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Gabrilovich et al.

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(45) **Date of Patent: Sep. 15, 2026**

(54) **METHODS FOR IDENTIFYING DEVOLVED SEQUENCES OF HANDWRITING MOTIONS FOR GENERATING TARGET INPUTS USING A CO-ADAPTED INPUT-DETECTION MODEL, AND DEVICES AND SYSTEMS THEREFOR**

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(73) Assignee: **Meta Platforms Technologies, LLC**, Menlo Park, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 101 days.

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(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**

G06F 3/04883	(2022.01)
G06T 11/00	(2026.01)
G06F 3/01	(2006.01)

(52) **U.S. Cl.**
CPC ***G06F 3/04883*** (2013.01); ***G06T 11/00*** (2013.01); *G06F 3/015* (2013.01); *G06T 2200/24* (2013.01)

(58) **Field of Classification Search**
CPC G06F 3/014; G06F 3/015; G06F 3/017; G06F 3/04883; G06T 11/00; G06T 2200/24
See application file for complete search history.

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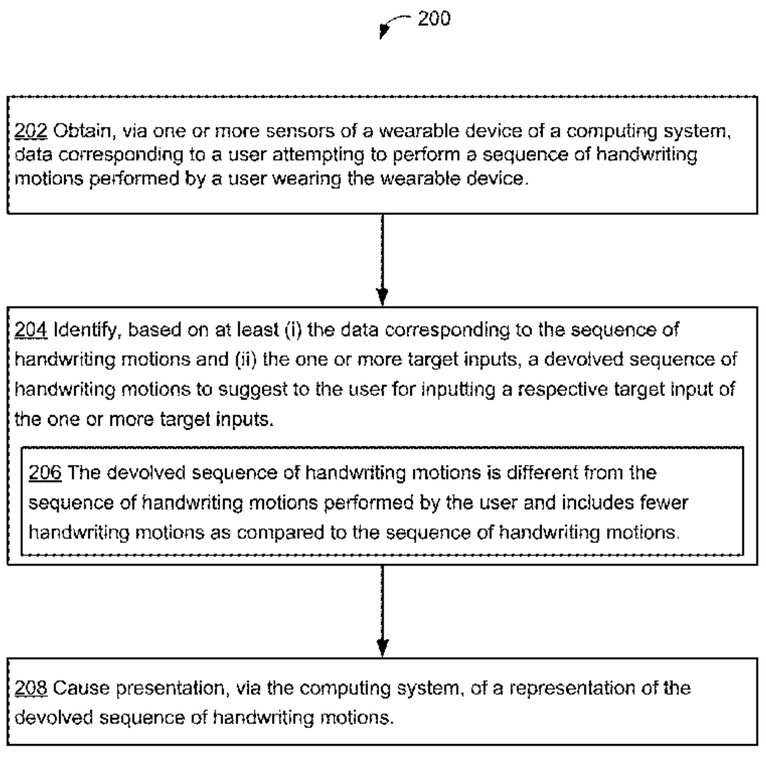
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(74) *Attorney, Agent, or Firm* — Morgan, Lewis & Bockius LLP

(57) **ABSTRACT**

A method of identifying devolved sequences of handwriting motions is described. The method includes obtaining, via sensors of a wearable device of a computing system, data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs while wearing the wearable device. The method

(Continued)



includes identifying, based on at least (i) the data corresponding to the user attempting to perform the sequence of handwriting motion and (ii) the one or more target inputs associated with the sequence of handwriting motions, a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs. The devolved sequence of handwriting motions is a different sequence and includes fewer handwriting motions as compared to the sequence of handwriting motions. And the method includes presenting a representation of the devolved sequence of handwriting motions.

