user device resp. mobile device. Such a notification may be displayed on the user device.

[0027] According to an embodiment, the control system includes at least three control levels, such as three control levels or four control levels.

[0028] A control entity assigned to a lowest, first control level may correspond to the control unit, and/or a control entity assigned to a next higher, second control level may correspond to a user of the hearing system and/or a further device of the hearing system, and/or a control entity assigned to a next higher, third control level may correspond to an HCP or a caretaker, and/or a control entity assigned to a next higher, fourth control level may correspond to a regulatory body or a manufacturer. A respective control unit may be associated with each of the control levels and/or control entities.

[0029] The HCP may get notified as well about the recommended and/or accepted changes of the hearing device settings. The notification can be sent to the HCP, in particular to a device, e.g. computer device, of the HCP as message whenever the user gets this information. Alternatively, the message is stored and the HCP is notified when the user is the next time at the HCP office, thus e.g. when the hearing device is connected to a device of the HCP.

[0030] According to an embodiment, the hearing system includes interfaces or is communicatively coupled to interfaces for presenting information to and receiving information from one or more of the control entities. In particular, the information may be displayed on a screen of the user device or on a device of the HCP or other control entity.

[0031] According to an embodiment, the status of the hearing system is based on sensor data acquired by the hearing system. For example, the status of the hearing system includes a motion status and/or a temperature.

[0032] According to an embodiment, the hearing situation is determined and monitored by classifying sensor data acquired by the hearing system and optional the user related data, which is stored in the hearing system, in particular the hearing device. As an example, the audio data acquired by the hearing device may be classified to determine, what kind of sounds the user is hearing in the moment. Such hearing situations may distinguish between speech and music. As a further example, motion data or position data may be classified, whether the user is walking, riding or going by car.

[0033] According to an embodiment, the sensor data comprises audio data acquired with a microphone of the hearing system and the audio data is classified with respect to different sound situations as hearing situations.

[0034] According to an embodiment, the sensor data comprises position data acquired with a position sensor of the hearing system and the position data is classified with respect to different locations and/or movement situations of the user as hearing situations.

[0035] According to an embodiment, the sensor data comprises medical data acquired with a medical sensor of the

hearing system and the medical data is classified with respect to different medical conditions of the user as hearing situation.

[0036] According to an embodiment, the user related data comprises information on a hearing loss of the user and/or an audiogram of the user. The user related data also may comprise settings of a sound processing of the hearing system, in particular, the hearing device.

[0037] According to an embodiment, the hearing situation is classified with a first machine learning algorithm. The first machine learning algorithm may be executed in the hearing system, in particular in the hearing device.

[0038] According to an embodiment, the updated hearing device setting is determined with a second machine learning algorithm. The second machine learning algorithm may be executed in a control unit associated with one control entity. The classification of the hearing situation may be sent to the control unit, which then selects the updated hearing device setting from the data base.

[0039] A further aspect of the invention relates to a method for controlling a hearing system and for improving the settings of a hearing device.

[0040] According to an embodiment, the method comprises: determining and monitoring a hearing situation of a user of the hearing system based on a status of the hearing system and user related data; and determining, based on the hearing situation of the user, an updated hearing device setting. For example, based on the hearing situation of the user, an updated hearing device setting may be selected from a database of available hearing device settings, each available hearing device setting being associated with one of the at least two control levels.

[0041] According to an embodiment, the method further comprises: associating the updated hearing device setting with one of the at least two control levels.

[0042] According to an embodiment, the method further comprises: querying the control entity assigned to the control level associated with the updated hearing device setting for approval of the updated hearing device setting, upon approval, allowing the hearing system to apply the updated hearing device setting; and subsequently notify at least the control entity assigned to the next higher control level about the application of the updated hearing device setting, if the control system comprises a next higher control level.

[0043] A further aspect of the invention relates to a computer program for controlling a hearing system, which, when being executed by at least one processor, is adapted to carry out the method such as described above and below. A further aspect of the invention relates to a computer-readable medium, in which such a computer program is stored.

[0044] For example, the computer program may be executed in a processor of the hearing system and/or a hearing device, which hearing device, for example, may be carried by the person behind the ear. The computer-readable medium may be a memory of this hearing system and/or hearing device. The computer program also may be executed by a processor of a mobile device, which is part of the hearing system, and the computer-readable medium may be a memory of the mobile device. It also may be that steps of the method are performed by the hearing device and other steps of the method are performed by the mobile device.

[0045] In general, a computer-readable medium may be a floppy disk, a hard disk, an USB (Universal Serial Bus) storage device, a RAM (Random Access Memory), a ROM (Read Only Memory), an EPROM (Erasable Programmable Read Only Memory) or a FLASH memory. A computer-readable medium may also be a data communication network, e.g. the Internet, which allows downloading a program code. The computer-readable medium may be a non-transitory or transitory medium.

[0046] It has to be understood that features of the method as described in the above and in the following may be features of the computer program, the computer-readable medium and the hearing system as described in the above and in the following, and vice versa.

[0047] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0048] Below, embodiments of the present invention are described in more detail with reference to the attached drawings.

Fig. 1 schematically shows a hearing system according to an embodiment of the invention.

Fig. 2 shows a block diagram of components of the hearing system according to figure 1.

Fig. 3 schematically shows a basic shared control loop between a user and at least one hearing device,

Fig. 4 schematically shows the hearing system with the control system.

Fig. 5 schematically shows control units associated with the different control entities.

Fig. 6 schematically shows a shared control topology.

5 Fig. 7 hierarchical shows a shared control system with four layers.

[0049] The reference symbols used in the drawings, and their meanings, are listed in summary form in the list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

10 DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0050] Fig. 1 schematically shows a hearing system 10 according to an embodiment of the invention. The hearing system 10 includes a hearing device 12 and a user device 14 connected to the hearing device 12. As an example, the hearing device 12 is formed as a behind-the-ear device carried by a user (not shown) of the hearing device 12. It has to be noted that the hearing device 12 is a specific embodiment and that the method described herein also may be performed with other types of hearing devices, such as e.g. an in-the-ear device or one or two of the hearing devices 12 mentioned above. The user device 14 may be a smartphone, a tablet computer, and/or smart glasses.

[0051] The hearing device 12 comprises a part 15 behind the ear and a part 16 to be put in the ear canal of the user. The part 15 and the part 16 are connected by a tube 18. The part 15 comprises at least one sound detector 20, e.g. a microphone or a microphone array, a sound output device 22, such as a loudspeaker, and an input mean 24, e.g. a knob, a button, or a touch-sensitive sensor, e.g. capacitive sensor. The sound detector 20 can detect a sound in the environment of the user and generate an audio signal indicative of the detected sound. The sound detector 20 may be one of the sensors for determining the hearing situation. The sound output device 22 can output sound based on the audio signal modified by the hearing device 12 in accordance with the hearing device settings, wherein the sound from the sound output device 22 is guided through the tube 18 to the part 16. The input mean 24 enables an input of the user into the hearing device 12, e.g. in order to power the hearing device 12 on or off, and/or for choosing a sound program resp. hearing device settings or any other modification of the audio signal.

