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(54) **SYSTEMS AND APPARATUS FOR MULTIFACTOR AUTHENTICATION USING BONE CONDUCTION AND AUDIO SIGNALS**

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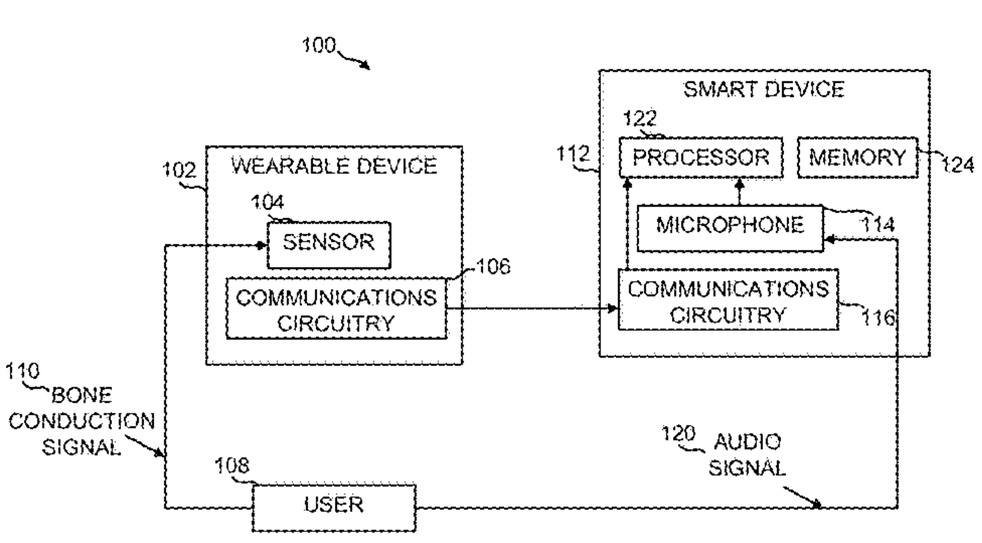
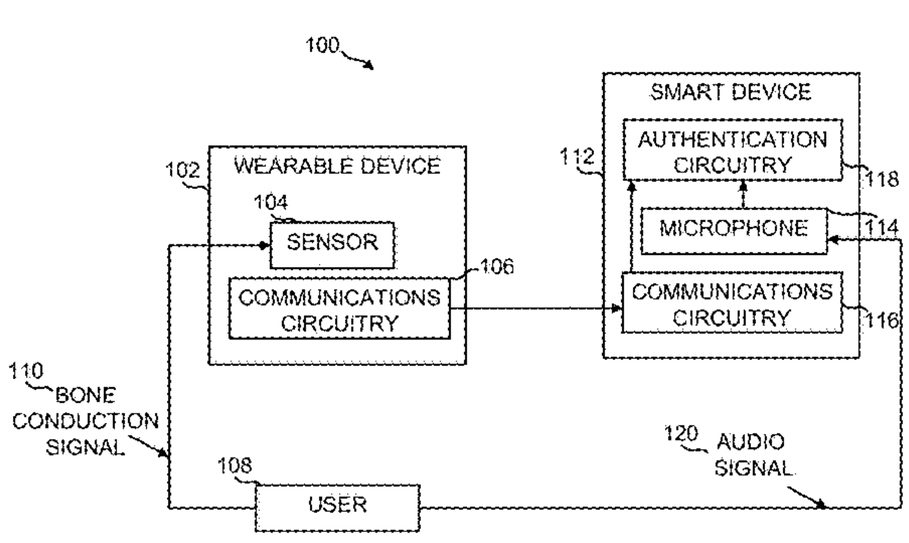
(57) **ABSTRACT**

Provided here are systems and method for two-way authentication of a user. In embodiments, the method may include, in response to reception of an audio signal from a user, determining, via a smart device and/or authentication circuitry, whether a corresponding bone conduction signal is received from one of one or more separate wearable devices. The method may include, in response to determination that the corresponding bone conduction signal is received: determining, via the smart device and/or authentication circuitry, whether the audio signal and corresponding conduction signal are consistent. The method may include, in response to a determination that the audio signal and corresponding conduction signal are consistent: verifying, via the smart device, the audio signal; verifying, via the smart device, the corresponding bone conduction signal; and, in response to verification of the audio signal and the corresponding bone conduction signal, authenticating a user.





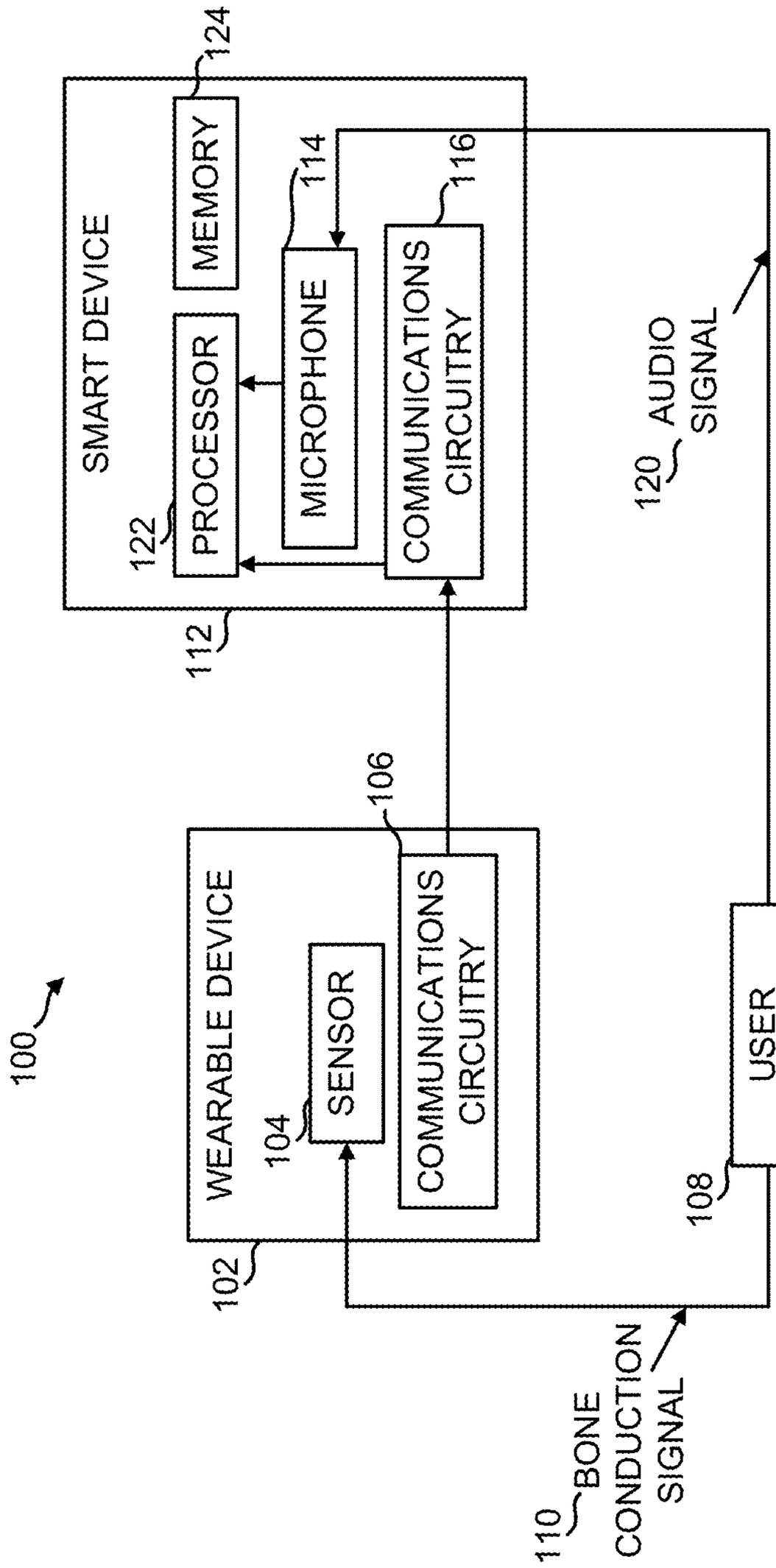

100
WEARABLE DEVICE
102
SENSOR
104
COMMUNICATIONS CIRCUITRY
106
SMART DEVICE
112
PROCESSOR
122
MICROPHONE
114
COMMUNICATIONS CIRCUITRY
116
MEMORY
124
BONE CONDUCTION SIGNAL
110
USER
108
AUDIO SIGNAL
120

FIG. 1A

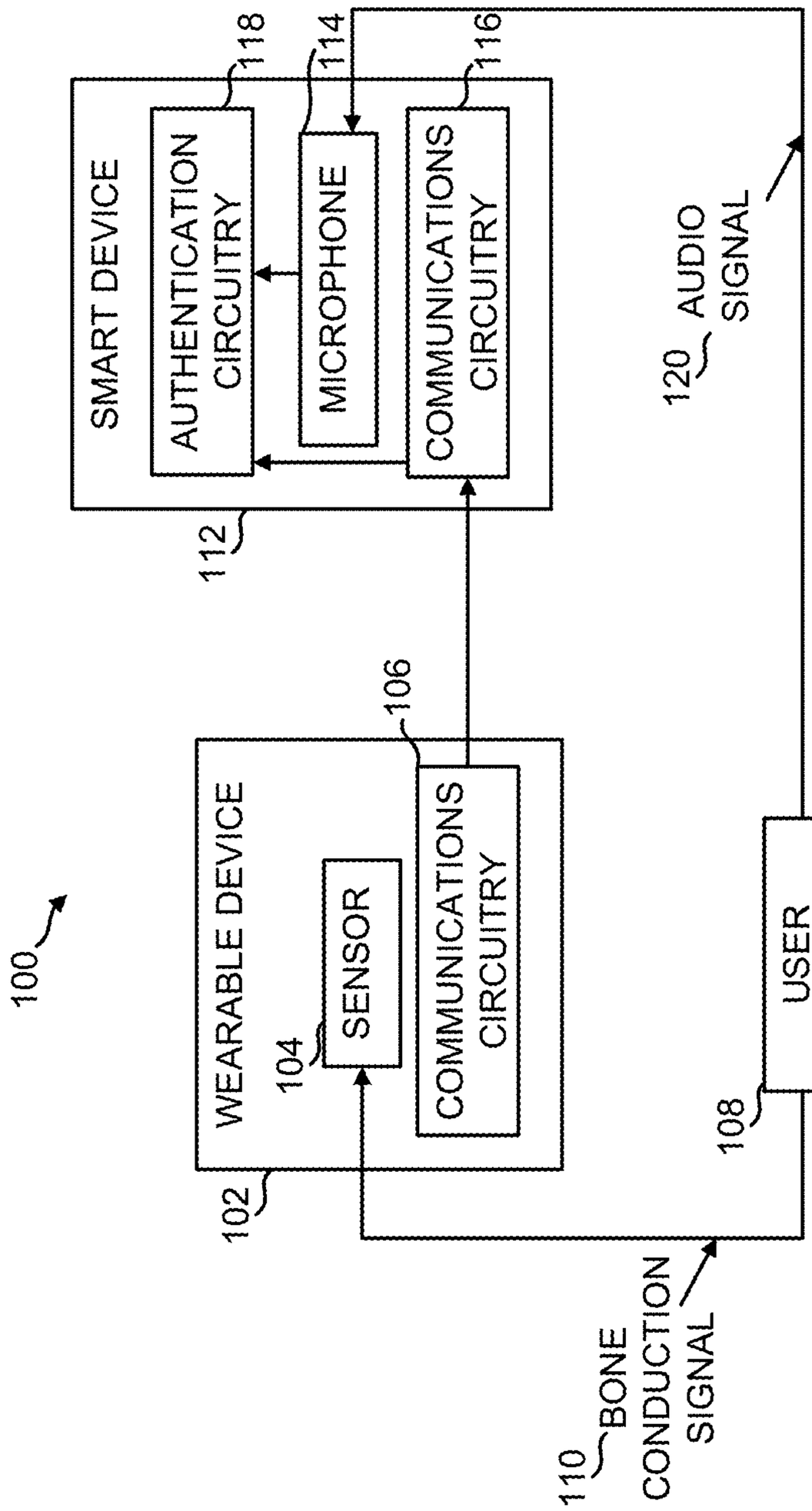
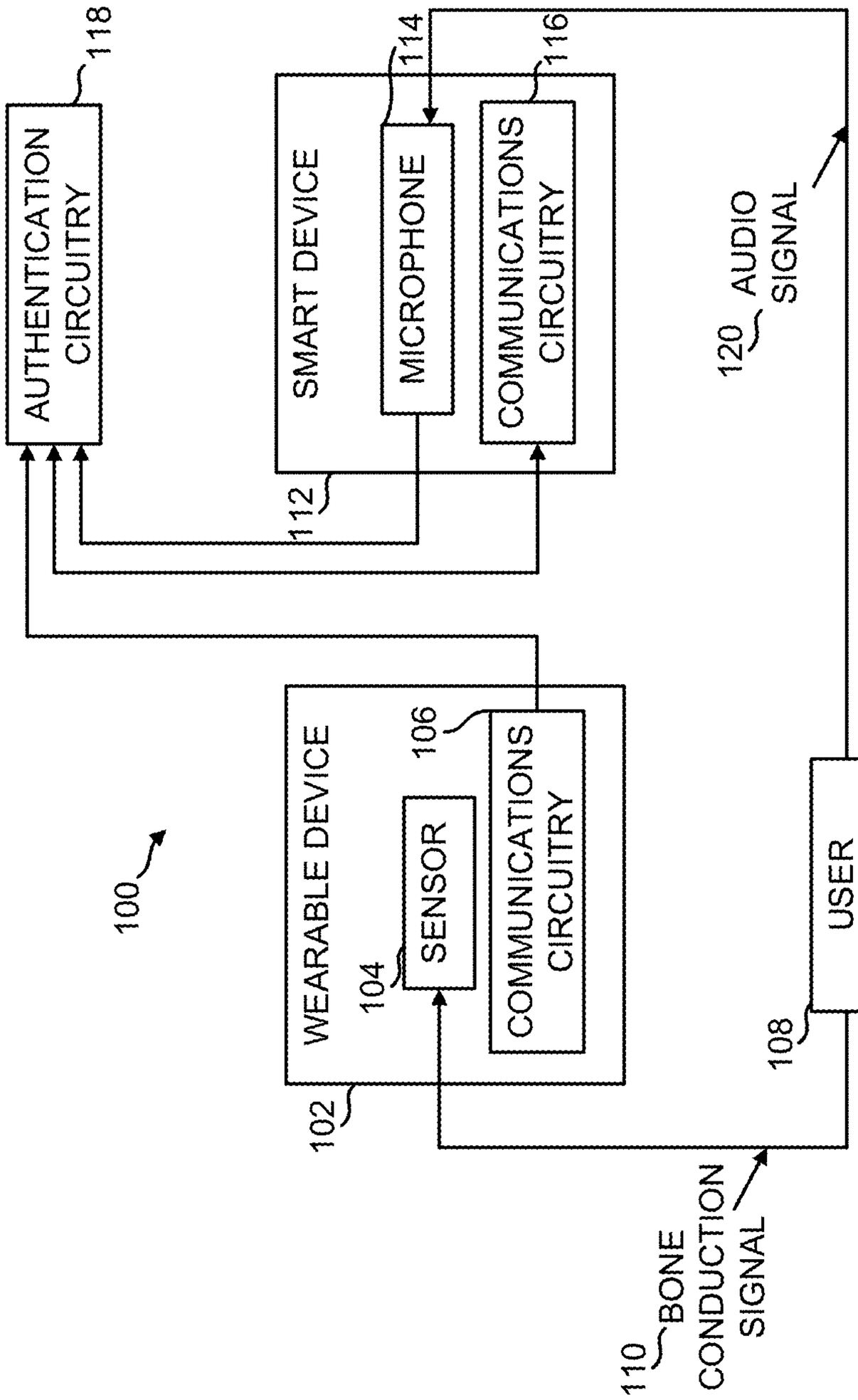

100
WEARABLE DEVICE
102
SENSOR
104
COMMUNICATIONS CIRCUITRY
106
SMART DEVICE
112
AUTHENTICATION CIRCUITRY
118
MICROPHONE
114
COMMUNICATIONS CIRCUITRY
116
120 AUDIO SIGNAL
USER
108
110 BONE CONDUCTION SIGNAL