20 Claims, 22 Drawing Sheets

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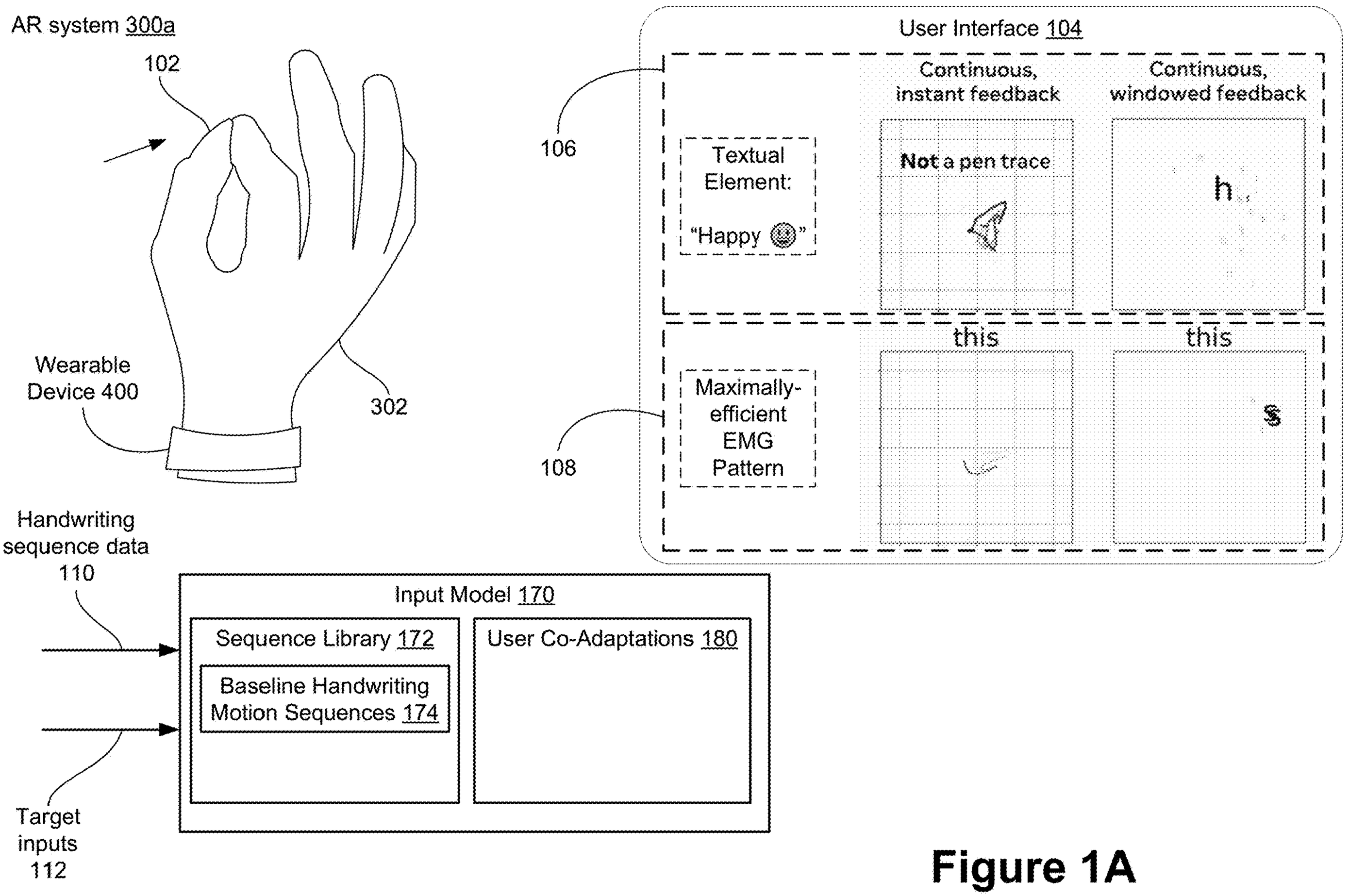

AR system 300a
102
Wearable Device 400
302
User Interface 104
106
Continuous, instant feedback
Continuous, windowed feedback
Textual Element:
"Happy"
Not a pen trace
h
108
Maximally-efficient EMG Pattern
this
this
Handwriting sequence data 110
Input Model 170
Sequence Library 172
Baseline Handwriting Motion Sequences 174
User Co-Adaptations 180
Target inputs 112