[0052] The user device 14, which may be a Smartphone, a tablet computer, or Smart glasses, comprises a display 30, e.g. a touch-sensitive display, providing a graphical user interface 32 including control element 32, e.g. a slider, which may be controlled via a touch on the display 30. The control element 32 may be referred to as input means of the user device 14. If the user device 14 are smart glasses, the user device 14 may comprise a knob or button instead of a touch-sensitive display.

[0053] Fig. 2 shows a block diagram of components of the hearing system 10 according to figure 1.

[0054] The hearing device 12 comprises a first processing unit 40. The first processing unit 40 is configured to receive the audio signal generated by the sound detector 20. The hearing device 12 may include a sound processing module 42. For instance, the sound processing module 42 may be implemented as a computer program executed by the first processing unit 40, which may comprise a CPU for processing the computer program. Alternatively, the sound processing module 42 may comprise a sound processor implemented in hardware or more specific a DSP (digital signal processor) for modifying the audio signal. The sound processing module 42 may be configured to modify, in particular amplify, dampen and/or delay, the audio signal generated by the sound detector 20, e.g. some frequencies or frequency ranges of the audio signal depending on parameter values of parameters, which influence the amplification, the damping and/or, respectively, the delay, e.g. in correspondence with a current sound program. The parameter may be one or more of the group of frequency dependent gain, time constant for attack and release times of compressive gain, time constant for noise canceller, time constant for dereverberation algorithms, reverberation compensation, frequency dependent reverberation compensation, mixing ratio of channels, gain compression, gain shape/amplification scheme. A set of one or more of these parameters and parameter values may correspond to a predetermined sound program included in hearing device settings.

[0055] In general, a sound program resp. hearing device settings may be defined by parameters and/or parameter values defining the sound processing of the sound processing module 42, such as the parameters described above. Different sound programs resp. hearing device settings are then characterized by correspondingly different parameters and parameter values.

[0056] A sound program resp. hearing device settings furthermore may comprise a list of sound processing features. The sound processing features may for example be a noise cancelling algorithm or a beamformer, which strengths can be increased to increase speech intelligibility but with the cost of more and stronger processing artifacts.

[0057] The sound output device 22 generates sound from the modified audio signal and the sound is guided through the tube 18 and the in-the-ear part 16 into the ear canal of the user.

[0058] The hearing device 12 may include a control module 44, being a control unit. For instance, the control module 44 may be implemented as a computer program executed by the first processing unit 40. Alternatively, the control module

44 may comprise a control processor implemented in hardware or more specific a DSP (digital signal processor). The control module 44 may be configured for adjusting the parameters of the sound processing module 42, e.g. such that an output volume of the sound signal is adjusted based on an input volume. For example, the user may select a modifier (such as bass, treble, noise suppression, dynamic volume, etc.) and levels and/or values of the modifiers with the input mean 24. From this modifier, an adjustment command may be created and processed as described above and below. In particular, processing parameters may be determined based on the adjustment command and based on this, for example, the frequency dependent gain and the dynamic volume of the sound processing module 42 may be changed.

[0059] All these functions may be implemented as different sound programs stored in a first memory 50 of the hearing device 12, which sound programs may be executed by the sound processing module 42. The first memory 50 may be implemented by any suitable type of storage medium, in particular a non-transitory computer-readable medium, and can be configured to maintain, e.g. store, data controlled by the first processing unit 40, in particular data generated, accessed, modified and/or otherwise used by the first processing unit 40. The first memory 50 may also be configured to store instructions for operating the hearing device 12 and/or the user device 14 that can be executed by the first processing unit 40, in particular an algorithm and/or a software that can be accessed and executed by the first processing unit 40.

[0060] The first memory 50 of the hearing device may be the memory 130 storing instructions according to the present invention and the first processing unit 40 may be the processor 132 of the control system. In particular the database 140 may be stored in the first memory 50. In this case, the hearing system 10 determines and monitors the hearing situation of the user i.a. by the sound detector 20

[0061] The hearing device 12 may further comprise a first transceiver 52. The first transceiver 52 may be configured for a wireless data communication with a remote server 72. Additionally or alternatively, the first transceiver 52 may be adapted for a wireless data communication with a second transceiver 64 of the user device 14. The first and/or the second transceiver 52, 64 each may be e.g. a Bluetooth or RFID radio chip.

[0062] A sound source detector 46 may be implemented in a computer program executed by the first processing unit 40. The sound source detector 46 is configured to determine at least the one sound source from the audio signal. In particular, the sound source detector 46 may be configured to determine a spatial relationship between the hearing device 12 and the corresponding sound source. The spatial relationship may be given by a direction and/or a distance from the hearing device 12 to the corresponding audio source, wherein the audio signal may be a stereo-signal and the direction and/or distance may be determined by different arrival times of the sound waves from one audio source at two different sound detectors 20 of the hearing device 12 and/or a second hearing device 12 worn by the same user.

[0063] A first classifier 48 may be implemented in a computer program executed by the first processing unit 40. The first classifier 48 can be configured to evaluate the audio signal generated by the sound detector 20. The first classifier 48 may be configured to classify the audio signal generated by the sound detector 20 by assigning the audio signal to a class from a plurality of predetermined classes. The first classifier 48 may be configured to determine a characteristic of the audio signal generated by the sound detector 20, wherein the audio signal is assigned to the class depending on the determined characteristic. For instance, the first classifier 48 may be configured to identify one or more predetermined classification values based on the audio signal from the sound detector 20. The classification may be based on a statistical evaluation of the audio signal and/or a machine learning algorithm that has been trained to classify the ambient sound, e.g. by a training set comprising a huge amount of audio signals and associated classes of the corresponding acoustic environment. So, the machine learning algorithm may be trained with several audio signals of acoustic environments, wherein the corresponding classification is known.

[0064] The first classifier 48 may be configured to identify at least one signal feature in the audio signal generated by the sound detector 20, wherein the characteristic determined from the audio signal corresponds to a presence and/or absence of the signal feature. Exemplary characteristics include, but are not limited to, a mean-squared signal power, a standard deviation of a signal envelope, a mel-frequency cepstrum (MFC), a mel-frequency cepstrum coefficient (MFCC), a delta mel-frequency cepstrum coefficient (delta MFCC), a spectral centroid such as a power spectrum centroid, a standard deviation of the centroid, a spectral entropy such as a power spectrum entropy, a zero crossing rate (ZCR), a standard deviation of the ZCR, a broadband envelope correlation lag and/or peak, and a four-band envelope correlation lag and/or peak. For example, the first classifier 48 may determine the characteristic from the audio signal using one or more algorithms that identify and/or use zero crossing rates, amplitude histograms, auto correlation functions, spectral analysis, amplitude modulation spectrums, spectral centroids, slopes, roll-offs, auto correlation functions, and/or the like. In some instances, the characteristic determined from the audio signal is characteristic of an ambient noise in an environment of the user, e.g. a noise level, and/or a speech, e.g. a speech level. The first classifier 48 may be configured to divide the audio signal into a number of segments and to determine the characteristic from a particular segment, e.g. by extracting at least one signal feature from the segment. The extracted feature may be processed to assign the audio signal to the corresponding class.