FIG. 1B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102
SENSOR
104
COMMUNICATIONS CIRCUITRY
106
AUTHENTICATION CIRCUITRY
118
SMART DEVICE
112
MICROPHONE
114
COMMUNICATIONS CIRCUITRY
116
USER
108
BONE CONDUCTION SIGNAL
110
AUDIO SIGNAL
120

FIG. 1C

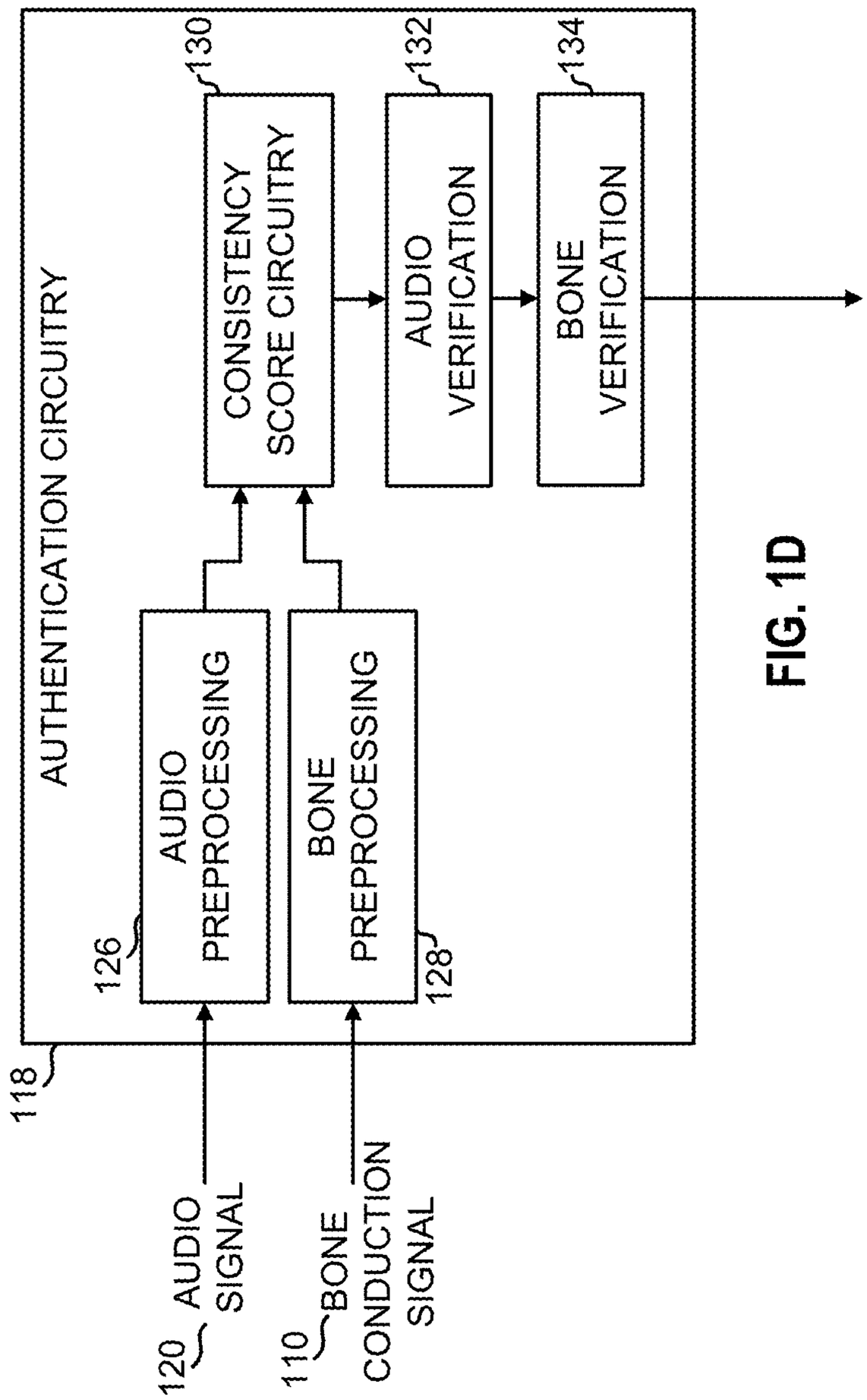
AUTHENTICATION CIRCUITRY
118
AUDIO PREPROCESSING
126
BONE PREPROCESSING
128
CONSISTENCY SCORE CIRCUITRY
130
AUDIO VERIFICATION
132
BONE VERIFICATION
134
120 AUDIO SIGNAL
110 BONE CONDUCTION SIGNAL

FIG. 1D

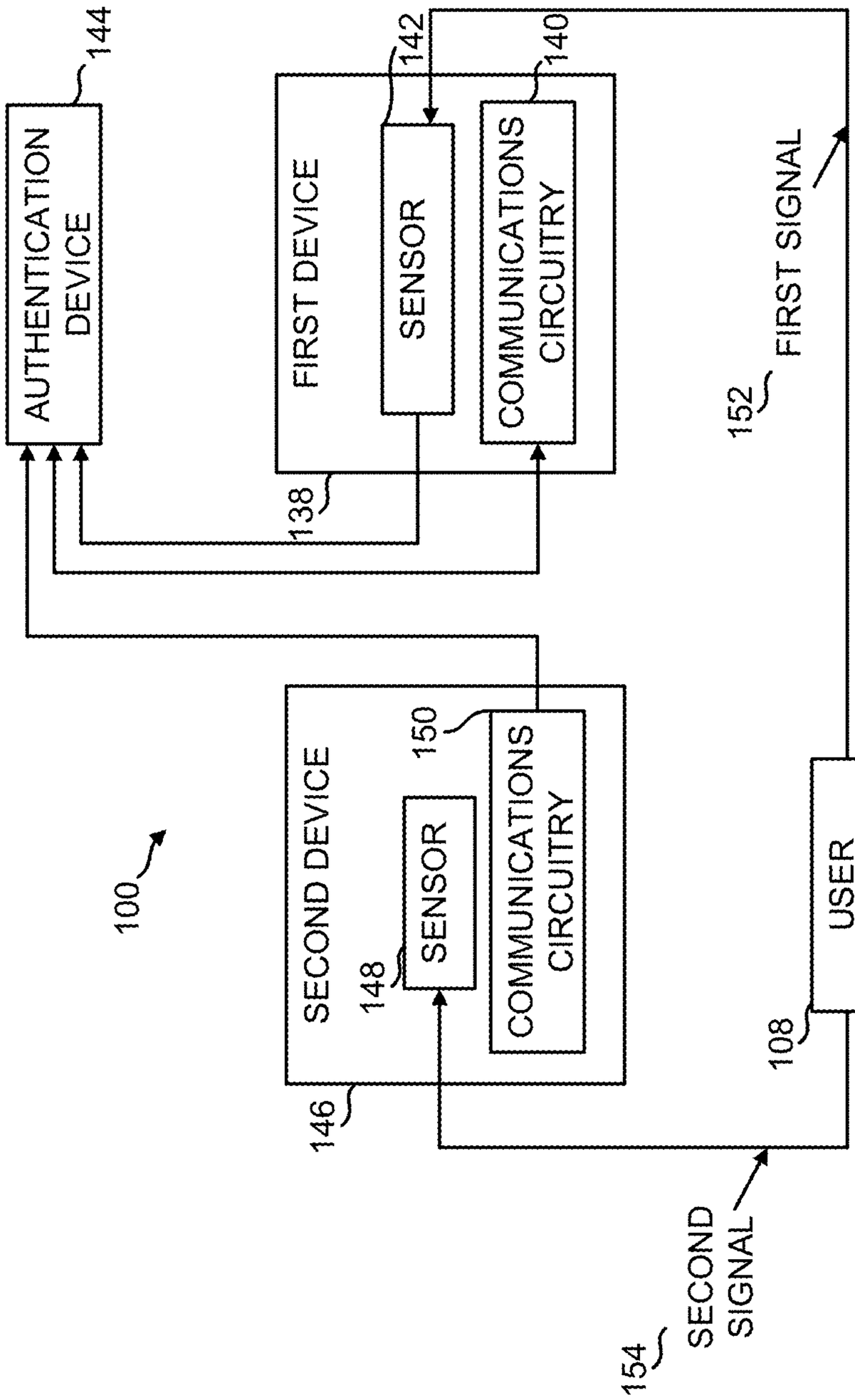
100
AUTHENTICATION DEVICE
144
FIRST DEVICE
138
SENSOR
142
COMMUNICATIONS CIRCUITRY
140
SECOND DEVICE
146
SENSOR
148
COMMUNICATIONS CIRCUITRY
150
FIRST SIGNAL
152
USER
108
SECOND SIGNAL
154

FIG. 1E

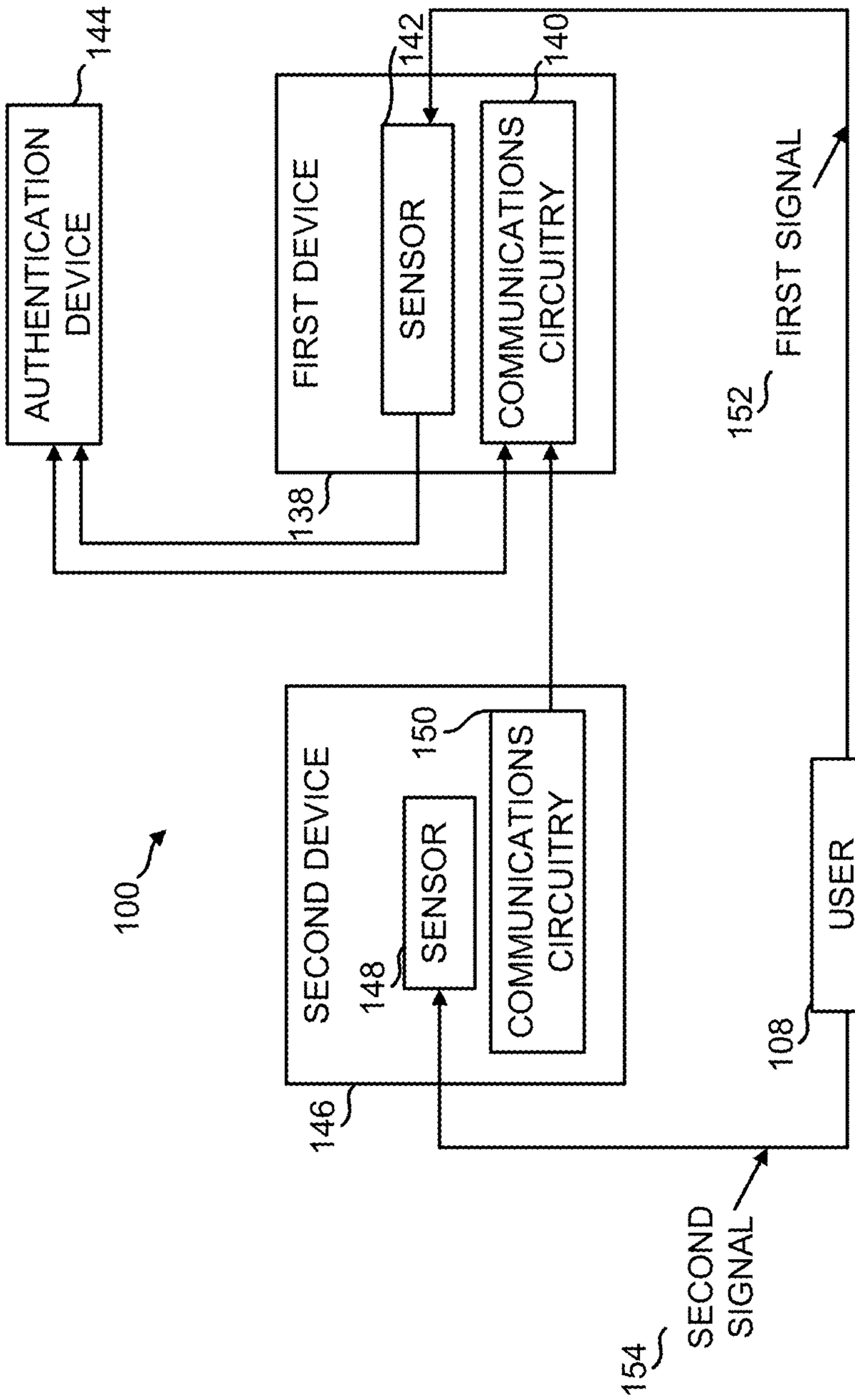
100
AUTHENTICATION DEVICE
144
FIRST DEVICE
138
SENSOR
142
COMMUNICATIONS CIRCUITRY
140
SECOND DEVICE
146
SENSOR
148
COMMUNICATIONS CIRCUITRY
150
FIRST SIGNAL
152
USER
108
SECOND SIGNAL
154

FIG. 1F

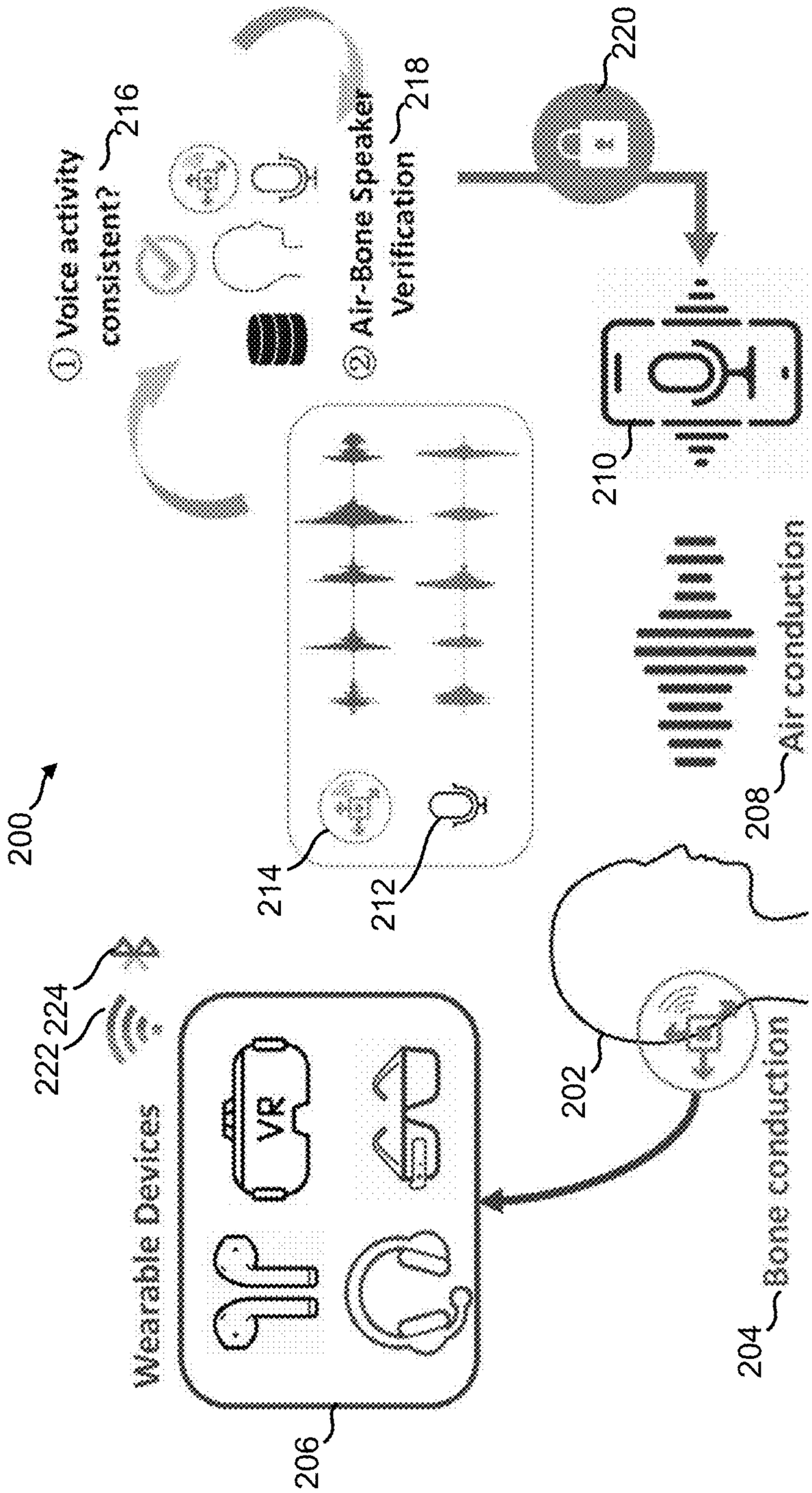
① Voice activity consistent?
216
② Air-Bone Speaker Verification
218
220
210
Air conduction
208
200
214
212
222
224
Wearable Devices
VR
206
202
Bone conduction
204