Figure 1A

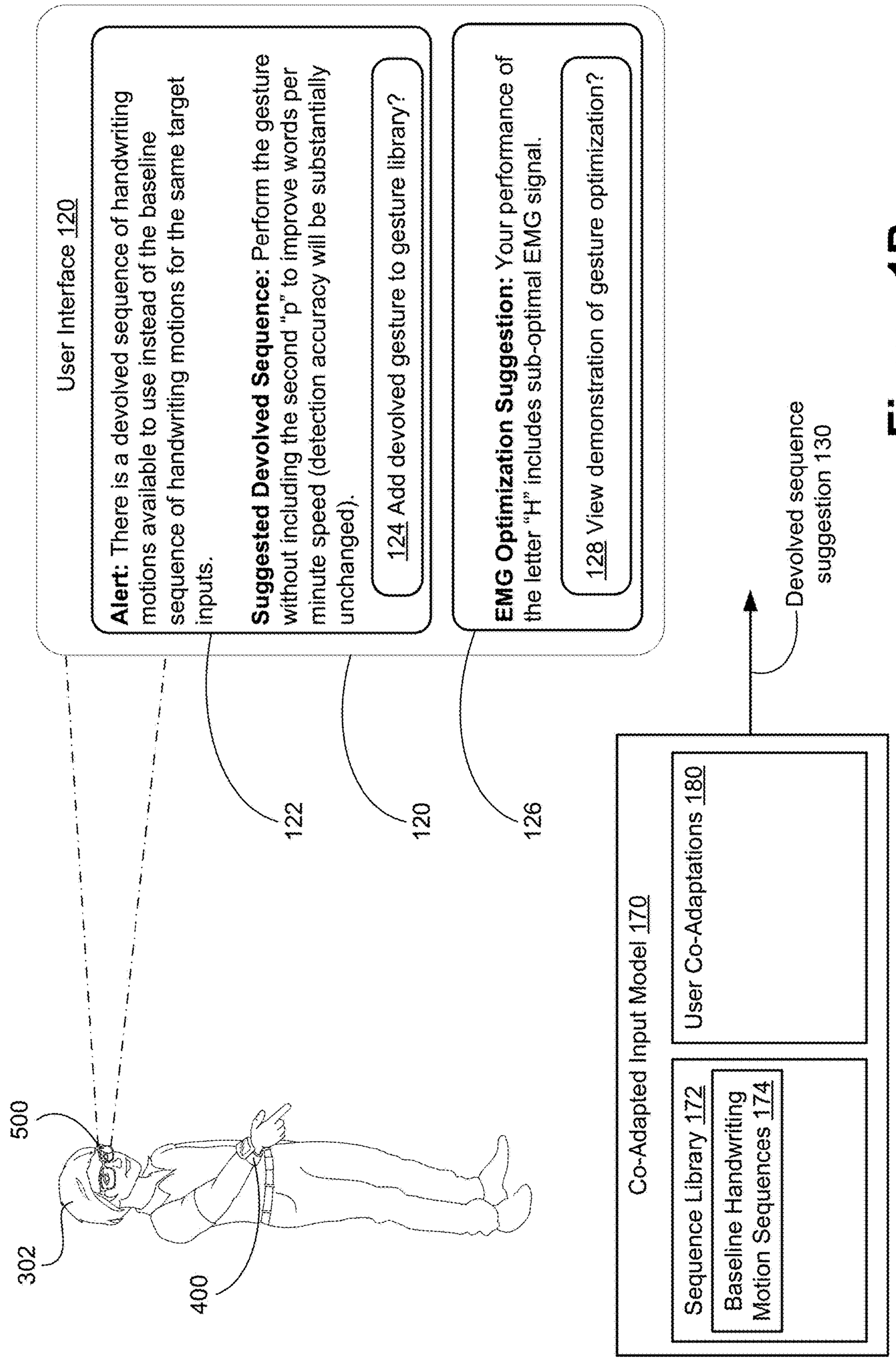

User Interface 120
Alert: There is a devolved sequence of handwriting motions available to use instead of the baseline sequence of handwriting motions for the same target inputs.
Suggested Devolved Sequence: Perform the gesture without including the second "p" to improve words per minute speed (detection accuracy will be substantially unchanged).
124 Add devolved gesture to gesture library?
EMG Optimization Suggestion: Your performance of the letter "H" includes sub-optimal EMG signal.
128 View demonstration of gesture optimization?
122
120
126
500
302
400
Devolved sequence suggestion 130
Co-Adapted Input Model 170
Sequence Library 172
Baseline Handwriting Motion Sequences 174
User Co-Adaptations 180