[0065] The first classifier 48 may be further configured to assign, depending on the determined characteristic, the audio signal generated by the sound detector 20 to a class of at least two predetermined classes. The classes may represent a specific content in the audio signal. For instance, the classes may relate to a speaking activity of the user

and/or another person and/or an acoustic environment of the user. Exemplary classes include, but are not limited to, low ambient noise, high ambient noise, traffic noise, music, machine noise, babble noise, public area noise, background noise, speech, nonspeech, speech in quiet, speech in babble, speech in noise, speech in loud noise, speech from the user, speech from a significant other, background speech, speech from multiple sources, calm situation and/or the like.

The first classifier 48 may be configured to evaluate the characteristic relative to a threshold. The classes may comprise a first class assigned to the audio signal when the characteristic is determined to be above the threshold, and a second class assigned to the audio signal when the characteristic is determined to be below the threshold. For example, when the characteristic determined from the audio signal corresponds to ambient noise, a first class representative of a high ambient noise may be assigned to the audio signal when the characteristic is above the threshold, and a second class representative of a low ambient noise may be assigned to the audio signal when the characteristic is below the threshold. As another example, when the characteristic determined from the audio signal is characteristic of a speech, a first class representative of a larger speech content may be assigned to the audio signal when the characteristic is above the threshold, and a second class representative of a smaller speech content may be assigned to the audio signal when the characteristic is below the threshold.

[0066] At least two of the classes can be associated with different sound programs i.e. hearing device settings, in particular with different sound processing parameters, which may be applied by the sound processing module 42 for modifying the audio signal. To this end, the class assigned to the audio signal, which may correspond to a classification value, may be provided to the control module 44 in order to select the associated audio processing parameters, in particular the associated sound program, which may be stored in the first memory 50. The class assigned to the audio signal may thus be used to determine the sound program, which may be proposed as updated hearing device settings by the control system 100, in particular depending on the audio signal received from the sound detector 20.

[0067] The hearing device 12 may further comprise a first transceiver 52. The first transceiver 52 may be configured for a wireless data communication with a remote server 72. Additionally or alternatively, the first transceiver 52 may be adapted for a wireless data communication with a second transceiver 64 of the user device 14. The first and/or the second transceiver 52, 64 each may be e.g. a Bluetooth or RFID radio chip.

[0068] Each of the sound processing module 42, the control module 44, the sound source detector 46, and the first classifier 48 may be embodied in hardware or software, or in a combination of hardware and software. Further, at least two of the modules 42, 44, 46, 48 may be consolidated in one single module or may be provided as separate modules. The first processing unit 40 may be implemented with a single processor or with a plurality of processors. For instance, the first processing unit 40 may comprise a first processor in which the sound processing module 42 is implemented, and a second processor in which the control module 44 and/or the sound source detector 46 and/or the first classifier 48 are implemented. The first processing unit 40 may further comprise the processor 132 for executing the control system 100 as a further processor. Alternatively the one of first or second processor may be used as processor 132.

[0069] The user device 14, which may be connected to the hearing device 12 for data communication, may comprise a second processing unit 60 with a second memory 62, and a second transceiver 64.

[0070] The second processing unit 60 may comprise one or more processors, such as CPUs. If the hearing device 12 is controlled via the user device 14, the second processing unit 60 of the user device 14 may be seen at least in part as a controller of the hearing device 12. In other words, according to some embodiments, the first processing unit 40 of the hearing device 12 and the second processing unit 60 of the user device 14 may form the controller of the hearing device 12. A processing unit of the hearing system 10 may comprise the first processing unit 40 and the second processing unit 60. Thus, first and second processing unit may form the processor 132.

[0071] The second processing unit 60 and the second memory 62 may be alternatively processor 132 and memory 130 according to the present invention. In particular the database 140 may be stored in the second memory 62.

[0072] The hearing device 12 and the user device 14 and in particular the processing units 40, 60 may communicate data via the first and second transceivers 52, 64, which may be Bluetooth[®] transceivers. The hearing device 12 and the user device 14 may be connected for data communication via a wireless data communication connection.

[0073] With the hearing system 10 it is possible that the above-mentioned modifiers and their levels and/or values are adjusted with the user device 14 and/or that an adjustment command is generated with the user device 14 and sent to the hearing device 12. This may be performed with a computer program run in the second processing unit 60 and stored in the second memory 62 of the user device 14. This computer program may also provide the graphical user interface 32 on the display 30 of the user device 14. For example, for adjusting the modifier, such as volume, the graphical user interface 32 may comprise the control element 34, such as a slider. When the user adjusts the slider, an adjustment command may be generated, which will change the sound processing of the hearing device 12. Alternatively or additionally, the user may adjust the modifier with the hearing device 12 itself, for example via the input mean 24.

[0074] The hearing device 12 and/or the user device 14 may communicate with each other and/or with the remote server 72 via the Internet 70. The method explained below may be carried out at least in part by the remote server 72. For example, processing tasks, which require a huge amount of processing resources, may be outsourced from the hearing device 12 and/or the user device of 14 to the remote server 72. Further, the processing units (not shown) of the

remote server 72 may be used at least in part as the controller for controlling the hearing device 12 and/or the use device 14. Thus, the processor 132 for executing the control system of the hearing system as well as the memory 130 may be at least partially located on the remote server 72.

[0075] The user device 14 may comprise a second classifier 66 and/or a further module 68.

[0076] The second classifier 66 may have the same functionality as the first classifier 48 explained above and/or also may be based on a machine learning algorithm. The second classifier 66 may be arranged alternatively or additionally to the first classifier 48 of the hearing device 12. The second classifier 66 may be configured to classify the acoustic environment of the user and the user device 14 depending on the received audio signal, as explained above with respect to the first classifier 48, wherein the acoustic environment of the user and the user device 14 corresponds to the acoustic environment of the hearing device 12 and wherein the audio signal may be forwarded from the hearing device 12 to the user device 14. The system as explained here may thus comprise a certain number of classifiers, for example classifying movement, time, noise, environment for describing the possible hearing situations of the user.

[0077] In the following an embodiment of the method of the control system 100 of the hearing system 10 is described along with Fig. 3.

[0078] The hearing system 10 as shown in Fig. 4 according to the present invention is configured for determining and monitoring a hearing situation of a user of the hearing system 10 based on a status of the hearing system 10 and user related data stored in the memory 132. The memory 132 may be the first memory 50 or the second memory 62 or even a memory on a remote server or a combination of first memory 50 and/or the second memory 62 and/or even a memory on a remote server 72. The method is now explained with reference to Fig. 3.

[0079] When the hearing system 10 is started by the user for example by switching the hearing device 12 to on the routine starts in step S2. The hearing system 10 includes a control system 100 further including a processor 132 and a memory 130. In step S4, the control system 100 determines the hearing situation of the user in particular with internal and/or external sensors. Internal sensors are in particular the sound detector 20 and/or sound source detector 42. Furthermore, there may be other sensors like motion sensors, health sensors, such as blood pressure sensors, heart beat sensors, etc. or temperature sensors which may be either included in the hearing device 12 or in the user device 14. If the user device 14 is for example a smart phone, such a smartphone itself typically includes a microphone and a motion sensor and may have a temperature sensor.