FIG. 2

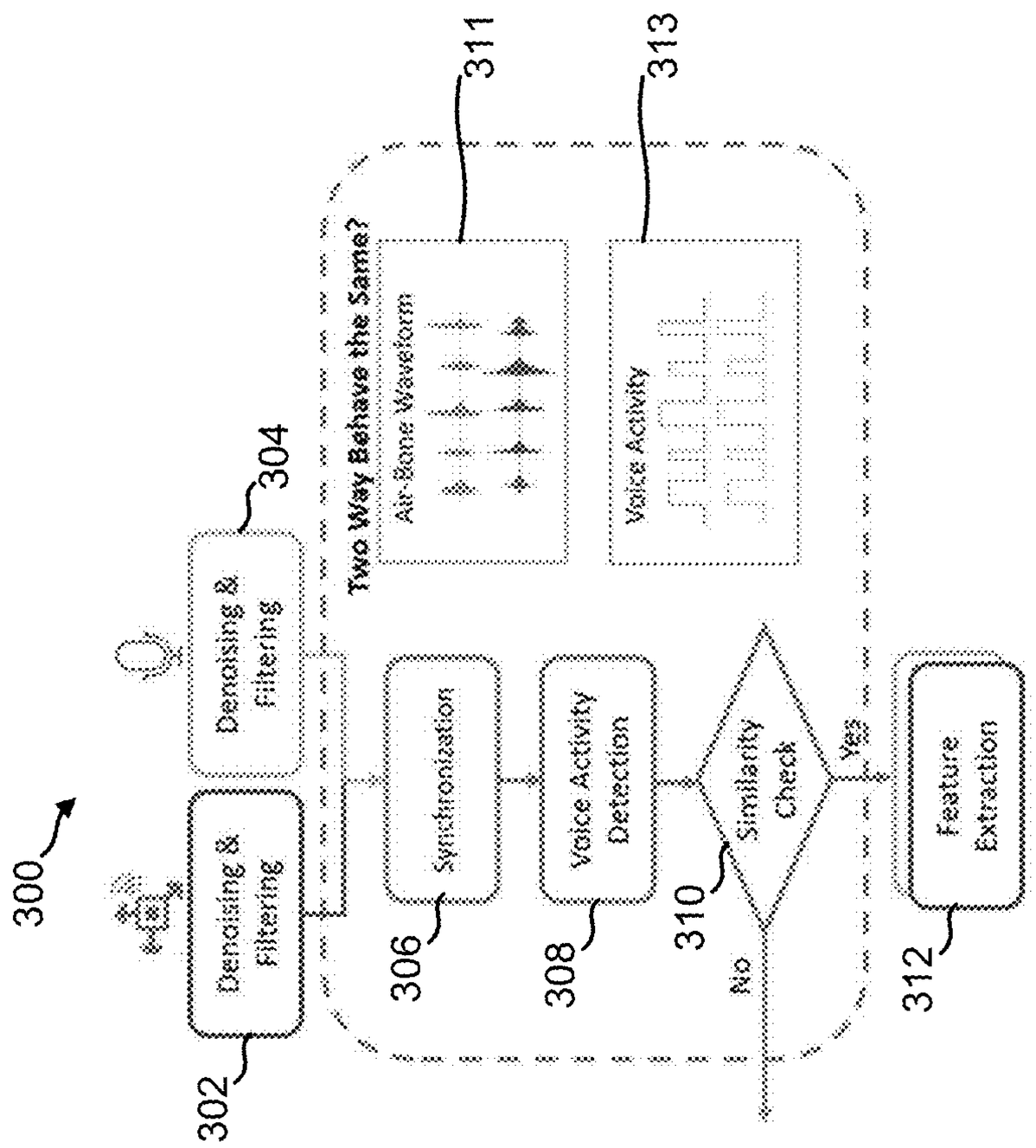
300
302
Denoising & Filtering
304
Denoising & Filtering
Two Way Behave the Same?
Air-Bone Waveform
Voice Activity
306
Synchronization
308
Voice Activity Detection
310
Similarity Check
No
Yes
312
Feature Extraction

FIG. 3A

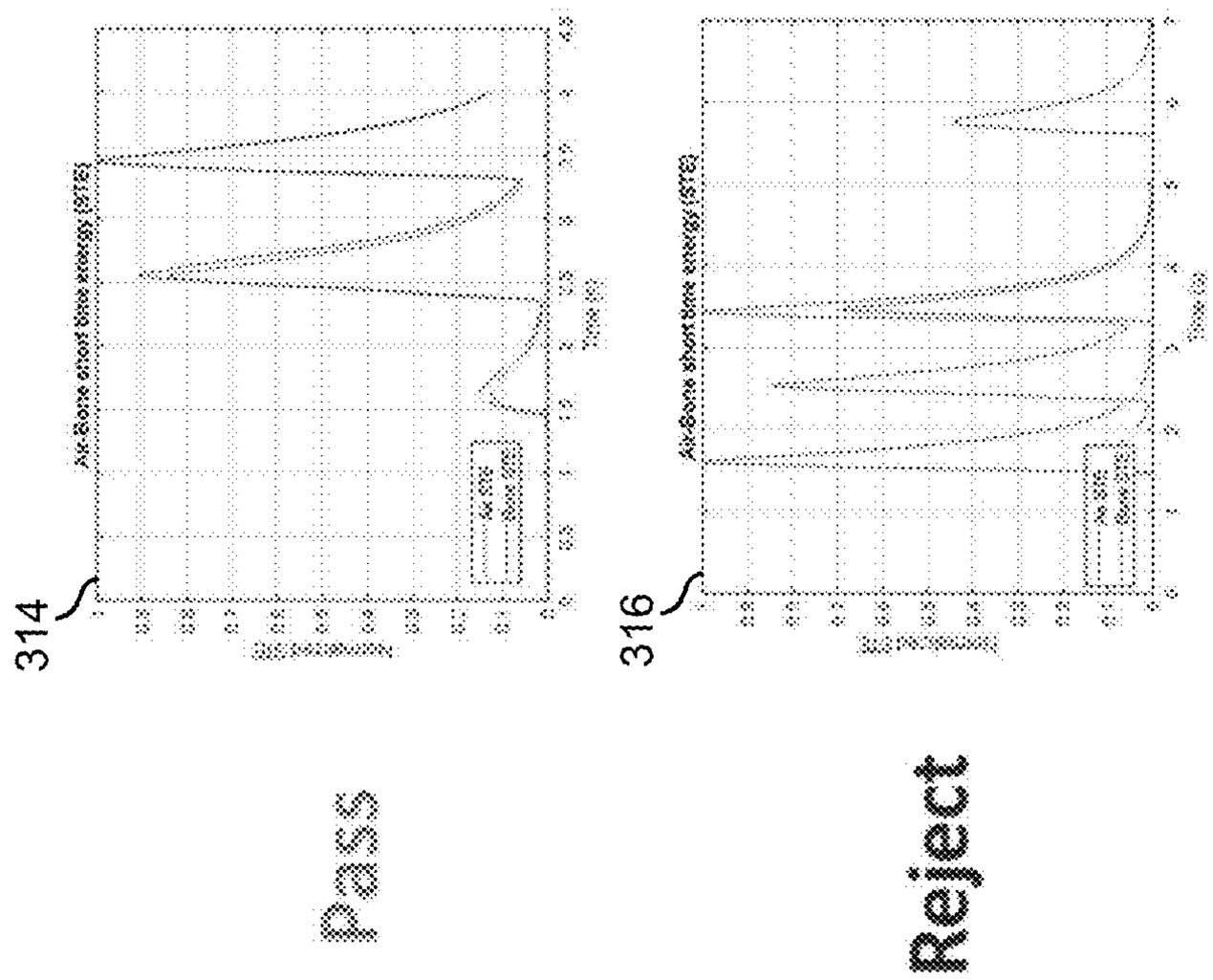

FIG. 3B

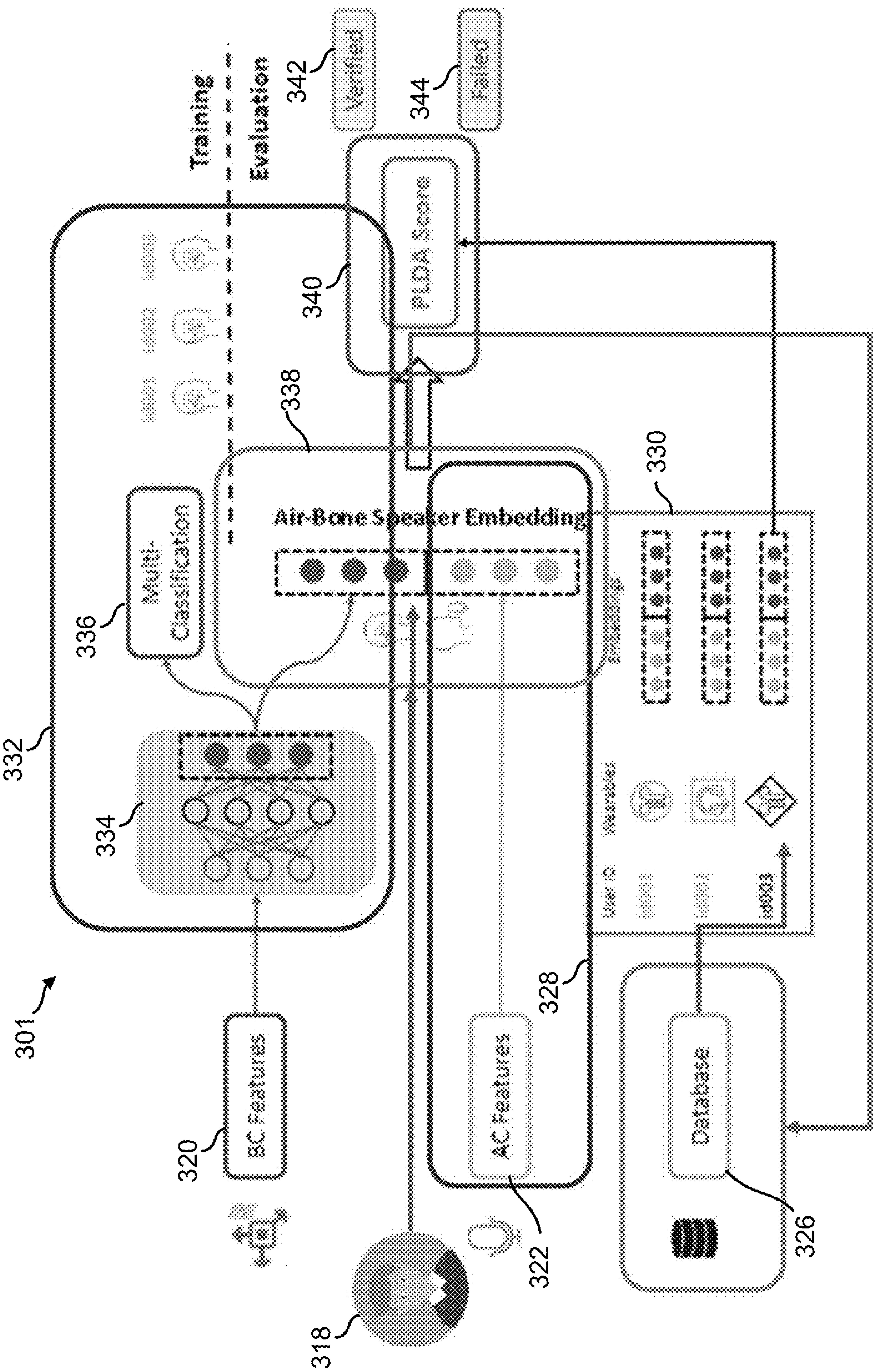
301
332
334
336
Multi-Classification
338
Air-Bone Speaker Embedding
340
PLDA Score
Training
Evaluation
342
Verified
344
Failed
330
328
320
BC Features
322
AC Features
318
326
Database

FIG. 3C

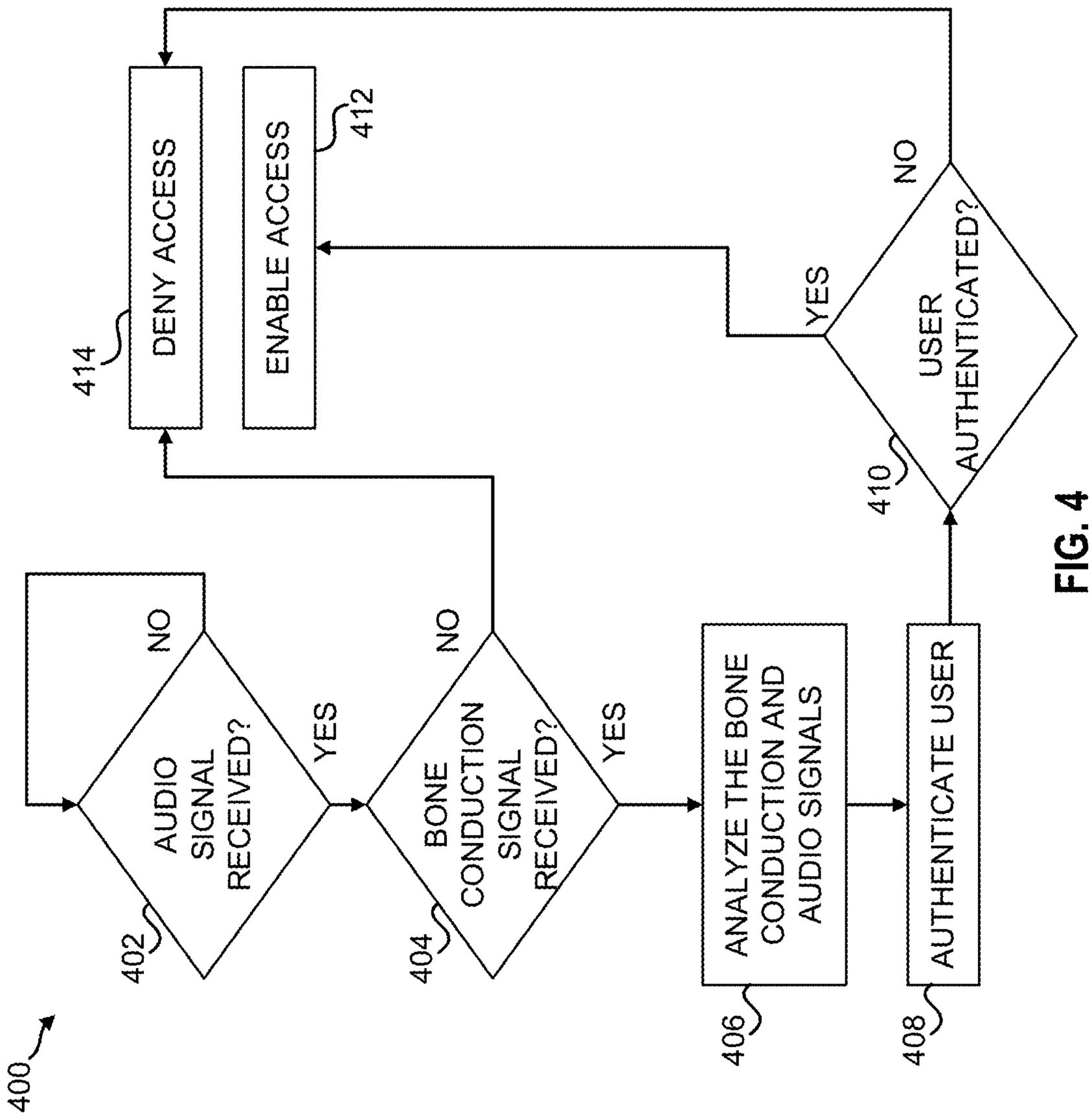
400
AUDIO SIGNAL RECEIVED?
NO
YES
402
BONE CONDUCTION SIGNAL RECEIVED?
NO
YES
404
ANALYZE THE BONE CONDUCTION AND AUDIO SIGNALS
406
AUTHENTICATE USER
408
USER AUTHENTICATED?
NO
YES
410
ENABLE ACCESS
412
DENY ACCESS
414