Figure 1B

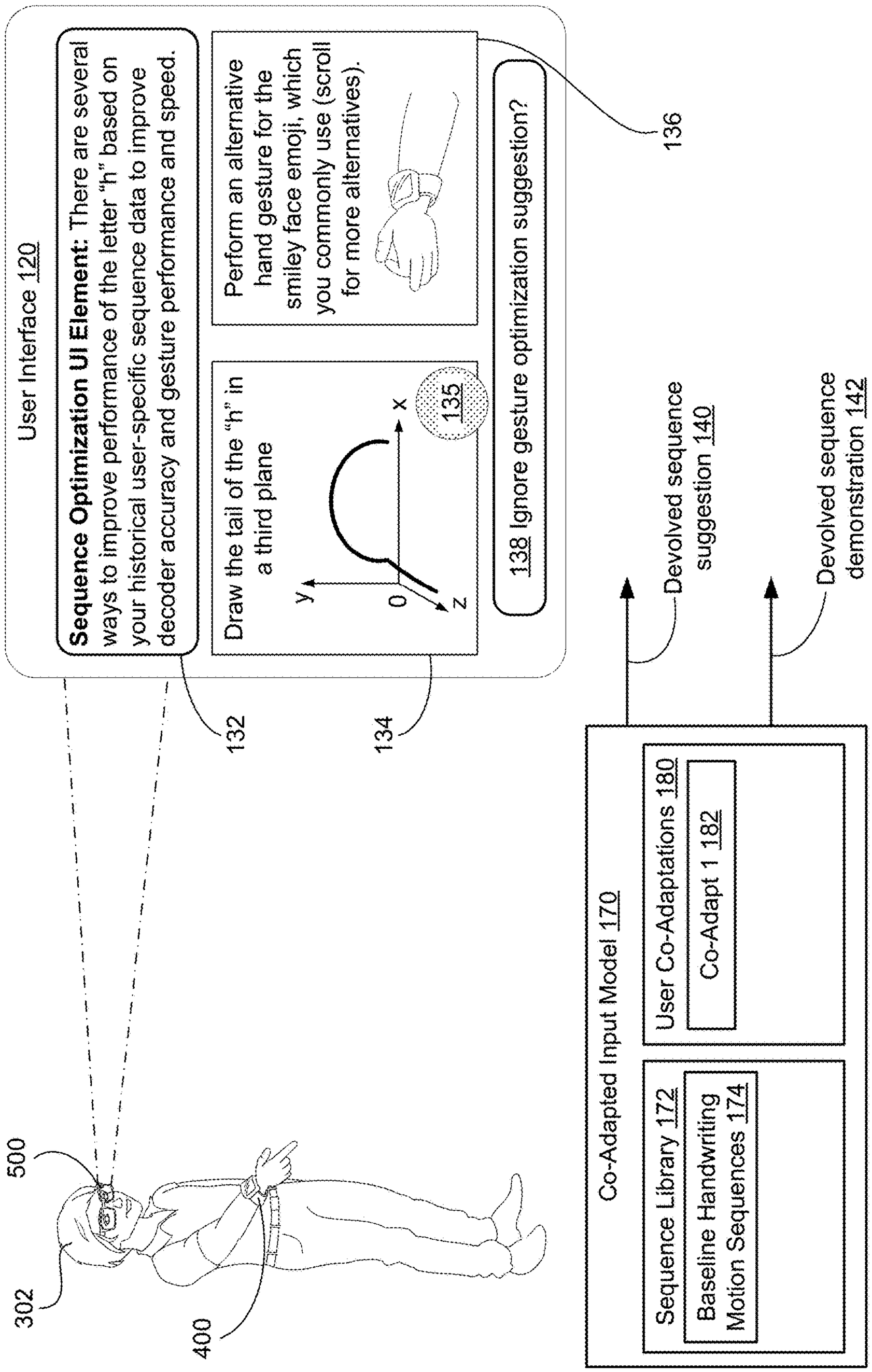

User Interface 120
Sequence Optimization UI Element: There are several ways to improve performance of the letter "h" based on your historical user-specific sequence data to improve decoder accuracy and gesture performance and speed.
Perform an alternative hand gesture for the smiley face emoji, which you commonly use (scroll for more alternatives).
Draw the tail of the "h" in a third plane
y
0
x
z
135
138 Ignore gesture optimization suggestion?
132
134
136
Devolved sequence suggestion 140
Devolved sequence demonstration 142
Co-Adapted Input Model 170
Sequence Library 172
Baseline Handwriting Motion Sequences 174
User Co-Adaptations 180
Co-Adapt 1 182
500
302
400