[0080] The hearing situation may be determined by the hearing device 12 alone, by the user device 14 or with both the hearing device 12 and the user device 14.

[0081] If the hearing system includes the first and/or second classifiers 48, 66 or even further classifiers, those may be applied to classify the hearing situation.

[0082] The hearing situation may be classified with a first machine learning algorithm provided by the first classifier 48 and/or the second classifier 66.

[0083] Based on the hearing situation and user related data, the control system selects from the database 140, as depicted in Fig. 4, a hearing device setting in step 6. The database 140 comprises hearing device settings 142, 144. If this hearing device setting is equal to the used hearing device setting 142, no change is required, and the loop returns to step S4. If the hearing device setting is different from the used one, it is an updated hearing device setting 144, which is selected.

[0084] The database 140 may be stored in the hearing system 10 or in a control unit associated with one control entity. For example, the server 72 may be such a control unit.

[0085] The updated hearing device setting 144 may be determined with a second machine learning algorithm, which is executed in a control unit associated with one control entity.

[0086] The classification of the hearing situation, which has been generated by the first machine learning algorithm may be sent to the control unit and may be used there as input to the second machine learning algorithm.

[0087] In step S8, the control system 100 determines, which control level the updated hearing device setting is assigned to. Each of the available hearing settings is assigned to one control level.

[0088] The control system 100 is a hierarchical control system.

[0089] Typically, in such a hierarchical control framework, inner layers/loops run at higher frequency than outer layers/loops. Notifications or feedback can happen instantaneously or may be batched (e.g., as summary report). The notification and feedback can be applied on the hearing device directly or alternatively on third devices, such as smartphones that provide a display to highlight and type, or computer terminals that close the control loop via connection to the cloud. Thus, in particular by a message send to the user or HCP. Feedbacks allow to acknowledge, rate, override, oversteer, revert single changes or roll back multiple changes in history at several layers in hierarchy. They can be triggered by the user right on the device or by an actor at higher layer indirectly via remote connection (via proxies like cloud, smartphones, fitting stations at HCPs). They can be actively submitted by the user on the devices as explicit feedbacks but may also happen implicitly as the hearing devices observe the user, its behavior and interactions with the hearing devices. The feedback to the hearing devices can also be given by speech: either actively by the user via voice control or passively by having the hearing devices monitor the user's speech in daily conversations and detect

keywords that indicate some reinforcement, rejection or hint regarding an applied functional change or future change still to be applied. These feedbacks shall help to personalize the steering of the hearing device, enable learning but also forgetting (which is important for lifelong learning systems), safeguard regulatory aspects with respect to machine learning algorithm (as user has the final say through shared control and override mechanism) and make the hearing device a self-aware system that applies changes where it can do or initiates queries to higher control levels.

[0090] In step S10, the control system 100 initiates a query to the control entity 120, 122, 124, 126 assigned to the respective hearing setting. The query can be sent for example as a message.

[0091] As depicted in fig. 5, the control entity 120 may be associated with the control unit 150, which may be the control module 44 of the hearing device 12. The control entity 122 is associated with a control unit 152 or 152', wherein the control unit 152 is for example implemented into a smartphone of the user or the control unit 152' is for example implemented in a computer of the user. The control entity 154, may be the HCP, can be associated with the control unit 154, which is implanted in a computing device of the HCP and the control entity 156 may be associated with a control unit 156, wherein the control entity 156 may be a regulatory body or manufacturer. Thus a query may be either send by a direct (wireless connection) as depicted between the user device 14 and the hearing device 12 or via a network connection, e.g. internet 70, as depicted for the control units 152', 154 and 156.

[0092] Upon approval, the hearing system 10 is allowed to apply the updated hearing device setting. If the update is not allowed, the hearing system returns to step S4. If the updated hearing device setting is applied, the control system subsequently notifies at least the control entity assigned to the next higher control level about the application of the updated hearing device setting in step S12 if the control system comprises a next higher control level. This notification can be either send directly or may be batched. Thus, the new settings are applied. Now either the routine ends with step S14, for example by switching the hearing system off, or returns to step S4, if a continuous monitoring is exhibited.

[0093] The notifications to the next higher control entity cover functional changes (e.g., new functions, modes, configuration settings) that have already been applied and are perceivable for the user, that are suggested by the hearing devices (aka recommender systems) based on user history (e.g., user interaction history) or context (e.g., sensed acoustic environments a user stays in during the day). There may be further notifications to a control entity that are enforced by an entity of a higher control level in future. A notification may also comprise several options for the user to choose from (e.g., to apply and test out, eventually rate and single out the preferred one). These notifications shall improve the transparency of the system towards the user.

[0094] The basic shared control loop as shown in Fig. 3 is a loop between user and at least one hearing device 12. The hearing device 12 may comprise at least one processing unit dedicated to AI, like a deep neural network processor, and one or several sensors and user interactions. Machine learning may happen during operation on the hearing devices or a third connected device, based on data sensed by the hearing device sensors or data obtained by the user interacting with the hearing device. Further data may be prescribed, defining preconditions (e.g., severity or type of hearing loss, user type) for learning from the sensed or user/usage data, or itself being the output from learning algorithms applied to other data sources offline (e.g., deep neural network models trained on other user data from manufacture's database). The user and the hearing devices are both involved in steering the system behavior: the user receives notifications with information about system functions applied or recommended to be applied from the hearing device resp. hearing system, the hearing system receives feedback from the user (acknowledge, revert and roll back, override), from which it can learn further.

[0095] The control system 100 shows that the processor 132 is communicatively coupled with the memory 130, not depending on whether processor 132 and memory 130 are assigned directly to the hearing device or to another device as discussed above. The processor communicates with the different control entities 120, 122, 124, 126, which may be for example assigned as control entity 120 being the control module 44, control entity 122 being the user, control entity 124 being the HCP and control entity 126 being the manufacturer or a regulatory body.

[0096] Figure 6 shows a hierarchical (respectively layered) shared control topology with an inner control loop, comprising the shared control among the user and the hearing devices according to Figure 3. The hearing device constitutes the lowest control level 110 with control entity 120. The user constitutes the next higher control level 112 with control entity 122. The shared control topology further comprises an outer control loop, comprising the shared control among the hearing care professional (HCP) and the system of the user and the hearing devices, wherein the HCP constitutes a third level 114, the HCP being the third control entity 124. The HCP may receive notifications from the system about changes applied or suggested, and can act upon them by triggering recommendations for the user, enabling new functions or features, adjusting configuration settings or enforcing hard bounds on the configuration space for the user as well as the steering units of the hearing devices. The optional fourth level 116 is constituted by the control entity 116, which may be for example the manufacturer, e.g. limiting the learning and changing of device settings.