FIG. 4

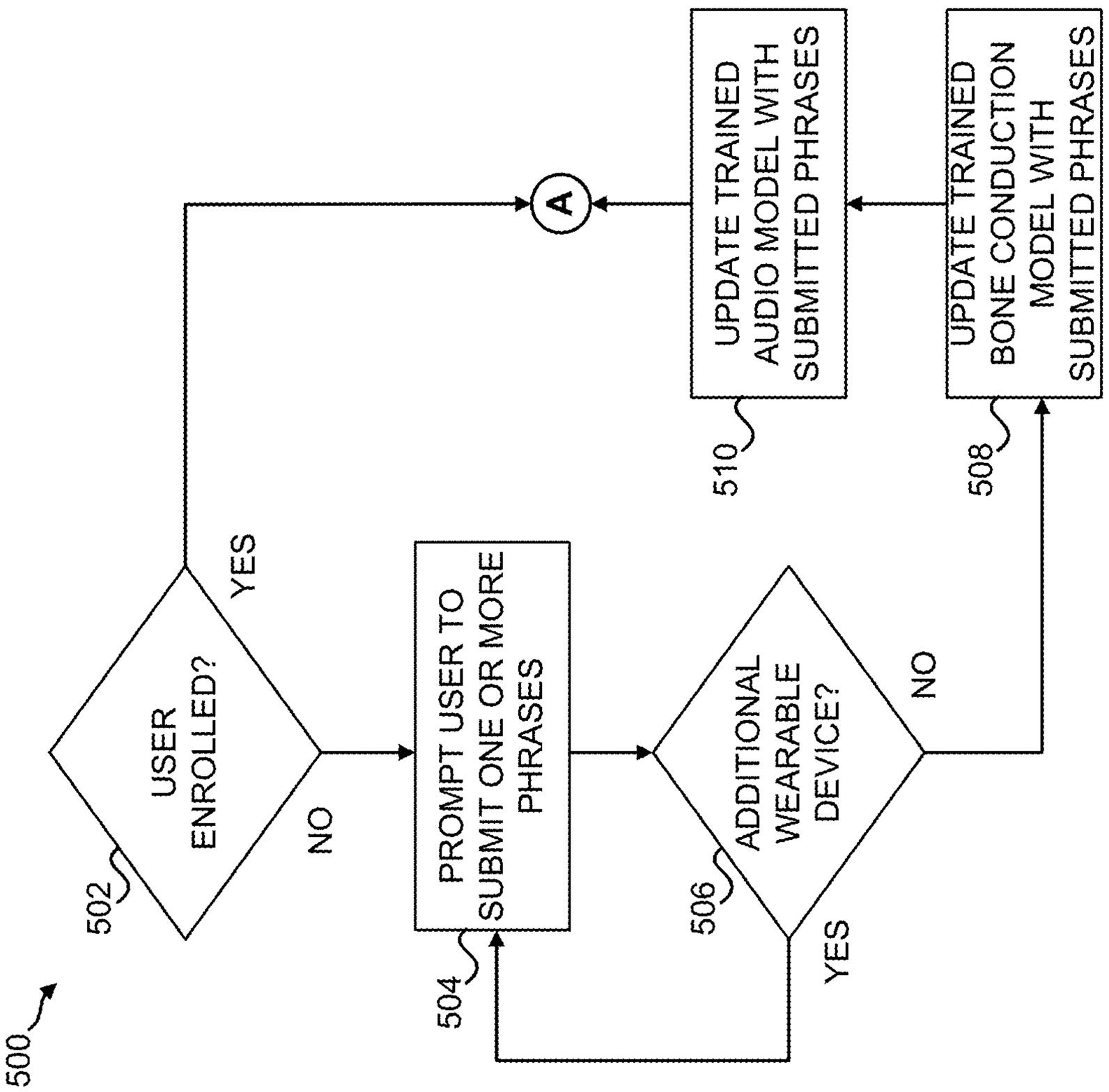
500
502
USER ENROLLED?
YES
NO
504
PROMPT USER TO SUBMIT ONE OR MORE PHRASES
506
ADDITIONAL WEARABLE DEVICE?
YES
NO
508
UPDATE TRAINED BONE CONDUCTION MODEL WITH SUBMITTED PHRASES
510
UPDATE TRAINED AUDIO MODEL WITH SUBMITTED PHRASES
A

FIG. 5A

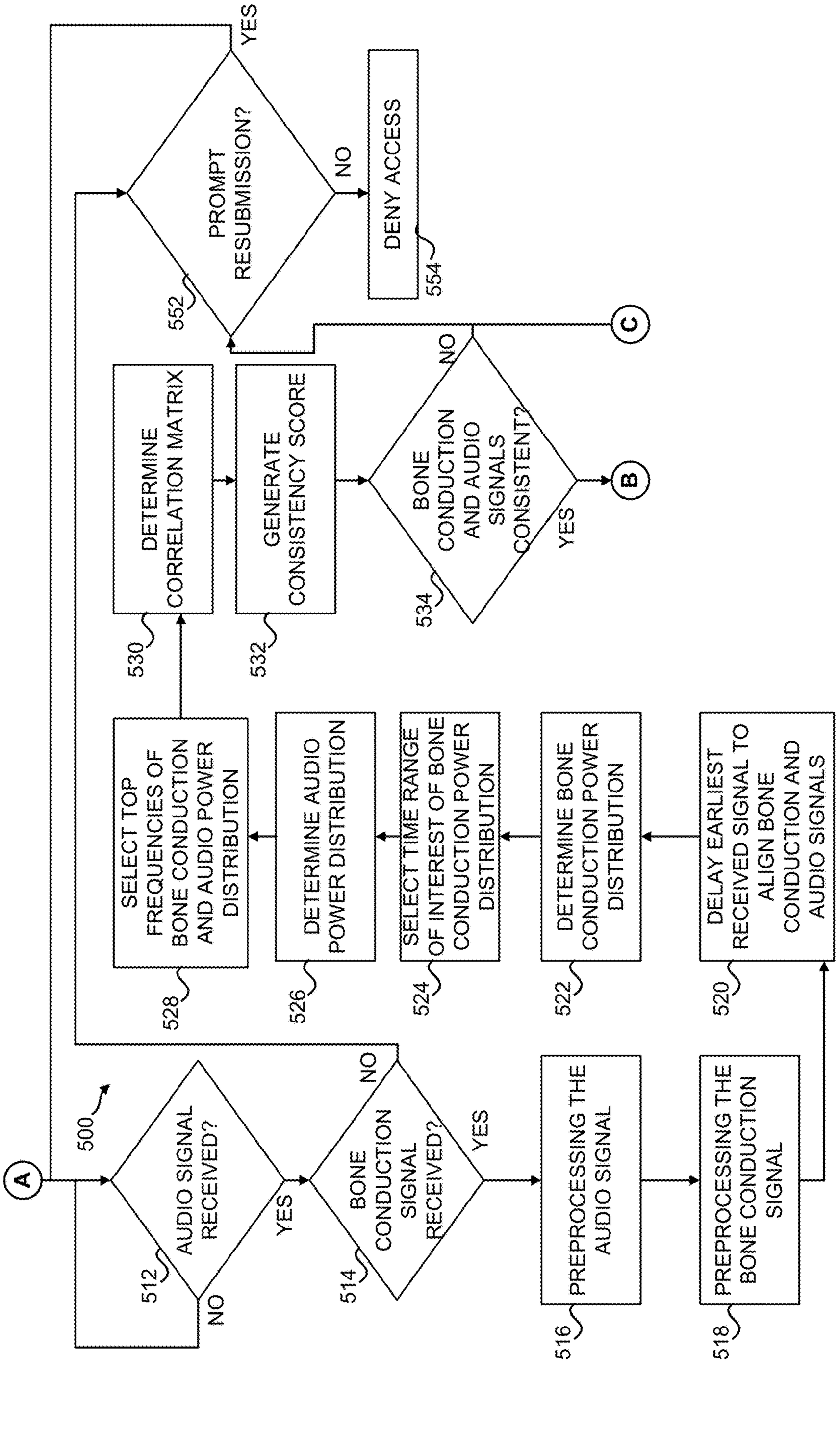
A
500
AUDIO SIGNAL RECEIVED?
512
NO
YES
BONE CONDUCTION SIGNAL RECEIVED?
514
NO
YES
PREPROCESSING THE AUDIO SIGNAL
516
PREPROCESSING THE BONE CONDUCTION SIGNAL
518
DELAY EARLIEST RECEIVED SIGNAL TO ALIGN BONE CONDUCTION AND AUDIO SIGNALS
520
DETERMINE BONE CONDUCTION POWER DISTRIBUTION
522
SELECT TIME RANGE OF INTEREST OF BONE CONDUCTION POWER DISTRIBUTION
524
DETERMINE AUDIO POWER DISTRIBUTION
526
SELECT TOP FREQUENCIES OF BONE CONDUCTION AND AUDIO POWER DISTRIBUTION
528
DETERMINE CORRELATION MATRIX
530
GENERATE CONSISTENCY SCORE
532
BONE CONDUCTION AND AUDIO SIGNALS CONSISTENT?
534
NO
YES
B
C
PROMPT RESUBMISSION?
552
NO
YES
DENY ACCESS
554

FIG. 5B

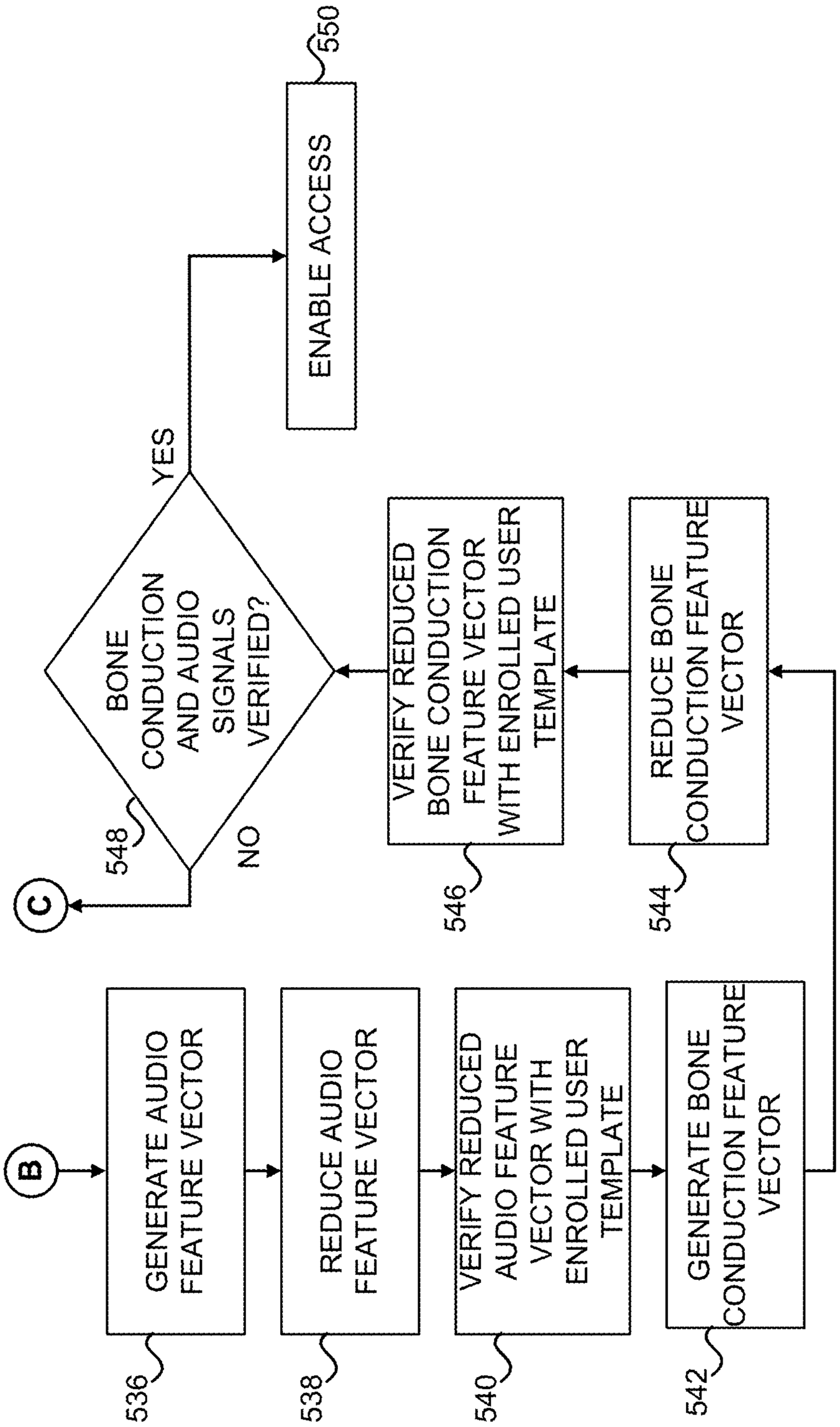
B
GENERATE AUDIO FEATURE VECTOR
536
REDUCE AUDIO FEATURE VECTOR
538
VERIFY REDUCED AUDIO FEATURE VECTOR WITH ENROLLED USER TEMPLATE
540
GENERATE BONE CONDUCTION FEATURE VECTOR
542
REDUCE BONE CONDUCTION FEATURE VECTOR
544
VERIFY REDUCED BONE CONDUCTION FEATURE VECTOR WITH ENROLLED USER TEMPLATE
546
BONE CONDUCTION AND AUDIO SIGNALS VERIFIED?
548
NO
YES
C
ENABLE ACCESS
550

FIG. 5C

SYSTEMS AND APPARATUS FOR MULTIFACTOR AUTHENTICATION USING BONE CONDUCTION AND AUDIO SIGNALS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to U.S. Provisional Application No. 63/268,999, filed Mar. 8, 2022, titled "SYSTEMS AND APPARATUS FOR MULTIFACTOR AUTHENTICATION USING BONE CONDUCTION AND AUDIO SIGNALS," U.S. Provisional Application No. 63/269,001, filed Mar. 8, 2022, titled "METHOD FOR MULTIFACTOR AUTHENTICATION USING BONE CONDUCTION AND AUDIO SIGNALS," and U.S. Provisional Application No. 63/380,229, filed Oct. 19, 2022, titled "SYSTEMS AND METHODS FOR CONTINUOUS, ACTIVE, AND NON-INTRUSIVE USER AUTHENTICATION," the disclosures of which are incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0002] The disclosure relates to methods and systems for using a bone conduction signal and an audio signal for two-way or multifactor authentication of user. More specifically, the methods and systems use a bone conduction signal from a wearable device and an audio signal from a smart device to authenticate a user of the smart device.

BACKGROUND

[0003] Smart voice assistants or smart devices typically include a vocal or audio based authentication process, if any authentication at all. For example, a user may speak a specific phrase or statement and the smart device may recognize the user based on the unique audio characteristics of the user's vocals when speaking the specific phrase. Such audio characteristics are usually determined during an enrollment or initialization period. However, a user's submission during enrollment or initialization may not match a current attempt to authenticate due to differences in tone and volume, thus resulting in a mismatch or denial of access to the smart device. Further, a third party may spoof or copy a user's audio signal and utilize such a spoof or copy of the audio signal to imitate the user, thus gaining access to, potentially, sensitive and/or private user data or information.

SUMMARY

[0004] Accordingly, Applicants have recognized a need for systems and methods to utilize two-factor or multifactor authentication to enable user access to a smart device, the two-factor or multifactor authentication including verifying a user via a bone conduction signal from a wearable device and an audio signal obtained by the smart device. The present disclosure is directed to embodiments of such systems and methods.

[0005] The present disclosure is generally directed to systems and methods for utilizing two-factor or multifactor authentication to enable user access to a smart device, the two-factor or multifactor authentication including verifying a user via a bone conduction signal from a wearable device and an audio signal obtained by the smart device. In such embodiments, a smart device may request an input from a user prior to access to a portion of or all of the functionality and/or data of the smart device. Prior to a request for such an input, the smart device may prompt the user to initialize or enroll with the smart device. Such an enrollment or initialization may include prompting a user to speak a particular phrase or phrases using each of one or more wearable devices associated with the user. In other words, the user may speak or submit a phrase for each wearable device the user desires to utilize for subsequent verifications and/or authentications. In such embodiments, the smart device and/or an authentication circuitry may store the audio signals, obtained from a microphone or other sensor of the smart device, and bone conduction signals, obtained from each of the one or more wearable devices. Further, an identifier or tag may be stored alongside each submission or entry, such an identifier or tag associated with one of the one or more wearable devices. The identifier or tag may be a device name obtained via data in a connection (for example, Bluetooth, WiFi, or other signal communication standard) between the wearable device and the smart device and/or authentication circuitry. Further still, more than one user may access a smart device. In such embodiments, different users may be able to access different functionality and/or data of the smart device. In such examples, when initializing or enrolling a user, a user identifier may be generated and may be stored with associated wearable devices and level of access. In an embodiment, functionality may include the smart device, after determining consistency and verifying the bone conduction signal and audio signal, utilizing natural language processing to interpret voice commands from the user and, based on the interpretation, performing an action or operation. The smart device may be configured to provide the additional functionality of granting access to virtual or physical locations and/or data, enabling a user to purchase goods and/or utilize services (for example, play music, view video of cameras connected to and/or proximate the smart device, among other services and/or functions), allowing a user to access a computing device or user profile, among other functionality.