[0097] Figure 7 shows another embodiment of the hierarchical shared control system with three layers and several actors on each layer. In addition to Figure 5, there are additional actors on the outmost layer, such as a regulatory body (e.g., a public health authority or the US food and drug administration) or a manufacturer (e.g., a hearing device manufacturer like Sonova), which may receive notifications from the underlying system of applied configuration settings,

exercised working modes, provided quality guarantees or compliance with regulations, specifications or best practice guidelines. In turn being able to influence and partially control the underlying system by providing approval or additional support (e.g., provision of an additional deep neural network model for a desired concrete use case by the manufacturer), or simply enforcing the abidance of their requirements. On the inner layers, also one or more additional actors may be present compared to Figure 5. Besides the HCP, significant others or family members may be informed or provide control inputs to the underlying system. Besides the main user of the hearing devices, other hearing device users or the community of hearing device wearers or hearing impaired may be involved in the shared control of the hearing devices or other accessories that connect to the hearing devices (e.g., remote microphones, smart chargers or mobile apps on a smart-phone). For example, hearing devices of different users may connect to each other to exchange control inputs or notifications for the user. Alternatively, or additionally feedback from other users or the hearing device wearer community may find its way via the manufacturer's ICT infrastructure to the user's hearing devices. Feedback and notifications may be exchanged between user and accessory, resulting in shared control among user and accessory itself or indirectly among user and hearing devices again, using the accessory as a proxy.

[0098] The hearing system as described above provides in the different embodiments one or more of the following benefits:

The machine learning algorithm is improved by collecting feedback (e.g., ratings, acknowledgments) from users for applied configurations and configuration changes, which can be used as labels for learning (knowledge about true improvements); a bad rating or a user's veto could also indicate uncertainty of the steering unit and a need for gathering more representative data for the given situation.

[0099] The machine learning algorithm learns users' preferences. It can use them for abstraction of user groups/profiles, provide recommendations/predictions to users based on their own and/or other users' feedback, as well as environmental clues as part of the hearing situation of the user from sensor measurements, which helps to increase users' convenience and hearing devices' performance (i.e., continuous adjustments in the field to make up for potentially limited product requirements/verification of the AI system) The users interacts with the system and thus set their requirements which leads to a user-centered/driven customized settings and takes care of personalized requirements quasi a posteriori).

[0100] The inclusion of a machine learning algorithm in the system is in particular beneficial, if the AI can learn from the preferences and data of a multitude of users providing heterogeneous data.

[0101] The safety of the system is enhanced by having human control entities at several levels (user himself, experts like HCP, manufacturer, regulatory body) to acknowledge decisions by machine learning algorithm to ensure compliance with medical regulations (medical safety, application/network security) and/or performance as intended, i.e., according to requirements/specification (machine learning algorithm safety as well as machine learning algorithm security: increase users' safety/security and hearing devices' quality, eventual verification - according to users' requirements - to make up for limited product verification of machine learning algorithm systems and anticipate unexpected situations as quasi verification of the "black box" in the field through experts instances).It also remedies inherent limitations of the machine learning algorithm of missing determinism and transparency (e.g. what has been learnt exactly) and its predictions implying uncertainty.

[0102] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art and practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or controller or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

LIST OF REFERENCE SYMBOLS

[0103]

- 10 hearing system
- 12 Hearing device
- 14 User device
- 15 part behind the ear
- 16 part to be put in the ear
- 18 tube
- 20 sound detector
- 22 device

24	input mean	
30	display	
32	control element	
5 34	control element	
40	first processing unit	
42	sound module	
44	control module	
10 46	sound source detector	
48	first classifier	
50	first memory	
52	first transceiver	
15 60	second processing unit	
62	second memory	
64	second transceiver	
66	second classifier	
70	Internet	
20 72	remote server	
100	control system	
110, 112, 114, 116	control level	
120, 122, 124, 126	control entity	
130	memory	
25 132	processor	
140	database	
142	hearing device settings	
144	updated hearing device settings	
150, 152, 154, 156	control unit	
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Claims

1. A hearing system (10) including a hearing device (12),

the hearing system (10) implementing a hierarchical control system with at least two hierarchical ordered control levels (110, 112, 114, 116), wherein at least one control entity (120, 122, 124, 126) is assigned to each of the control levels (110, 112, 114, 116),
the hearing system (10) including:

a memory (130) storing instructions, and
a processor (132) communicatively coupled to the memory (130) and configured to execute the control system (100) and the following instructions:

determining and monitoring a hearing situation of a user of the hearing system (10) based on a status of the hearing system (10) and user related data stored in the memory (130); and
determining, based on the hearing situation of the user, an updated hearing device setting (144), associating the updated hearing device setting (144) with one of the at least two control levels, wherein the hierarchical control system (100) is configured to
query the control entity (120, 122, 124, 126) assigned to the control level (110, 112, 114, 116) associated with the updated hearing device setting (144) for approval of the updated hearing device setting (144), upon approval, allow the hearing system (10) to apply the updated hearing device setting (144); and, notify the control entity (120, 122, 124, 126) assigned to the next higher control level about the application of the updated hearing device setting (144) if the hierarchical control system (100) comprises a next higher control level.

2. The hearing system (10) according to claim 1,

wherein a user or a HCP or a regulatory body or a manufacturer is chosen as control entity (120, 122, 124, 126), and/or
 wherein the control system (100) comprises a control unit, the control unit being one control entity (120, 122, 124, 126) or being associated with one control entity (120, 122, 124, 126).

3. The hearing system (10) according to claim 1 or 2,

wherein the control system (100) includes at least three control levels, and a control entity (120) assigned to a lowest, first control level (110) corresponds to the control unit, and/or
 a control entity (122) assigned to a next higher, second control level (112) corresponds to a user of the hearing system (10) and/or a further device of the hearing system (10), and/or
 a control entity (124) assigned to a next higher, third control level (114) corresponds to an HCP or a care taker, and/or
 a control entity (126) assigned to a next higher, fourth control level corresponds to a regulatory body or a manufacturer.

4. The hearing system (10) according to one of the preceding claims,
 the hearing system (10) including interfaces or being communicatively coupled to interfaces for presenting information to and receiving information from one or more of the control entities (110, 112, 114, 116).

5. The hearing system (10) according to one of the preceding claims,

wherein the status of the hearing system (10) is based on sensor data acquired by the hearing system (10); and/or
 wherein the hearing situation is determined and monitored by classifying sensor data acquired by the hearing system (10) and the user related data.

6. The hearing system (10) according to claim 5,

wherein the sensor data comprises audio data acquired with a microphone (20) of the hearing system (10) and the audio data is classified with respect to different sound situations as hearing situations; and/or
 wherein the sensor data comprises position data acquired with a position sensor of the hearing system (10) and the position data is classified with respect to different locations and/or movement situations of the user as hearing situations; and/or
 wherein the sensor data comprises medical data acquired with a medical sensor of the hearing system (10) and the medical data is classified with respect to different medical conditions of the user as hearing situation.

7. The hearing system (10) according one of the previous claims,

wherein the user related data comprises information on a hearing loss of the user and/or an audiogram of the user; and/or
 wherein the user related data comprises settings of a sound processing of the hearing system (10).

8. The hearing system (10) according to one of the preceding claims,

wherein the hearing situation is classified with a first machine learning algorithm (48, 66);
 wherein the first machine learning algorithm (48, 66) is executed in the hearing system (10).

9. The hearing system (10) according to one of the preceding claims,

wherein the updated hearing device setting (144) is determined with a second machine learning algorithm;
 wherein the second machine learning algorithm is executed in a control unit associated with one control entity and wherein the classification of the hearing situation is sent to the control unit.

10. A method for controlling a hearing system (10) implementing a hierarchical control system with at least two control levels (110, 112, 114, 116), wherein at least one control entity (120, 122, 124, 126) is assigned to each of the control levels, the method comprising:

determining and monitoring a hearing situation of a user of the hearing system (10) based on a status of the

hearing system (10) and user related data; and
determining, based on the hearing situation of the user, an updated hearing device setting (144),
associating the updated hearing device setting (144) with one of the at least two control levels,
querying the control entity (120, 122, 124, 126) assigned to the control level (110, 112, 114, 116) associated
5 with the updated hearing device setting (144) for approval of the updated hearing device setting (144),
upon approval, allowing the hearing system (10) to apply the updated hearing device setting (144); and,
subsequently notify at least the control entity (120, 122, 124, 126) assigned to the next higher control level about
the application of the updated hearing device setting (144) if the control system (100) comprises a next higher
control level.

10 **11.** A computer program for controlling a hearing system, which, when being executed by at least one processor, is
adapted to carry out the steps of the method of claim 10.

15 **12.** A computer-readable medium, in which a computer program according to claim 11 is stored.