[0006] The smart device and/or authentication circuitry may include one or more trained models. The smart device and/or authentication circuitry may include a bone conduction verification model and an audio conduction verification model. The bone conduction verification model may be trained based on previous users' bone conduction signals, previous users' enrollment or initialization bone conduction signals, and the outcome of previous verifications. Further, when a user submits a bone conduction signal enrollment or initialization, the bone conduction signal enrollment or initialization may be utilized to refine, re-train, or further train the bone conduction verification model. The audio conduction verification model may be trained based on previous users' audio signals, previous users' enrollment or initialization audio signals, and the outcome of previous verifications. Further, when a user submits an audio signal enrollment or initialization, the audio signal enrollment or initialization may be utilized to refine, re-train, or further train the audio conduction verification model.

[0007] As noted, prior to providing access to some or all of the functionality of the smart device, the smart device and/or authentication circuitry may request authentication and/or verification. In response to such a prompt, the smart device and/or authentication circuitry may wait until an audio signal and/or bone conduction signal is received. Once one signal (for example, the audio signal and/or bone conduction signal) is received by the smart device and/or

authentication circuitry, the smart device and/or authentication circuitry may wait for the other signal to be received (for example, the bone conduction signal and/or the audio signal, respectively). If the other signal is not received within a pre-selected or specified time interval, the smart device and/or authentication circuitry may deny the user access to some or all functionality (for example, a user may play a song, but not access private or sensitive data or information relating to the user). Further, the smart device and/or authentication circuitry may prompt the user to resubmit a phrase or phrases for authentication or verification for an amount of pre-determined or pre-selected times.

[0008] Once the smart device and/or authentication circuitry receives both signals (for example, the bone conduction signal and the audio signal), the smart device and/or authentication circuitry may determine whether the bone conduction signals and audio signals are consistent. In other words, whether the bone conduction signals and audio signals are based on the same phrase and/or from the same user. Such a determination may include pre-processing each signal (for example, delaying or aligning one of the signals to match the other and/or reducing noise of the signals by passing the signals through a Wiener filter or other audio or signal filter, among other pre-processing steps), determining a consistency score, and/or determining whether the consistency score is greater than or equal to a consistency threshold. Such a consistency score may be based on similarities between the audio signal and/or bone conduction signal. In such embodiments, since the audio signal and bone conduction signal are from the same user, some aspects of each signal should be consistent. After consistency is determined, the audio signal may be verified and the bone conduction signal may be verified. Such verifications may occur simultaneously, substantially simultaneously, and/or in sequence. Once verified, the smart device and/or authentication circuitry may grant access to some or all functionality of the smart device to the user.

[0009] In other embodiments, rather than a smart device obtaining an audio signal to be utilized for two-factor or multi-factor authentication of a user, a device may obtain an identification signal via a sensor of the device. Such an identification signal may include a signal generated by one or more of a badge scan, an identification card scan, a retinal scan, a fingerprint scan, or other scan configured to obtain a signal to be utilized for authentication. In such embodiments, authentication of a user may include authenticating a user based on the bone conduction signal and the identification signal.

[0010] Accordingly, an embodiment of the disclosure is directed to a system for two-way authentication of a user. The system may include a wearable device. The wearable device may include a sensor. The sensor may receive or sense a bone conduction signal based on a user's speech. The wearable device may include a communication circuitry. The communication circuitry may be configured to transmit the bone conduction signal. The system may include a smart device. The smart device may include a microphone. The microphone may be configured to receive an audio signal from the user's speech. The smart device may include bone and audio authentication circuitry. The bone and audio authentication circuitry may be configured to receive the bone conduction signal from the communication circuitry. The bone and audio authentication circuitry may be configured to analyze the bone conduction signal and audio signal. The bone and audio authentication circuitry may further be configured to authenticate a user in response to the analysis of the bone conduction signal and audio signal.

[0011] In another embodiment, the wearable device may include one or more of a headphone, a headset, an earbud, a virtual reality (VR) headset, or an augmented reality (AR) headset. The smart device may include one or more of a computing device, a smart phone, a tablet, a remote control, a television, a video game entertainment system, a household internet enabled device, a household smart device, a voice controlled intelligent personal assistant device, or a voice controlled intelligent personal vehicle management device. The bone and audio authentication circuitry, during analysis of the bone conduction signal and the audio signal, may be configured to pre-process the bone conduction signal and the audio signal. Further, the bone and audio authentication circuitry may be configured to generate a bone conduction feature vector and an audio conduction feature vector. The bone and audio authentication circuitry may be configured to reduce the bone conduction feature vector and the audio conduction feature vector to generate a reduced bone conduction feature vector and a reduced audio conduction feature vector. The bone and audio authentication circuitry may be configured to determine, using a trained model, a probability that the reduced bone conduction feature vector and the reduced audio conduction feature vector originate from or are from the user.

[0012] In another embodiment, the bone and audio authentication circuitry may further be configured to, prior to analysis of the bone conduction signal and the audio signal, prompt a user to enroll in relation to the smart device. Enrollment may include speaking a random or specified phrase to the smart device and with the wearable device to thereby generate an enrollment template. The bone and audio authentication circuitry, during analysis of the bone conduction signal and the audio signal, may be configured to compare the reduced bone conduction feature vector and the reduced audio conduction feature vector to the enrollment template to determine authentication of the user.

[0013] In an embodiment, authentication of a user may enable a user to access functionality of the smart device. The smart device may be configured to prompt an unauthenticated user to give at least one additional attempt to obtain authentication from the smart device. In another embodiment, an unauthenticated user may be an attacker and the smart device may be configured to, in response to unauthenticated bone and audio signals, locks access to personal user data. The smart device may be configured to, in response to unauthenticated bone and audio signals, lock functionality of the smart device and notify the user via a pre-selected alternative form of communication.

[0014] Another embodiment of the disclosure is directed to a smart device for two-way authentication of a user. The smart device may include a communications interface configured to receive a bone conduction signal from a user via one or more wearable devices; The smart device may include a microphone or other sensor configured to receive an audio signal from the user. The smart device may include a bone and audio authentication circuitry. The bone and audio authentication circuitry may be configured to analyze the bone conduction signal and the audio signal and, in response to a score based on analysis of the bone conduction signal and the audio signal being greater than or equal to a preselected threshold, authenticate the user.

[0015] In an embodiment, the bone conduction signal may be received by the wearable device at substantially the same time as the audio signal is received by the microphone. The bone and audio authentication circuitry may be configured to, prior to analysis, prompt a user to submit an enrollment template or response. The enrollment template or response may include one or more specific phrase to be spoken by the user. The smart device may be configured to prompt the user to submit the enrollment template or response for each of one or more wearable devices.

[0016] Another embodiment of the disclosure is directed to a system for two-way authentication of a user. The system may include one or more wearable devices. Each of the one or more wearable devices may include a sensor to receive a bone conduction signal based on a user's speech and a communication circuitry configured to wirelessly transmit the bone conduction signal. The system may include a smart device. The smart device may include a microphone or other sensor configured to receive or sense an audio signal from the user's speech. The smart device may include bone and audio authentication circuitry. The bone and audio authentication circuitry may be configured to receive the bone conduction signal from the communication circuitry. The bone and audio authentication circuitry may be configured to determine, using a consistency evaluation algorithm, a consistency score based on a comparison of the bone conduction signal and the audio signal. The bone and audio authentication circuitry may be configured to, in response to the consistency score being greater than or equal to a predetermined threshold: (a) determine, using a first verification model, a probability indicating that the audio signal is or originates from the user, (b) determine, using a second verification model, a probability indicating that the bone conduction signal is or originates from the user, and (c) in response to the probability indicating that the audio signal is or originates from the user being greater than or equal to a second preselected threshold and the probability indicating that the bone conduction signal is or originates from the user being greater than or equal to a third preselected threshold, authenticate a user based on the analysis of the bone conduction signal and audio signal.

[0017] In an embodiment, the smart device may be configured to, prior to authentication, prompt a user to submit an enrollment response. The smart device may be further configured to prompt the user to submit the enrollment response for each of the one or more wearable devices. The first verification model and the second verification model may be trained using data from prior users and using the user's enrollment response. The enrollment response may include one or more bone conduction signals and corresponding one or more audio signals. The enrollment response may further include an indicator to identify one of the one or more wearable devices corresponding to at least one of the one or more bone conduction signals and at least one of the one or more audio signals. In another embodiment, the smart device may be configured to, prior to determination of the consistency score, align the bone conduction signal and audio signal. In such embodiments, the consistency score may be based on the aligned bone conduction signal and audio signal.

[0018] Another embodiment of the disclosure is directed to a method two-way authentication of a user. The method may include, in response to reception of an audio signal from a user, determining, via the smart device, whether a corresponding bone conduction signal is received from one of one or more separate wearable devices. The method may include, in response to determination that the corresponding bone conduction signal is received, determining, via the smart device, whether the audio signal and corresponding conduction signal are consistent. The method may include, in response to a determination that the audio signal and corresponding conduction signal are consistent, verifying, via the smart device, the audio signal. The method may include verifying, via the smart device, the corresponding bone conduction signal. The method may include, in response to verification of the audio signal and the corresponding bone conduction signal, authenticating a user. The method may include, upon authentication of the user, allowing the user to (a) access or utilize the smart device and (b) access data on the smart device. In another embodiment, the method may include, upon authentication of the user, allowing the user to (a) access or utilize the smart device and (b) access data on the smart device associated with the user. In yet another embodiment, the method may include, upon authentication of the user, allowing the user to (a) access or utilize the smart device and (b) access personal data on the smart device associated with the user.

[0019] Another embodiment of the disclosure is directed to a system for two-way authentication of a user. The system may include a wearable device. The wearable device may include 1 a first sensor to receive a bone conduction signal based on a user's speech, and 2 a first communication circuitry configured to transmit the bone conduction signal to an authentication circuitry. The system may include a device. The device may include (a) a second sensor configured to receive an identification signal from a user, and (b) a second communication circuitry configured to transmit the identification signal to the authentication circuitry. The identification signal may include a signal generated by scanning a badge or identification card. The system may include an authentication circuitry. The authentication circuitry may be configured to receive the bone conduction signal from the first communication circuitry, receive the identification signal from the second communication circuitry, analyze the bone conduction signal and identification signal, and authenticate the user in response to the analysis of the bone conduction signal and identification signal.

[0020] Another embodiment of the disclosure is directed to a smart device for two-way authentication of a user. The smart device may include a communications interface configured to receive a bone conduction signal from a user. The smart device may include a microphone configured to receive an audio signal from the user. The smart device may include a bone and audio authentication circuitry. The bone and audio authentication circuitry may be configured to analyze the bone conduction signal and the audio signal; and, in response to a score, based on analysis of the bone conduction signal and the audio signal, being greater than or equal to a preselected threshold, authenticate the user.

[0021] Another embodiment of the disclosure is directed to an authentication device for two-way authentication of a user. The authentication device may include a communications interface configured to receive (a) a first signal from a user and (b) a second signal from the user, the second signal being a different type of signal than the first signal. The first signal and/or the second signal may each include one or more of an audio signal, a bone conduction signal, or signals associated with a badge scan, identification scan, retinal

scan, fingerprint scan, facial scan, or gesture scan. The authentication device may include an authentication circuitry. The authentication circuitry may be configured to analyze the first signal and the second signal. The authentication circuitry may be further configured to, in response to a score, based on analysis of the first signal and the second signal, being greater than or equal to a preselected threshold, authenticate the user. In an embodiment, analysis of the first signal and second signal includes (a) a determination of whether the first signal and the second signal are from the user, and (b) a determination, if the first signal and the second signal are from the user, of the score based on a verification that each of the first signal and the second signal are authentic.

[0022] Still other aspects and advantages of these embodiments and other embodiments, are discussed in detail herein. Moreover, it is to be understood that both the foregoing information and the following detailed description provide merely illustrative examples of various aspects and embodiments, and are intended to provide an overview or framework for understanding the nature and character of the claimed aspects and embodiments. Accordingly, these and other objects, along with advantages and features herein disclosed, will become apparent through reference to the following description and the accompanying drawings. Furthermore, it is to be understood that the features of the various embodiments described herein are not mutually exclusive and may exist in various combinations and permutations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] These and other features, aspects, and advantages of the disclosure will become better understood with regard to the following descriptions, claims, and accompanying drawings. It is to be noted, however, that the drawings illustrate only several embodiments of the disclosure and, therefore, are not to be considered limiting of the scope of the disclosure.

[0024] FIG. **1**A, FIG. **1**B, FIG. **1**C, FIG. **1**D, FIG. **1**E, and FIG. **1**F are block diagrams of systems to authenticate a user, according to an embodiment of the present disclosure.

[0025] FIG. **2** is a block diagram of a system to authenticate a user, according to an embodiment of the present disclosure.

[0026] FIG. **3**A, FIG. **3**B, and FIG. **3**C are block diagrams of systems to authenticate a user, according to an embodiment of the present disclosure.

[0027] FIG. **4** is a flow diagram of two-way user authentication, according to an embodiment of the present disclosure.

[0028] FIG. **5**A, FIG. **5**B, and FIG. **5**C are flow diagrams of two-way user authentication, according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0029] So that the manner in which the features and advantages of the embodiments of the systems and methods disclosed herein, as well as others that will become apparent, may be understood in more detail, a more particular description of embodiments of systems and methods briefly summarized above may be had by reference to the following detailed description of embodiments thereof, in which one or more are further illustrated in the appended drawings, which form a part of this specification. It is to be noted, however, that the drawings illustrate only various embodiments of the systems and methods disclosed herein and are therefore not to be considered limiting of the scope of the systems and methods disclosed herein as it may include other effective embodiments as well.

[0030] The present disclosure is directed to systems and methods for two-way authentication or multifactor authentication for a user. Such authentication may occur be in response to a user's attempt to access a device or smart device. Typically, a smart device or other device may utilize audio or actual passwords or pins to authenticate a user. However, a user's speech may be spoofed or copied or a user's password determined or stolen, thus allowing a third party to take control of a user's account. To prevent such issues, the systems and methods described herein may utilize a two-factor or multifactor authentication. For example, a user attempting to access functionality or data associated with a particular device or smart device may be prompted to submit a phrase or one or more phrases. The data may include personal data, data associated with the user, data stored on the smart device, data associated with the smart device, and/or data stored in a specified location accessible via the smart device. Functionality of the smart device may include (for example, the smart device may be configured to) the smart device accepting voice commands, the smart device performing an action based on the received voice commands, granting access to virtual or physical locations and/or data, and/or enabling a user to purchase goods and/or utilize services (for example, play music, view video of cameras connected to and/or proximate the smart device, among other services and/or functions), among other functionality. In an example, the smart device may, after determining consistency and verifying the bone conduction signal and audio signal, utilize natural language processing to interpret voice commands from the user and, based on the interpretation, perform an action or operation. Further, to ensure proper authentication, the user may submit such a phrase or one or more phrases while wearing a wearable device. While the smart device may include a microphone or other sensor to obtain an audio signal or other identification signal from the user, the wearable device may be configured to obtain a bone conduction signal from the user and transmit the bone conduction signal to the smart device and/or an authentication circuitry. Thus, at least two different factors may be gathered to authenticate a user.

[0031] Further, such systems and methods may authenticate the user when the bone conduction signal and audio signal or other signal are received. In such examples, the smart device and/or authentication circuitry may first determine whether the bone conduction signal and audio signal or other signal are consistent. If the signals (for example, the bone conduction signal and audio signal or other signal) are consistent, then each signal (for example, the bone conduction signal and audio signal or other signal) may be verified. If each signal (for example, the bone conduction signal and audio signal or other signal) is verified, then the smart device and/or authentication circuitry may authenticate the user.

[0032] The systems and methods may utilize various machine learning and/or signal processing techniques to analyze the bone conduction and the audio signal or other signal. Additionally, machine learning models or classifiers used may be trained based on a user's enrollment or initial submission of one or more phrases. In other words, the smart

device and/or authentication circuitry may prompt the user to submit the enrollment or initialization. Such an enrollment or initialization may be prompted for each wearable device the user utilizes (for example, a headphone, headset, earbud, smart glasses, smart phone, virtual reality (VR) headset, and/or augmented reality (AR) headset, among other devices), as the interaction between such wearable devices and the user's skull may produce different bone conduction signals. Once enrolled or initialized, the smart device and/or authentication circuitry may update, refine, re-train, or further train any machine learning models, probabilistic models, and/or statistical models utilized in such systems and methods. Thus, when the smart device and/or authentication device verifies a bone conduction signal and/or audio signal or other signal, the smart device and/or authentication device may grant the user access to all or some portion of the functionality and/or data for the smart device or other devices.

[0033] A solution to such issues, as noted, include the use of a wearable device in conjunction with a microphone or other sensor of a smart device or other device. The user can provide an audio signal and bone conduction signal and, based on such signals, be authenticated. Other and/or different signals may be utilized in the systems and methods. Further, a user may submit an enrollment or initialization for each of one or more wearable devices the user owns or that the user wishes to utilize for authentication.

[0034] FIG. **1**A, FIG. **1**B, FIG. **1**C, FIG. **1**D, FIG. **1**E, and FIG. **1**F are block diagrams of systems to authenticate a user, according to an embodiment of the present disclosure. Turning first to FIG. **1**A, the system **100** may include a wearable device **102** and a smart device **112**. In such embodiments, a user **108** may be wearing the wearable device **102**. The wearable device **102** may be a number of different devices, for example, such as audio headphones (wired or wireless), a headset, smart glasses, earbuds, a VR headset, an AR headset, a smart watch, and/or another wearable device including a bone conduction sensor. In another embodiment, rather than a wearable device **102**, another device may be utilized to gather, obtain, or receive a bone conduction signal **110** via a bone conduction sensor, for example, such as a smart phone with an embedded bone conduction sensor. Such wearable devices **102**, describe herein, may include a sensor **104**, such as a sensor **104** configured to detect or sense bone conduction signals from a user **108**, and communications circuitry **106**. The sensor **104**, in an example, may be an accelerometer to measure the vibrations created when the user **108** speaks and that travel through the user's **108** skull. The communications circuitry **106** may be configured to allow communication with the smart device **112** and/or an authentication circuitry (for example, authentication circuitry in FIG. **1**C). Such a configuration may be based on a Bluetooth, WiFi, and/or other communication standard. The wearable device may detect or sense bone conduction signal **110** from a user when a user speaks. The bone conduction signal **110** may then be transmitted to the smart device and/or authentication circuitry. In an embodiment, the user **108** may utilize one or more different wearable devices at different times.

[0035] A user may include a person attempting to utilize the smart device **112**. A user may also include a person, third person, and/or designee who may be directed, permitted, and/or appointed by a person who is verified as a user or accessor able to authorize other users.

[0036] The system **100** in FIG. **1**A may illustrate, at a high level, the interaction between the wearable device **102**, the smart device **112**, and the user **108**, when the user **108** seeks authentication from and/or access to the smart device **112** (for example, to perform one or more functions, including, but not limited to, operating a drone, playing music or videos, accessing user data or information, and/or performing smart home functions, among other operations or functions). In such embodiments, the smart device **112** may include a voice enabled smart assistant (for example, Siri, Alexa, Google, among others), a voice controlled device, a smart voice controlled device, a connected or internet of things (IoT) enabled device, smart appliances, a remote control, a television, a video game entertainment system, a household internet enabled device, a household smart device, a voice controlled intelligent personal assistant device, a voice controlled intelligent personal vehicle management device, computing devices (for example, cell phones, smart phones, laptops, desktops, tablets, among other computing devices), among other smart devices configured to receive an input from a user and, based on the input, perform a function or operation.

[0037] In an embodiment, and as illustrated in FIG. **1**A, the smart device **112** may include a processor **122**, a memory **124** (for example, a non-transitory machine readable medium), a microphone **114** or other sensor, and/or a communications circuitry **116**. In some examples, the smart device **112** may be a computing device. The term "computing device" is used herein to refer to any one or all of servers, a virtual computing device or environment, desktop computers, personal data assistants (PDAs), laptop computers, tablet computers, smart books, palm-top computers, personal computers, smartphones, wearable devices (such as headsets, smartwatches, or the like), and similar electronic devices equipped with at least a processor and any other physical components necessarily to perform the various operations described herein. Devices such as smartphones, laptop computers, tablet computers, and wearable devices are generally collectively referred to as mobile devices.

[0038] The term "server" or "server device" is used to refer to any computing device capable of functioning as a server, such as a master exchange server, web server, mail server, document server, or any other type of server. A server may be a dedicated computing device or a server module (for example, an application) hosted by a computing device that causes the computing device to operate as a server. A server module (for example, server application) may be a full function server module, or a light or secondary server module (for example, light or secondary server application) that is configured to provide synchronization services among the dynamic databases on computing devices. A light server or secondary server may be a slimmed-down version of server type functionality that can be implemented on a computing device, such as a smart phone, thereby enabling it to function as an Internet server (for example, an enterprise e-mail server) only to the extent necessary to provide the functionality described herein.

[0039] As used herein, a "non-transitory machine-readable storage medium" may be any electronic, magnetic, optical, or other physical storage apparatus to contain or store information such as executable instructions, data, and the like. For example, any machine-readable storage medium described herein may be any of random access memory (RAM), volatile memory, non-volatile memory,

flash memory, a storage drive (for example, a hard drive), a solid state drive, any type of storage disc, and the like, or a combination thereof. The memory may store or include instructions executable by the processor.

[0040] As used herein, a "processor" or "processing circuitry" may include, for example one processor or multiple processors included in a single device or distributed across multiple computing devices. The processor (for example, processor **122** shown in FIG. **1**A) may be at least one of a central processing unit (CPU), a semiconductor-based microprocessor, a graphics processing unit (GPU), a field-programmable gate array (FPGA) to retrieve and execute instructions, a real time processor (RTP), other electronic circuitry suitable for the retrieval and execution instructions stored on a machine-readable storage medium, or a combination thereof.

[0041] The smart device **112**, as noted, may include a memory **124** (for example, non-transitory machine readable storage medium). The memory **124** may include instructions or one or more sets of instructions. The instructions may be executed by the processor **122** of the smart device **112**. Such instructions may include instructions to authenticate the user **108**. The instructions to authenticate a user **108** may comprise one or more sets of instructions, sub-instructions, modules, and/or other routines or sub-routines. For example, such instructions may include a first set of instructions. The first set of instructions may include instructions to, when executed, determine whether a received bone conduction signal **110** is consistent with an audio signal **120**. Prior to or in conjunction with execution of the first set of instructions to determine consistency, instructions (for example, a second set of instructions) to pre-process the bone conduction signal **110** and audio signal **120** may be executed. Such pre-processing may include aligning the bone conduction signal **110** with the audio signal **120** (for example, by delaying an earliest received signal to align similar features or aspects of the signals) and passing each of the bone conduction signal **110** and the audio signal **120** through a noise reduction program, algorithm, and/or filter (for example, a Wiener filter). In another embodiment, pre-processing may include converting the bone conduction signal **110** and audio signal **120** to a binary waveform, for determining consistency.

[0042] After pre-processing, consistency of the signals may be determined via execution of the instructions noted above. For example, filtered and/or noise reduced signal waveforms (for example, waveforms for the bone conduction signal **110** and audio signal **120**) may be compared to determine whether the waveforms or features of the waveforms are similar, substantially similar, or consistent. The instructions, when executed, may determine a probability or score based on an amount of similar or consistent features or an amount of differences between the waveforms. The probability or score may indicate whether or not the signals (for example, the bone conduction signal **110** and audio signal **120**) are consistent. In such examples, the smart device **112** or instructions may utilize a threshold or consistency threshold to determine whether the generated probability or score indicates consistency or not. For example, if the generated probability or score is greater than or equal to the consistency threshold, then the instructions, when executed, may determine that the signals (for example, the bone conduction signal **110** and audio signal **120**) are consistent, while if the generated probability or score is less than the consistency threshold, then the instructions, when executed, may determine that the signals (for example, the bone conduction signal **110** and audio signal **120**) are not consistent. If the signals (for example, the bone conduction signal **110** and audio signal **120**) are determined to be not consistent, instructions, when executed, may notify the user **108** of inconsistent signals (for example, such a notification may be generated and sent to the user **108**). Further, if the bone conduction signal **110** and audio signal **120** are inconsistent, then instructions to prompt the user **108** to resubmit a phrase or phrases for authentication may be executed. In an embodiment, a prompt for the user **108** to resubmit a phrase or phrases may be submitted a predetermined or preselected number of times. After the prompt to resubmit has been given the predetermined or preselected number of times and the user **108** has submitted corresponding responses resulting in additional inconsistent bone conduction signals **110** and audio signals **120**, the user **108** may be locked out of the smart device **112** until the user's **108** identity can be verified (for example, via an email or phone call) or until after a predetermined amount of time has passed. In such examples, locking a user may prevent the user from accessing data on or associated with the smart device **112** and/or utilizing functionality of the smart device **112**. Further, after one or more attempts or a pre-determined or pre-selected number of attempts, the smart device **112** may generate a notification indicating a number of unsuccessful attempts at access. The smart device **112** may then transmit such a notification to the user **108**. Further, the notification may be sent via an alternative form of communication, such as email, text message, phone call, or other form of communication.

[0043] If the bone conduction signal **110** and audio signal **120** are determined to be consistent, instructions to verify each signal may be executed. The steps or operation for verification may include passing the bone conduction signal **110** and audio signal **120** through a corresponding trained model or classifier. Each corresponding trained model or classifier may be trained using a number of previous or pre-collected and stored signals and outcomes (for example, previously submitted bone conduction signals **110** or audio signals **120**, previously submitted enrollment bone conduction signals **110** or audio signals **120**, and an indicator to indicate whether the bone conduction signals **110** or audio signals **120** were verified). The trained model or classifier may also be re-trained or further trained using an initial or enrollment submission from the user **108** (for example, an initial or enrollment bone conduction signal or audio signal). In an embodiment, the trained model or classifier may be a supervised or unsupervised learning model. In an embodiment, the trained model or classifier may be based on one or more of decision trees, random forest models, random forests utilizing bagging or boosting (as in, gradient boosting), neural network methods, support vector machines (SVM), other supervised learning models, other semi-supervised learning models, other unsupervised learning models, or some combination thereof, as will be readily understood by one having ordinary skill in the art. Other types of models may be utilized to verify a bone conduction signal **110** or audio signal **120**, such as meta-analytical model or another statistical or probabilistic model. Upon verification or not of the bone conduction signal **110** and audio signals **120**, instructions may be executed to grant or deny access of the user **108** to the smart device **112**.

[0044] Turning to FIG. **1**B, the smart device **112** may include an authentication circuitry **118**. The authentication circuitry **118** may include or may perform the same or similar steps or operations as described herein for the instructions stored in the memory **124** and executed by the processor **122**. The authentication circuitry **118** may be included in or may be a part of the processor **122** and/or memory **124**. The authentication circuitry **118** may be a separate circuit in signal communication with the processor **122** and memory **124**. The authentication circuitry **118**, as illustrated in FIG. **1**C for example, may be separate from the smart device **112**. The authentication circuitry **118**, in such examples, may be a cloud computing service, may be stored on a server, may be accessible via a network (for example, local area network, wide area network, wireless network, and/or other network capable of allowing communication between the smart device **112**, authentication circuitry **118**, and/or the wearable device **102**), or may be stored or be a part of circuitry in signal communication with many smart devices and wearable devices. The authentication circuitry **118**, for example, may reside or may be a part of a server in signal communication with the smart device **112** and/or wearable device **102**. The authentication circuitry **118** may connect to the smart device **112** and wearable device **102** via the communications circuitry of each (for example, communications circuitry **116** and communications circuitry **106**, respectively). In another embodiment, the authentication circuitry **118** may be included in another device. The other device may utilize the authentication circuitry to authenticate users **108**. Other devices may include a security checkpoint (for example, a location where a user **108** swipes a badge or enters a code to access).

[0045] The wearable device **102**, as shown in FIG. **1**C, may connect to the authentication circuitry **118** to provide the bone conduction signal **110** to the authentication circuitry **118**. In another embodiment, the wearable device **102** may connect to the smart device **112** and provide the bone conduction signal **110** to the authentication circuitry **118** via the smart device **112**. In other words, the wearable device **102** may provide a bone conduction signal **110** to the smart device **112** and the smart device **112** may then provide the bone conduction signal **110** to the authentication circuitry **118**.

[0046] In an embodiment and referring to FIG. **1**C, once the authentication circuitry **118** authenticates the user **108**, the authentication circuitry **118** may transmit a signal to the smart device **112** indicating that the user **108** has been authenticated. Once such a signal is received by the smart device **112**, the smart device **112** may allow or enable the user **108** to access the smart device **112** (for example, access features and/or functionality of the smart device **112** and/or data associated with or stored in the smart device **112**).

[0047] Turning to FIG. **1**D, the authentication circuitry **118** may include one or more circuits, chips, sub-circuits, sets of instructions or code, routines or sub-routines, or components. The components included in the authentication circuitry **118** may include audio preprocessing circuitry **126**. The audio preprocessing circuitry **128** may preprocess the audio signal **120** by reducing noise. For example, the audio preprocessing circuitry **126** may include a low band pass filter, such as a Wiener filter, to remove background noise and other unwanted audio. A bone preprocessing circuitry **128** may preprocess the bone conduction signal **110** by aligning or synchronizing the bone conduction signal **110** with the audio signal **120**. The bone preprocessing circuitry **128** may additionally reduce noise from the bone conduction signal **110**, such as noise created by movement of the user. After pre-processing the bone conduction signal **110** and the audio signal **120**, the preprocessed bone conduction signal **110** and the preprocessed audio signal **120** may be transmitted to a consistency score circuitry **130**. The consistency score circuitry **130** may determine whether the bone conduction signal **110** and the audio signal **120** are consistent or, in other words, whether the bone conduction signal **110** and the audio signal **120** are or were produced by the user **108**. Following a determination of consistency, the audio signal may be verified via an audio verification circuitry **132**. The audio verification circuitry **132** may include a trained model or classifier to determine whether the audio signal **120** is from or originates from the user **108**. Following audio verification, the bone conduction signal **110** may be verified via the bone verification circuitry **134**. The bone verification circuitry **134** may include a trained model or classifier to determine whether the bone conduction signal **110** is from or originates from the user **108**. In another embodiment, the bone conduction signal **110** may be verified prior to verification of the audio signal **120**. In yet another embodiment, the audio signal **120** and bone conduction signal **110** may be verified in parallel or at a substantially similar time.

[0048] Turning to FIG. **1**E and FIG. **1**F, the system **100** may include an authentication device **144**. The authentication device **144** may include the authentication circuitry **118** described herein or may include similar or substantially similar functionality as the authentication circuitry **118**. The authentication device **144**, in such examples, may be included in or may be a cloud computing service. The authentication device **144** may be stored on or may be a server. In yet another embodiment, the authentication device **144** may be accessible via a network (for example, local area network, wide area network, wireless network, and/or other network capable of allowing communication between a first device **138**, authentication device **144**, and/or the second device **146**) or may be stored or be a part of circuitry or a computing device in signal communication with many different devices. The authentication device **144** may include a communications interface configured to receive signals from one or more devices.

[0049] The system **100** may include a first device **138** and a second device **146**. The first device **138** may include a computing device, a security device, or a device configured to receive a signal, communicate with the second device **146**, offer functionality or services, offer access to data, and/or offer physical or virtual access to a location, among other functionality. The first device **138** may include a sensor **142** and communications circuitry **140**. The sensor **142** may receive or sense a first signal **152** from the user **108** (for example, an identification signal). The first signal **152** may be an audio signal, a bone conduction signal, and/or signals associated with a badge scan, identification scan, retinal scan, fingerprint scan, facial scan (for example, facial recognition scan), gesture scan (for example, limb or body gesture recognition scan), and/or a scan of some other aspect of a user **108**. The first device **138** may include a communications circuitry **140**. The communications circuitry **140** may provide or transmit the first signal **152** to communications circuitry or a communications interface of the authentication device **144**.