FIG. 1

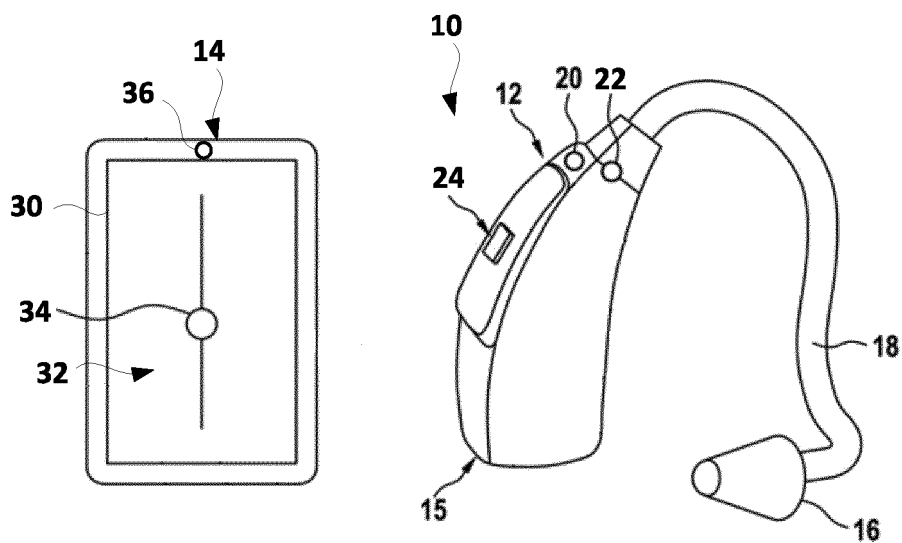


FIG. 2

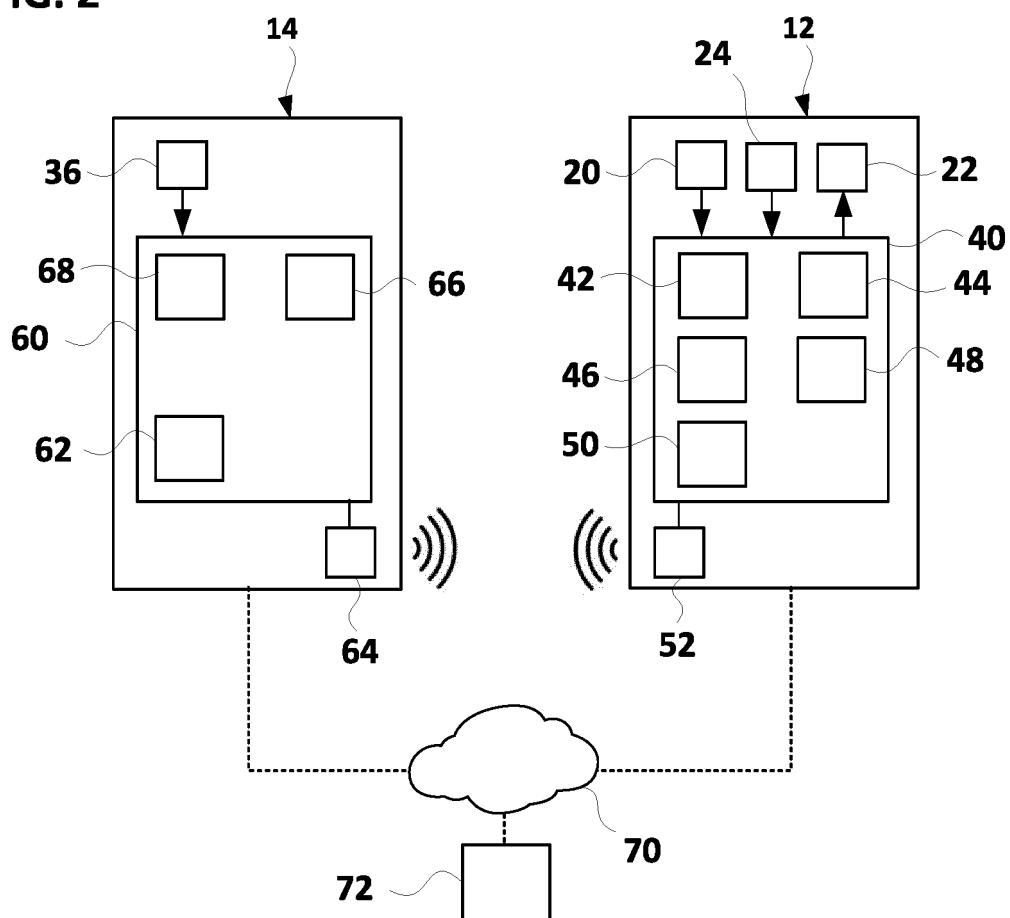


FIG. 3

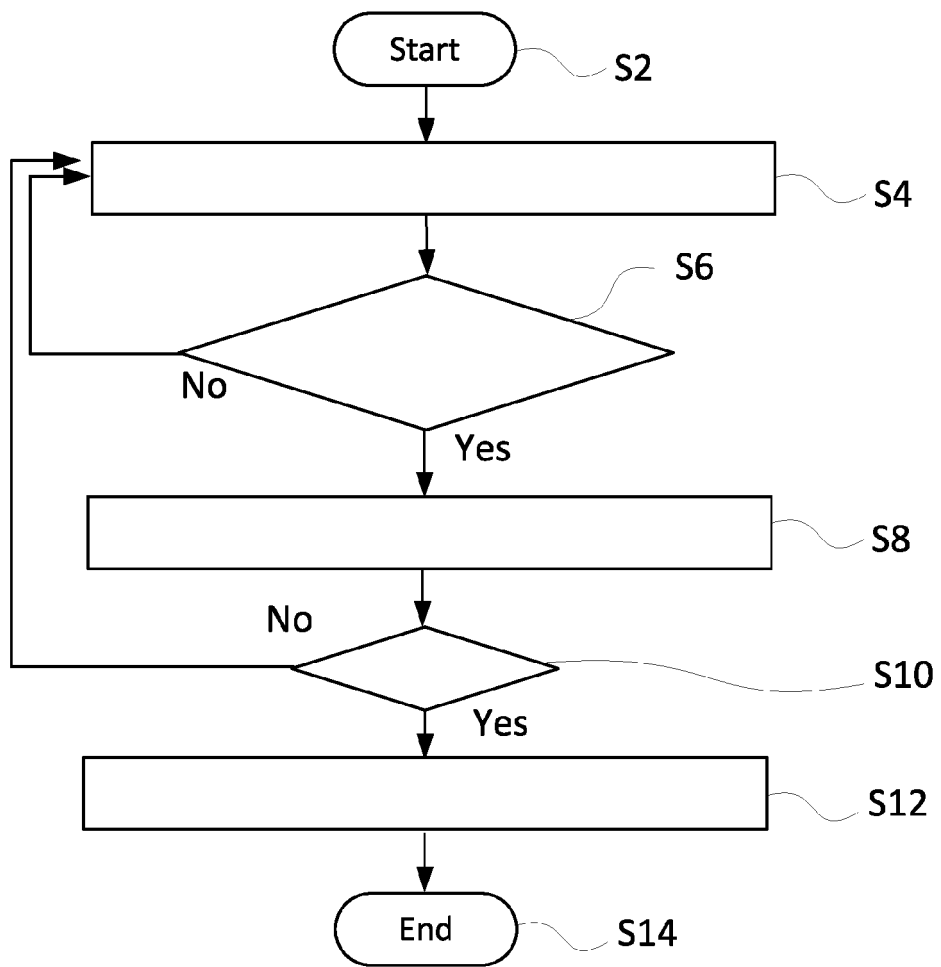


FIG. 4

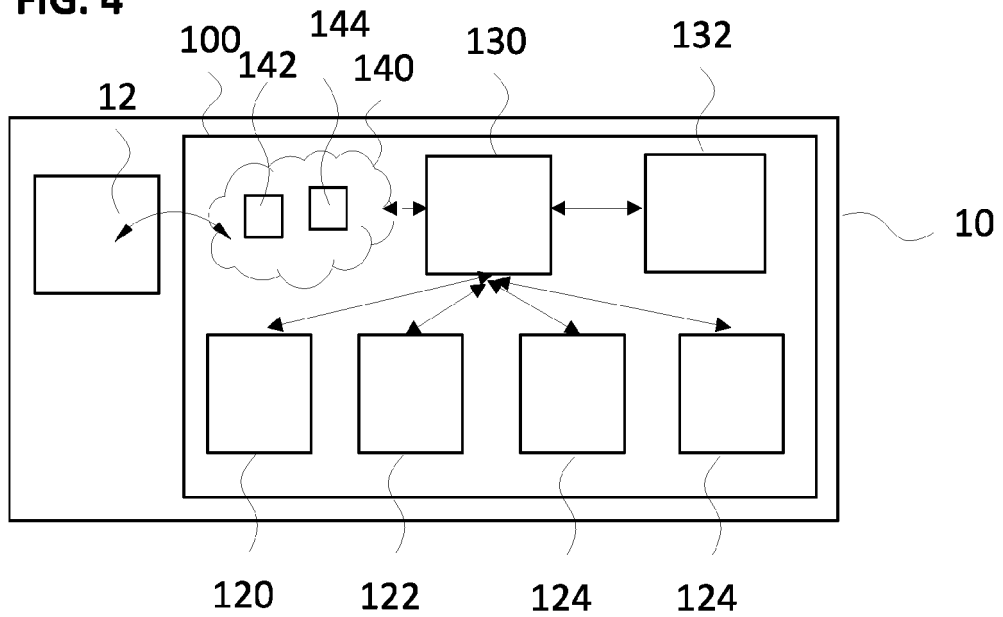


FIG. 5

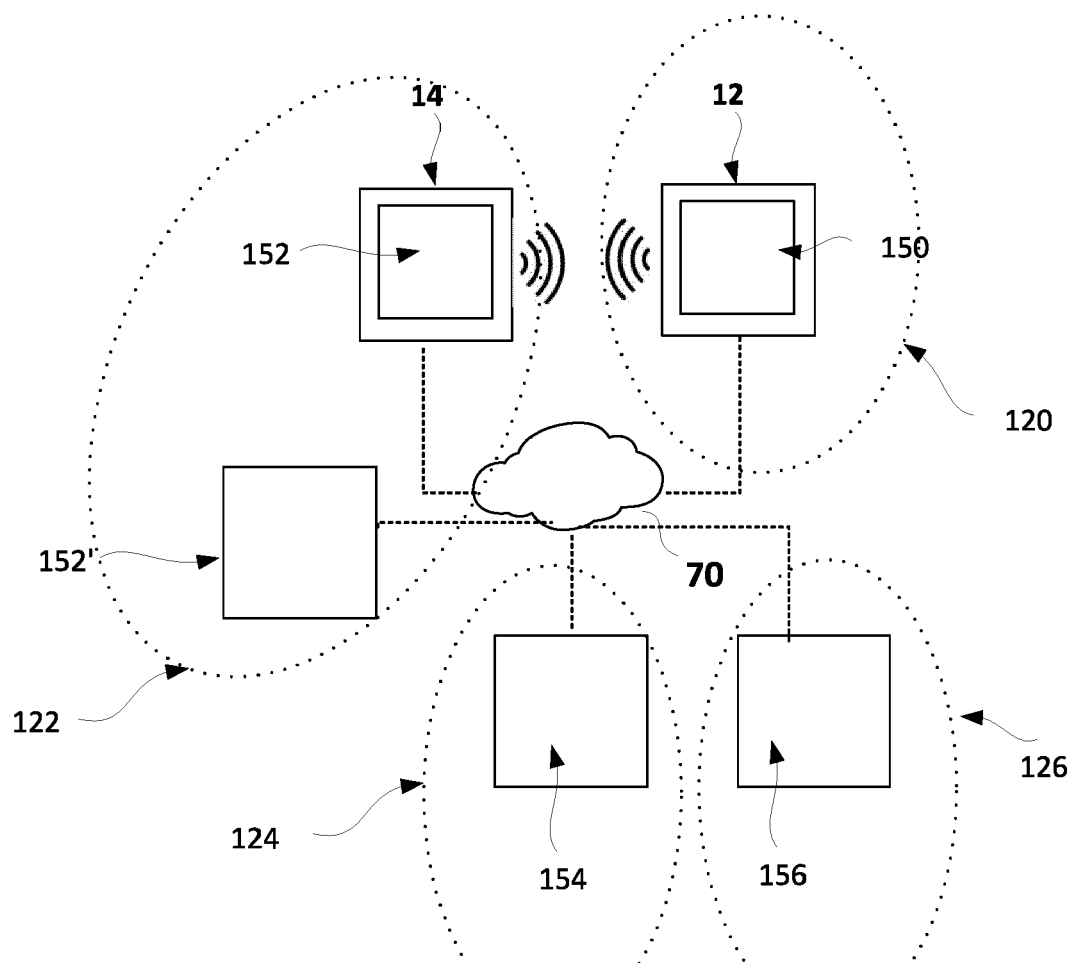


FIG. 6

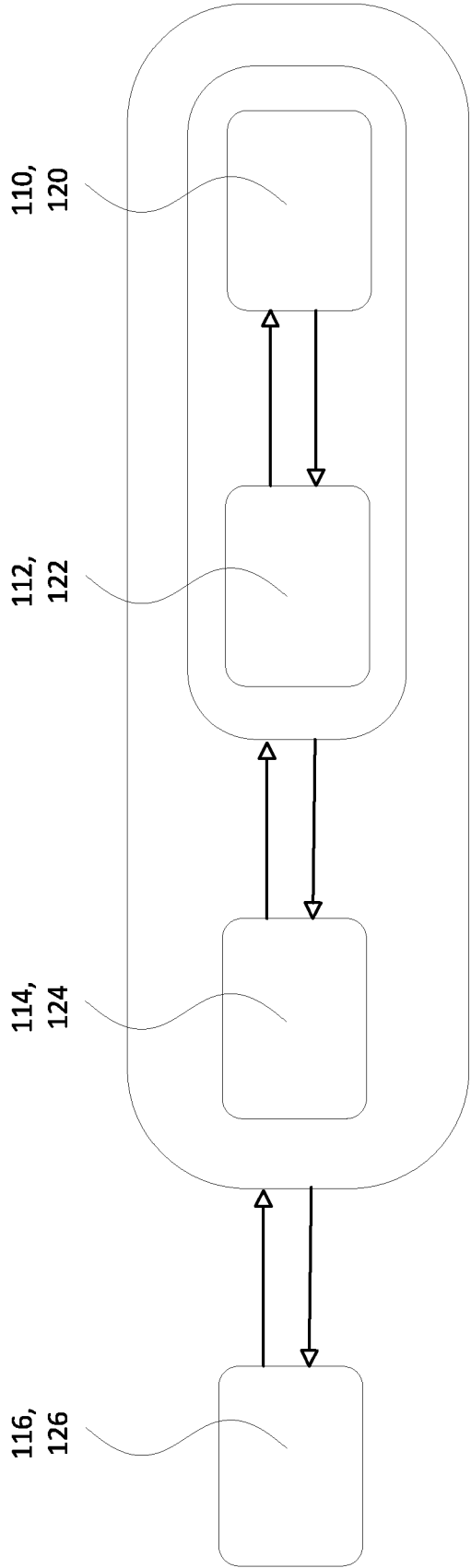
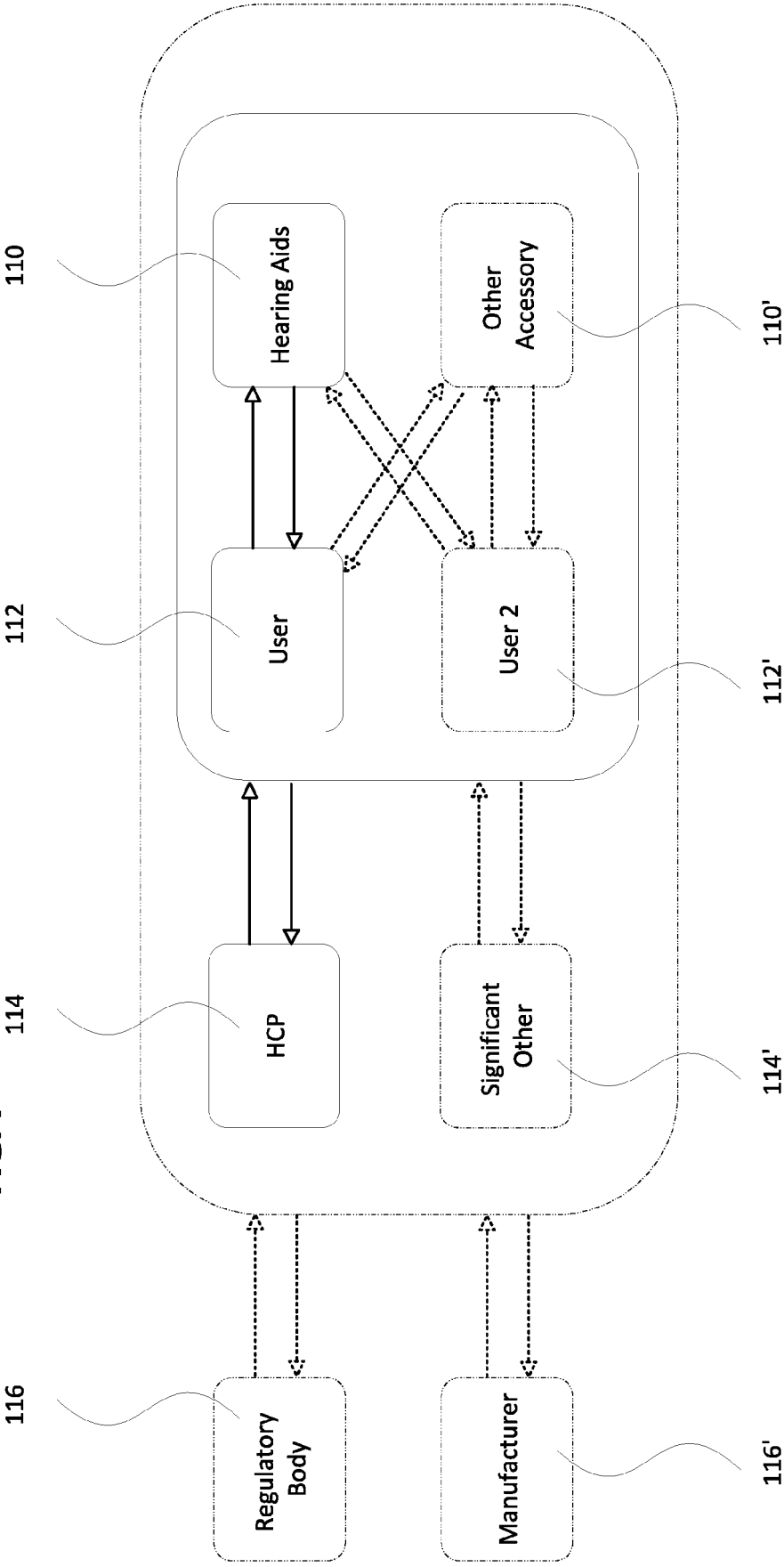


FIG. 7





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Application Number

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Place of search The Hague		Date of completion of the search 9 November 2022	Examiner Timms, Olegs
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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