[0050] As noted, the system **100** may include a second device **146**. The second device **146** may include a sensor **148** and a communications circuitry **150**. The sensor **148** may sense a second signal **154** from the user **108**. In an embodiment, the second signal **154** may be a different type of signal than the first signal **152** (for example, the first signal **152** may be an audio signal, while the second signal **154** may be a bone conduction signal). The second signal **154** may be an audio signal, a bone conduction signal, and/or signals associated with a badge scan, identification scan, retinal scan, fingerprint scan, facial scan (for example, facial recognition scan), gesture scan (for example, limb or body gesture recognition scan), and/or a scan of some other aspect of a user **108**. The second device **146** may include a communications circuitry **150**. The communications circuitry **150** may provide or transmit the second signal **154** to the communications circuitry **140** of the first device **138** (as illustrated in FIG. **1**E) and/or the authentication device **144** (as illustrated in FIG. **1**F). The second device **146**, in an embodiment, may be a device associated with and/or related to the user **108** or a personal device owned or utilized by the user **108**.

[0051] For example, the user **108** may generate a first signal **152** and a second signal **154**. The first signal **152** may be received or sensed by the sensor **142** of the first device **138**, while the second signal **154** may be received or sensed by the sensor **148** of the second device **146**. In another embodiment, additional signals may be utilized and/or sensed by the devices and/or other additional devices. The second signal **154** may be transmitted to the first device **138** or the authentication device **144** via communications circuitry **150**. The first device **138** may then transmit the first signal **152**, in addition to, in some embodiments, the second signal **154**, to the authentication device **144** via communications circuitry **140**. The authentication device **144** may determine whether the signals are consistent (for example, from the same user **108**). The authentication device **144** may determine a consistency score based on the two signals. For example, a user **108** may swipe or move a badge against a badge scanner (for example, the first device **138**) and speak into an audio device (for example, the second device **146**), thus generating a first signal (for example, based on the badge scan) and a second signal (for example, based on the audio signal). The authentication device **144** may determine the consistency score based on whether the badge associated with the user **108** matches an audio signal from the same user **108**. As noted, different and/or additional signals may be utilized in such operations, such as a bone conduction signal and/or signals associated with an identification scan, retinal scan, fingerprint scan, facial scan (for example, facial recognition scan), gesture scan (for example, limb or body gesture recognition scan), and/or a scan of some other aspect of a user **108**. After the consistency is determined, the authentication device **144** may verify each signal from the user **108** (for example, whether each of the signals are authentic or, in other words, actually from the user **108**). Verification, as described, may utilize models trained using submitted or previously submitted enrollment or submissions from the user **108**. After verification, the authentication device **144** may grant the user **108** access to utilize functionality of one or more devices (for example, the first device **138**, the second device **146**, and/or additional devices), access to data, and/or physical or virtual access to a location.

[0052] FIG. **2** is a block diagram of a system to authenticate a user, according to an embodiment of the present disclosure. As illustrated a user **202** may wear a wearable device **206** (for example, a headset, headphones, earbuds, smart glasses, and/or VR or AR headset, among other devices). As the user **202** speaks, vibrations from the user's **202** vocal chords may travel through the user's **202** jaw or skull to the wearable device **206** (for example, bone conduction **204**). The wearable device **206** may sense the vibrations and convert the vibrations to a bone conduction signal **214**. The bone conduction signal **214** may be transmitted from the wearable device **206** to a smart device and/or authentication circuitry for user **202** authentication via a WiFi **222** or Bluetooth **224** interface. In addition, the as the user **202** speaks, a user's **202** vocal chords may generate sound or speech (for example, an audio signal **212** generated via air conduction **208**). The sound or speech may be recorded or received by a microphone **210** or other sensor of the smart device. The sound or speech, as an audio signal **212**, may be remain with the smart device (for example, where authentication occurs at or in the smart device) or be transmitted to an authentication circuitry (for example, where authentication occurs separate from the smart device) for authentication.

[0053] Before granting the user **202** access, the smart device and/or authentication circuitry may determine whether the bone conduction signal **214** is consistent with the audio signal **212** (see voice activity consistent **216**). In other words, the smart device and/or authentication circuitry may determine whether the bone conduction signal **214** is from or originates from the same user **202** that provided the audio signal **212**. During the consistency check, the smart device and/or authentication circuitry may compare and/or analyze the bone conduction signal **214** and audio signal **212** to determine to determine consistency. If the bone conduction signal **214** and audio signal **212** are determined to be inconsistent, then the smart device may remain locked (see **220**).

[0054] If the bone conduction signal **214** and audio signal **212** are determined to be consistent, then the smart device and/or authentication circuitry may perform bone conduction signal **214** and audio signal **212** verification. In other words, the bone conduction signal **214** may be passed through a trained model or classifier and/or compared to previous submissions or enrollments to determine whether the bone conduction signal **214** is from or originates from a particular user **202**. Similarly, the audio signal **212** may be passed through a trained model or classifier and/or compared to previous submissions or enrollments to determine whether the audio signal **214** is from or originates from a particular user **202**. Such operations may occur simultaneously or in sequence. If at any point the smart device and/or authentication circuitry determines that either the bone conduction signal **214** or audio signal **212** are not from the user **202**, then the smart device may lock the user out or disable further access to the smart device by the user. If both the bone conduction signal **214** and audio signal **212** are verified, then the smart device may unlock or allow the user to access features of, functionality of, or data stored in the smart device.

[0055] FIG. **3**A, FIG. **3**B, and FIG. **3**C are block diagrams of systems to authenticate a user, according to an embodiment of the present disclosure. Turning first to FIG. **3**A, signals generated by a user may initially be transmitted to a

denoising and filtering module. For example, a bone conduction signal may be received at the denoising and filtering module **302**, while an audio signal may be received at the denoising and filtering module **304**. The denoising and filtering module **302** may remove different frequencies than that of denoising and filtering module **304**, due to the nature of the signals captured. For example, denoising and filtering module **302** may remove signals at about 20 Hz and under. Such signals at about 20 Hz and under may represent noise generated by gravity and human motion. Further a frequency of interest for bone conduction signals may be about 1.5 kHz. The denoising and filtering module **302** may remove frequencies outside of a range defined by the frequency of interest. For example, a band-pass filter, included in the denoising and filtering module **302**, may remove frequencies under about 20 Hz and over about 2 kHz. The denoising and filtering module **304** may include a low-pass band filter.

[0056] After denoising, the bone conduction signal and audio signal may be passed or transmitted to a synchronization module **306**. The synchronization module **306** may utilize cross-correlation to align the bone conduction signal with the audio signal. The synchronization module **306** may delay the earlier of the bone conduction signal and audio signal so that the bone conduction signal and audio signal reach a maximum cross-correlation, such that the signals may be further processed and analyzed to determine if they are from the same user.

[0057] After synchronization, a consistency score may be determined. The score may be generated using a voice activity detection module **308** and a similarity check module **310**. The voice activity module **308** may convert the bone conduction signal and the audio signal to binary waveforms. The binary waveforms may be compared to, at the least, ensure that voice and bone conduction activity is occurring at the same time. Such analysis ensures that an in depth consistency check is not performed if the bone conduction signal and audio signal do not at least include matching activity time frames.

[0058] The bone conduction signal and audio signal may then be analyzed and compared in the similarity check module **310**. The similarity check module **310** may normalize, chunk the signals into frames, and transform the signals into a time-frequency grid by a short-time Fourier Transform. The processed signals may then be compared and a score generated. Depending on the score, it may be determined whether the bone conduction signal and the audio signal are form the same user (for example, a high score indicating the bone conduction signal and the audio signal is consistent and a low score indicating bone conduction signal and the audio signal are inconsistent). Additionally, the consistency score may be compared to a threshold (for example, a consistency threshold) and if the score exceeds the threshold, then the bone conduction signal and the audio signal may be determined to be consistent.

[0059] In another embodiment, the bone conduction signal and the audio signal may be converted to a waveform and the waveform may be compared to determine whether certain features are similar. For example, the waveforms may simply be compared to determine each time of activity (for example, as illustrated in the air-bone waveform **311**). In another example, specific frequencies may be compared. In another example, or in addition to the waveform, the signals may be converted to a binary waveform (as noted above) which simply denotes activity using a square wave-form (for example, as illustrated in voice activity **313**, where a 1 would indicate activity and 0 would indicate non-activity).

[0060] In an embodiment, if the bone conduction signal and the audio signal are determined to be consistent, then features may be extracted from each of the bone conduction signal and the audio signal. The bone conduction features may be extracted using a convolutional neural network (CNN) or other neural network or machine learning model. The CNN may leverage an image-classification method to extract image-like feature maps from using a time-frequency analysis. The audio features extracted may include various spectral characteristics of the audio signal. In an embodiment, extracting features may include converting the audio signal to an audio signal feature vector and converting the bone conduction signal to a bone conduction signal vector.

[0061] FIG. **3**B illustrates two examples of a pass and a fail in regards to consistency between the audio signal and bone conduction signal. After preprocessing, the audio signal and bone conduction signal may align or may be substantially similar, in the case of an audio signal and bone conduction signal being from the same user (see **314**). In another example, after preprocessing some audio signals and bone conduction signals may not match (see **316**). In such an example, the audio signal and bone conduction signal may be so different as to indicate a potential attack or spoof, thus access to the smart device may be denied. Further, in some examples, no bone conduction signal may be detected, in which case access to the smart device may be denied.

[0062] Turning to FIG. **3**C, after consistency is determined and the features extracted, the bone conduction features **320** may be transmitted to a trained model or classifier **332**. The trained model or classifier may be trained using a user's **318** enrollment or submission bone conduction signals. The trained model or classifier may be based on a CNN or other neural network **334**. The output of the CNN or classifier may be a bone conduction vector. The system may include a multi-classification module **336** or a multi-class image classifier. An output of the multi-classification module **336** may include a probability indicating whether the original bone conduction signal is from or originates from a particular user. In another embodiment, the bone conduction vector may be combined with the audio vector at **338**. A score may then be generated at a probability linear discriminant analysis (PLDA) module **340** using the air-bone speaker embedding (for example, the bone conduction vector combined with the audio vector). In another embodiment, a linear discriminant analysis (LDA), a cosine similarity scorer (CSS), or another statistical or probabilistic model or classifier may be utilized, rather than the PLDA. Based on the score, the user may be verified **342** or filed **344**.

[0063] As noted, the audio features may be extracted after the consistency check. After the features are extracted, the audio features or vectors may be applied to a model or classifier to further reduce the amount of vectors. The reduced audio vectors, as noted, may be added to the air-bone speaker embedding **338**.

[0064] In another embodiment, prior to authentication of the user **318**, the smart device and/or authentication circuitry may prompt the user to submit an audio signal and bone conduction signal. Such a signal may be submitted for one or more wearable devices of the user. The results may be stored in a database **326** for future use. Further the model or

classifier used in relation to the bone conducting signal and the audio signal may be trained using the submission.

[0065] FIG. **4** is a flow diagram of two-way user authentication, according to an embodiment of the present disclosure. The method is detailed with reference to the smart device, wearable device, and system **100** of FIG. **1**A through FIG. **1**D. Unless otherwise specified, the actions of method **400** may be completed within the smart device, wearable device, and/or authentication circuitry. Specifically, method **400** may be included in one or more programs, protocols, or instructions loaded into the memory of the smart device or wearable device and executed on the processor or one or more processors of the smart device or wearable device. The order in which the operations are described is not intended to be construed as a limitation, and any number of the described blocks may be combined in any order and/or in parallel to implement the methods.

[0066] At block **402**, the smart device may determine whether an audio signal has been received. The smart device may wait until such a signal is received. In an embodiment, the smart device may prompt the user to submit the response (for example, the audio signal and the bone conduction signal).

[0067] At block **404**, the wearable device and/or smart device may determine whether the bone conduction signal has been received. In an embodiment, the smart device and/or authentication circuitry may wait for a specified period of time for the bone conduction signal. For example, the smart device and/or authentication circuitry may wait about 30 seconds, about 1 minute, or up to about 5 minutes. Longer periods of time between reception of signals may indicate a potential attack or spoof via a third party. After the period of time has lapsed, the smart device and/or authentication circuitry may deny access for the user to utilize the smart device. In an embodiment, a portion of functionality of the smart device may be available for use by the user.

[0068] At block **406**, the smart device and/or authentication circuitry may analyze the audio and bone conduction signals. Such analysis may include, at a high level, a consistency check and verification. The consistency check may include preprocessing the bone conduction signal and the audio signal. If the signals are consistent, then smart device and/or authentication circuitry may verify the audio signal and the bone conduction signal. The verification may include applying the audio signal or audio features or vectors and the bone conduction signal or bone conduction features or vectors to a trained model or classifier corresponding to the signal (for example, a model or classifier specific to either the bone conduction signal or the audio signal). The output of such a model may be transmitted to a PLDA or other statistical or probabilistic model to determine a score.

[0069] At block **408**, the smart device and/or authentication circuitry may authenticate the user. The smart device and/or authentication circuitry may determine, based on scores generated from during analysis of the bone conduction signal and audio signal, that the user is authentic or is verified.

[0070] At block **410**, if the user is authenticated, the smart device and/or authentication circuitry may grant access, at block **412**, to the smart device. If the user is not authenticated, the smart device and/or authentication circuitry, at block **414**, may deny access to the smart device.

[0071] FIG. **5**A and FIG. **5**B are flow diagrams of two-way user authentication, according to an embodiment of the present disclosure. The method is detailed with reference to the smart device, wearable device, and system **100** of FIG. **1**A through FIG. **1**D. Unless otherwise specified, the actions of method **400** may be completed within the smart device, wearable device, and/or authentication circuitry. Specifically, method **400** may be included in one or more programs, protocols, or instructions loaded into the memory of the smart device or wearable device and executed on the processor or one or more processors of the smart device or wearable device. The order in which the operations are described is not intended to be construed as a limitation, and any number of the described blocks may be combined in any order and/or in parallel to implement the methods.

[0072] At block **502**, the smart device and/or authentication circuitry may determine whether a user is enrolled or has been initialized. In other words, the smart device and/or authentication circuitry may determine whether the user has submitted an initial phrase or one or more phrases.

[0073] At block **504**, if the user has not been enrolled or initialized, then the smart device and/or the authentication circuitry may prompt a user to submit one or more phrases for initialization or enrollment. The one or more phrases may be random phrases and/or specified phrases (for example, specified by the smart device). In such examples, the smart device may issue or transmit a prompt as a text based message or as an audio prompt. In an embodiment, the smart device and/or authentication circuitry may issue or transmit the prompt for each of the user's wearable devices.

[0074] At block **506**, the smart device and/or authentication circuitry may issue or transmit a prompt as to whether an additional wearable device is to be enrolled or initialized. If an additional wearable device is to be initialized or enrolled, then the smart device and/or authentication circuitry may prompt the user to wear the wearable device and submit one or more phrases.

[0075] At block **508**, the smart device and/or authentication circuitry may update a trained bone conduction model with the submitted one or more phrases. The trained bone conduction model may be utilized to verify a user's bone conduction signal. Utilizing the user's submitted one or more phrases may ensure that an accurate verification may occur. At block **510**, the smart device and/or authentication circuitry may update a trained audio model with the submitted one or more phrases. The trained bone conduction model may be utilized to verify a user's bone conduction signal. Utilizing the user's submitted one or more phrases ensure that an accurate verification may occur.

[0076] At block **512**, the smart device and/or authentication circuitry may determine whether an audio signal has been received. The smart device and/or authentication circuitry may wait for such a signal prior to proceeding to the next operation. In another embodiment, the smart device and/or authentication circuitry may receive the bone conduction signal prior to the audio signal.

[0077] At block **514**, the smart device and/or the authentication circuitry may determine whether the bone conduction signal has been received. In an embodiment, the smart device and/or authentication circuitry may wait for a specified or preselected period of time prior to denying access to the user. The smart device and/or the authentication circuitry may wait for about 30 seconds, about 1 minute, or up to about 5 minutes. Longer periods of time between reception

of signals may indicate a potential attack or spoof via a third party. In an embodiment, the bone conduction signal is received by the wearable device at substantially the same time as the audio signal is received by the microphone or other sensor.

[0078] If the bone conduction signal is received, at block **516**, the smart device and/or authentication circuitry may preprocess the audio signal. Preprocessing the audio signal may include passing the audio signal through a low-band pass filter, through a Wiener filter, and/or utilizing other noise reduction techniques, as will be understood by those skilled in the art.

[0079] At block **518**, the smart device and/or the authentication circuitry may preprocess the bone conduction signal. Preprocessing the bone conduction signal may include passing the bone conduction signal through a band pass filter, through a Wiener filter, and/or utilizing other noise reduction techniques, as will be understood by those skilled in the art. The band pass filter may remove frequencies below about 20 Hz and frequencies above about 2 kHz.

[0080] At block **520**, the smart device and/or the authentication circuitry may delay the earliest received signal to align the preprocessed bone conduction signal and the preprocessed audio signal. The time that either signal is received may not match the other. As such, to ensure an accurate consistency check, the smart device and/or the authentication circuitry may shift the earliest received signal in relation to time. Thus, at least from the perspective of alignment according to or in relation to time, the preprocessed bone conduction signal and the preprocessed audio signal may align.

[0081] At block **522**, the smart device and/or the authentication circuitry may determine a bone conduction power distribution with respect to time. Higher spectral power for each signal may generate higher correlations considering the amplitude. Therefore, selecting the frequencies with the highest or largest power ensures accurate consistency checks. Such a determination may be represented by $y_b(t) \leftarrow \Sigma_f y_b(f,t)$.

[0082] At block **524**, the smart device and/or the authentication circuitry may select the time range of interest for the bone conduction power distribution. As indicated, the higher the power for a particular frequency the likelier correlation between a bone conduction signal and audio signal is, if the signals are from the same user. As such, the smart device and/or the authentication circuitry may select the time range with the highest power or spectral power. Such an operation may be represented by $t'\arg_t[y_b(t) \geq \theta]$.

[0083] At block **526**, the smart device and/or the authentication circuitry may determine an audio power distribution and/or bone conduction power distribution with respect to frequency. Such operations may be represented by, for audio, $y_a(f) \leftarrow \Sigma_{t'} y_a(f,t')$ and, for bone conduction $y_b(f) \leftarrow \Sigma_{t'} y_b(f,t')$.

[0084] At block **528**, the smart device and/or the authentication circuitry may select the top frequencies of the bone conduction signal and audio signal power distribution. Such an operation may be represented by $m \leftarrow \arg_l \text{Sort}\,(y_a(f))_{1:m}$, and $n \leftarrow \arg_l \text{Sort}\,(y_b(f))_{1:N}$. At block **530**, the smart device and/or authentication circuitry may determine a correlation matrix, as represented by $C \leftarrow \text{Corr}^{M \times N}\,[y_a(f,t'),y_b(f,t')]$. Using the correlation matrix, at block **532**, the smart device and/or the authentication circuitry may generate a consistency score, as represented by

$$S \leftarrow \max_{m \leq M, n \leq N} C(m, n).$$

[0085] At block **534**, the smart device and/or the authentication circuitry may determine whether the consistency score indicates that the bone conduction signal and audio signal are consistent or from the same user. The smart device and/or the authentication circuitry may utilize a consistency threshold to determine whether the consistency score indicates that the bone conduction signal and audio signal are consistent or from the same user (for example, the consistency score is greater than or equal to the consistency threshold.

[0086] At block **536**, the smart device and/or the authentication circuitry may generate an audio feature vector. Using a neural network, a max pooling layer, or a fully connected layer, at block **538**, the smart device and/or the authentication circuitry may reduce the audio feature vectors. At block **540**, the smart device and/or the authentication circuitry may verify the reduced audio feature vector with the enrolled user template and/or a classifier.

[0087] At block **542**, the smart device and/or the authentication circuitry may generate a bone conduction feature vector. Using a neural network, a max pooling layer, or a fully connected layer, at block **544**, the smart device and/or the authentication circuitry may reduce the bone conduction feature vector. At block **546**, the smart device and/or the authentication circuitry may verify the reduced bone conduction feature vector with the enrolled user template and/or a classifier.

[0088] At block **544**, the smart device and/or the authentication circuitry may utilize the results of block **546** and block **540** to determine whether the bone conduction signal and the audio signals have been verified. If the signals have been verified, at block **550**, the smart device and/or the authentication circuitry may enable access for the user.

[0089] If the signals have not been verified, at block **552**, the smart device and/or the authentication circuitry may prompt the user to resubmit an audio and bone conduction signal for resubmission (for example, submit an additional attempt). The smart device and/or the authentication circuitry may allow for a specified number of resubmissions or at least one resubmission. Once that number has been met, the smart device and/or the authentication circuitry may deny access to the user at block **554**.

[0090] FIG. **4** and FIG. **5**A through FIG. **5**C illustrate flowcharts describing sets of operations performed by apparatuses, methods, and computer program products according to various example embodiments. It will be understood that each block of the flowcharts, and combinations of blocks in the flowcharts, may be implemented by various means, embodied as hardware, firmware, circuitry, and/or other devices associated with execution of software including one or more software instructions. For example, one or more of the operations described above may be embodied by software instructions. In this regard, the software instructions which embody the procedures described above may be stored by a memory of an apparatus employing an embodiment and executed by a processor of that apparatus. As will be appreciated, any such software instructions may be loaded onto a computing device or other programmable apparatus (for example, hardware) to produce a machine, such that the resulting computing device or other program-

mable apparatus implements the functions specified in the flowchart blocks. These software instructions may also be stored in a computer-readable memory that may direct a computing device or other programmable apparatus to function in a particular manner, such that the software instructions stored in the computer-readable memory produce an article of manufacture, the execution of which implements the functions specified in the flowchart blocks. The software instructions may also be loaded onto a computing device or other programmable apparatus to cause a series of operations to be performed on the computing device or other programmable apparatus to produce a computer-implemented process such that the software instructions executed on the computing device or other programmable apparatus provide operations for implementing the functions specified in the flowchart blocks.

[0091] The flowchart blocks support combinations of means for performing the specified functions and combinations of operations for performing the specified functions. It will be understood that one or more blocks of the flowcharts, and combinations of blocks in the flowcharts, can be implemented by special purpose hardware-based computing devices which perform the specified functions, or combinations of special purpose hardware and software instructions.

[0092] In some embodiments, some of the operations above may be modified or further amplified. Furthermore, in some embodiments, additional optional operations may be included. Modifications, amplifications, or additions to the operations above may be performed in any order and in any combination.

[0093] This application is related to U.S. Provisional Application No. 63/268,999, filed Mar. 8, 2022, titled "SYSTEMS AND APPARATUS FOR MULTIFACTOR AUTHENTICATION USING BONE CONDUCTION AND AUDIO SIGNALS," U.S. Provisional Application No. 63/269,001, filed Mar. 8, 2022, titled "METHOD FOR MULTIFACTOR AUTHENTICATION USING BONE CONDUCTION AND AUDIO SIGNALS," and U.S. Provisional Application No. 63/380,229, filed Oct. 19, 2022, titled "SYSTEMS AND METHODS FOR CONTINUOUS, ACTIVE, AND NON-INTRUSIVE USER AUTHENTICATION," the disclosures of which are incorporated herein by reference in their entirety.

[0094] In the drawings and specification, several embodiments of systems and methods to provide two-way authentication for a user via a smart device or device and a wearable device have been disclosed, and although specific terms are employed, the terms are used in a descriptive sense only and not for purposes of limitation. Embodiments of systems and methods have been described in considerable detail with specific reference to the illustrated embodiments. However, it will be apparent that various modifications and changes can be made within the spirit and scope of the embodiments of systems and methods as described in the foregoing specification, and such modifications and changes are to be considered equivalents and part of this disclosure.

What is claimed is:

1. A system for two-way authentication of a user, the system comprising:

a wearable device including:

a sensor to receive a bone conduction signal based on a user's speech, and

a communication circuitry configured to transmit the bone conduction signal; and

a smart device including:

(a) a microphone configured to receive an audio signal from the user's speech, and

(b) a bone and audio authentication circuitry configured to:

receive the bone conduction signal from the communication circuitry,

analyze the bone conduction signal and the audio signal, and

authenticate the user in response to analysis of the bone conduction signal and the audio signal.

2. The system of claim **1**, wherein the wearable device comprises one or more of a headphone, a headset, an earbud, a virtual reality (VR) headset, or an augmented reality (AR) headset.

3. The system of claim **1**, wherein the smart device comprises one or more of a computing device, a smart phone, a tablet, a remote control, a television, a video game entertainment system, a household internet enabled device, a household smart device, a voice controlled intelligent personal assistant device, or a voice controlled intelligent personal vehicle management device.

4. The system of claim **1**, wherein the bone and audio authentication circuitry, during the analysis of the bone conduction signal and the audio signal, is configured to:

pre-process the bone conduction signal and the audio signal;

generate a bone conduction feature vector and an audio conduction feature vector;

reduce the bone conduction feature vector and the audio conduction feature vector to generate a reduced bone conduction feature vector and a reduced audio conduction feature vector; and

determine, using a trained model, a probability that the reduced bone conduction feature vector and the reduced audio conduction feature vector originate from the user.

5. The system of claim **4**, wherein the bone and audio authentication circuitry is further configured to, prior to analysis of the bone conduction signal and the audio signal, prompt the user to enroll in relation to the smart device.

6. The system of claim **5**, wherein enrollment includes speaking a random or specified phrase to the smart device and with the wearable device to thereby generate an enrollment template.

7. The system of claim **6**, wherein the bone and audio authentication circuitry, during analysis of the bone conduction signal and the audio signal, is configured to:

compare the reduced bone conduction feature vector and the reduced audio conduction feature vector to the enrollment template to determine authentication of the user.

8. The system of claim **1**, wherein authentication of the user enables the user to access functionality of the smart device.

9. The system of claim **1**, wherein the smart device is configured to prompt an unauthenticated user to give at least one additional attempt to obtain authentication from the smart device.

10. The system of claim **1**, wherein an unauthenticated user comprises an attacker, and wherein the smart device is configured to, in response to unauthenticated bone and audio signals, locks access to personal user data.

11. The system of claim **10**, wherein the smart device is configured to, in response to the unauthenticated bone and audio signals:

lock functionality of the smart device; and

notify the user via a pre-selected alternative form of communication.

12. A smart device for two-way authentication of a user, the smart device comprising:

a communications interface configured to receive a bone conduction signal from the user via a wearable device;

a microphone configured to receive an audio signal from the user;

a bone and audio authentication circuitry configured to:

analyze the bone conduction signal and the audio signal; and

in response to a score, based on analysis of the bone conduction signal and the audio signal, being greater than or equal to a preselected threshold, authenticate the user.

13. The smart device of claim **12**, wherein the wearable device receives the bone conduction signal at substantially a same time as the microphone receives the audio signal.

14. The smart device of claim **13**, wherein the bone and audio authentication circuitry is configured to, prior to analysis, prompt the user to submit an enrollment template or response.

15. The smart device of claim **14**, wherein the enrollment template or response includes one or more specific phrases to be spoken by the user.

16. The smart device of claim **15**, wherein the smart device is configured to prompt the user to submit the enrollment template or response for the wearable device.

17. A system for two-way authentication of a user, the system comprising:

one or more wearable devices, each of the one or more wearable devices including:

a sensor to receive a bone conduction signal based on a user's speech, and

a communication circuitry configured to wirelessly transmit the bone conduction signal; and

a smart device including;

(a) a microphone configured to receive an audio signal from the user's speech, and

(b) bone and audio authentication circuitry configured to:

receive the bone conduction signal from the communication circuitry,

determine, using a consistency evaluation algorithm, a consistency score based on a comparison of the bone conduction signal and the audio signal,

in response to the consistency score being greater than or equal to a predetermined threshold:

determine, using a first verification model, a first probability indicating that the audio signal originates from the user,

determine, using a second verification model, a second probability indicating that the bone conduction signal originates from the user, and

in response to the first probability indicating that the audio signal originates from the user being greater than or equal to a second preselected threshold and the second probability indicating that the bone conduction signal originates from the user being greater than or equal to a third preselected threshold:

authenticate the user based on the analysis of the bone conduction signal and audio signal.

18. The system of claim **17**, wherein the smart device is configured to, prior to authentication, prompt the user to submit an enrollment response.

19. The system of claim **18**, wherein the smart device is configured to prompt the user to submit the enrollment response for each of the one or more wearable devices.

20. The system of claim **19**, wherein the first verification model and the second verification model are trained using data from prior users and using a user's enrollment response.

21. The system of claim **20**, wherein the user's enrollment response includes one or more bone conduction signals and corresponding one or more audio signals.

22. The system of claim **21**, wherein the enrollment response further includes an indicator to identify one of the one or more wearable devices corresponding to at least one of the one or more bone conduction signals and at least one of the one or more audio signals.

23. The system of claim **17**, wherein the smart device is configured to, prior to determination of the consistency score, align the bone conduction signal and the audio signal, and wherein the consistency score is based on the aligned bone conduction signal and audio signal.

24. A system for two-way authentication of a user, the system comprising:

a wearable device including:

a first sensor to receive a bone conduction signal based on a user's speech, and

a first communication circuitry configured to transmit the bone conduction signal;

a device including:

a second sensor configured to receive an identification signal from a user, and

a second communication circuitry configured to transmit the identification signal; and

an authentication circuitry configured to:

receive the bone conduction signal from the first communication circuitry,

receive the identification signal from the second communication circuitry,

analyze the bone conduction signal and the identification signal, and

authenticate the user in response to analysis of the bone conduction signal and identification signal.

25. The system of claim **24**, wherein the identification signal includes a signal generated by scanning a badge or identification card.

26. A smart device for two-way authentication of a user, the smart device comprising:

a communications interface configured to receive a bone conduction signal from a user;

a microphone configured to receive an audio signal from the user;

a bone and audio authentication circuitry configured to:

analyze the bone conduction signal and the audio signal;

in response to a score, based on analysis of the bone conduction signal and the audio signal, being greater than or equal to a preselected threshold, authenticate the user.

27. The smart device of claim **26**, wherein a wearable devices transmits the bone conduction to the smart device.

28. The smart device of claim **27**, wherein the bone and audio authentication circuitry is configured to, prior to the analysis, prompt the user to submit an enrollment template or response.

29. The smart device of claim **28**, wherein the enrollment template or response includes one or more specific phrases to be spoken by the user.

30. The smart device of claim **29**, wherein the smart device is configured to prompt the user to submit the enrollment template or response for the wearable device.

31. An authentication device for two-way authentication of a user, the authentication device comprising:

a communications interface configured to receive:

a first signal from a user; and

a second signal from the user, the second signal being a different type of signal than the first signal; and

an authentication circuitry configured to:

analyze the first signal and the second signal; and

in response to a score, based on analysis of the first signal and the second signal, being greater than or equal to a preselected threshold, authenticate the user.

32. The authentication device of claim **31**, wherein the first signal includes one or more of an audio signal, a bone conduction signal, or signals associated with a badge scan, identification scan, retinal scan, fingerprint scan, facial scan, or gesture scan.

33. The authentication device of claim **31**, wherein the second signal includes one or more of an audio signal, a bone conduction signal, or signals associated with a badge scan, identification scan, retinal scan, fingerprint scan, facial scan, or gesture scan.

34. The authentication device of claim **33**, wherein analysis of the first signal and the second signal includes (a) a determination of whether the first signal and the second signal are from the user, and (b) a determination, if the first signal and the second signal are from the user, of the score based on a verification that each of the first signal and the second signal are authentic.

35. A method for two-way authentication of a user, the method comprising:

in response to reception of an audio signal from a user, determining, via a smart device, whether a corresponding bone conduction signal is received from one of one or more separate wearable devices;

in response to a determination that the corresponding bone conduction signal is received:

determining, via the smart device, whether the audio signal and corresponding conduction signal are consistent;

in response to a determination that the audio signal and corresponding conduction signal are consistent:

verifying, via the smart device, the audio signal;

verifying, via the smart device, the corresponding bone conduction signal;

in response to verification of the audio signal and the corresponding bone conduction signal, authenticating the user.

36. The method of claim **35**, further comprising, upon authentication of the user, allowing the user to (a) access or utilize the smart device and (b) access data on the smart device.

37. The method of claim **35**, further comprising, upon authentication of the user, allowing the user to (a) access or utilize the smart device and (b) access data on the smart device associated with the user.

38. The method of claim **35**, further comprising, upon authentication of the user, allowing the user to (a) access or utilize the smart device and (b) access personal data on the smart device associated with the user.

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