Figure 1C

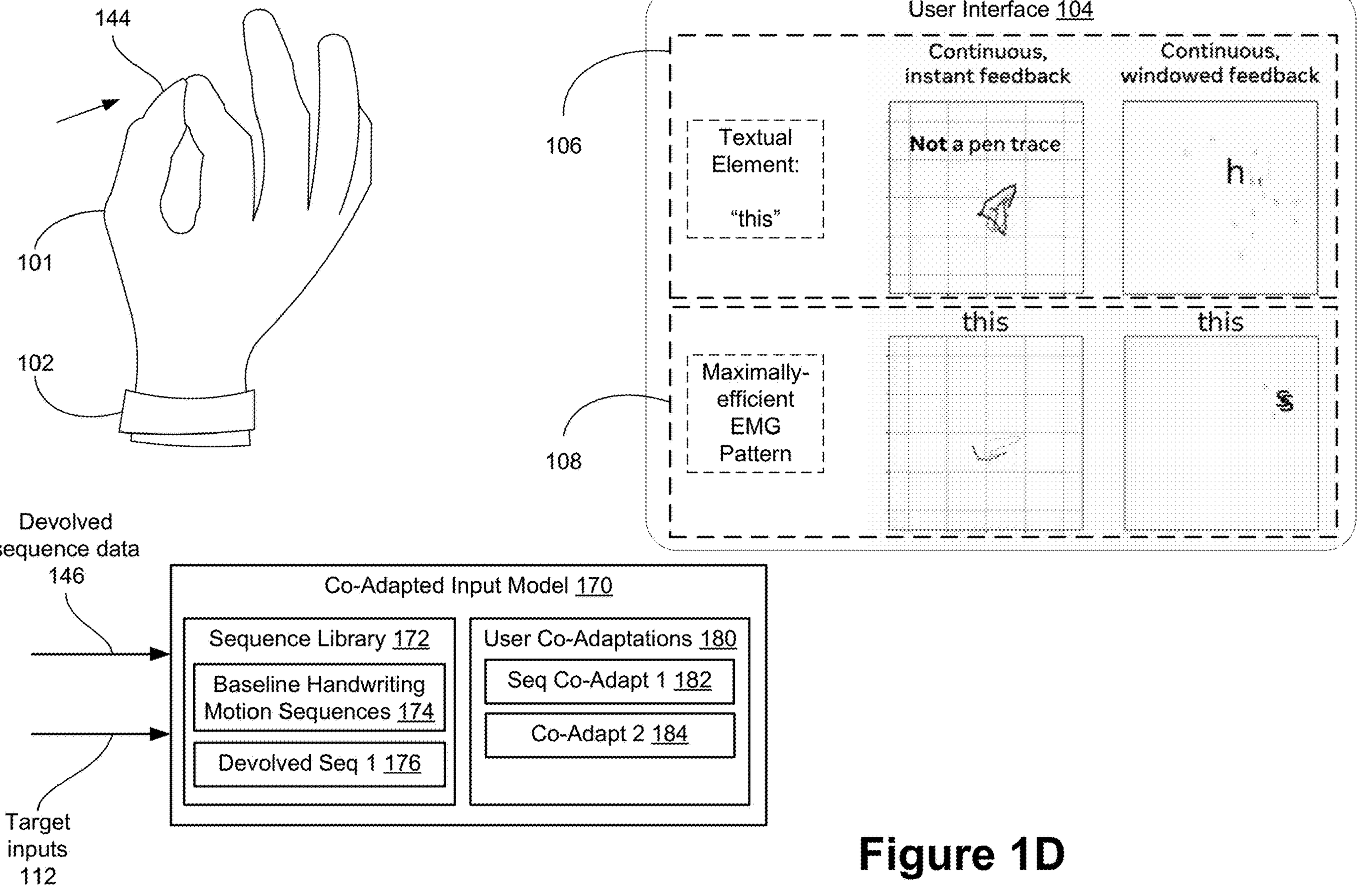

144
101
102
User Interface 104
106
Continuous, instant feedback
Continuous, windowed feedback
Textual Element: "this"
Not a pen trace
h
this
this
Maximally-efficient EMG Pattern
108
$
Devolved sequence data 146
Co-Adapted Input Model 170
Sequence Library 172
Baseline Handwriting Motion Sequences 174
Devolved Seq 1 176
User Co-Adaptations 180
Seq Co-Adapt 1 182
Co-Adapt 2 184
Target inputs 112

Figure 1D

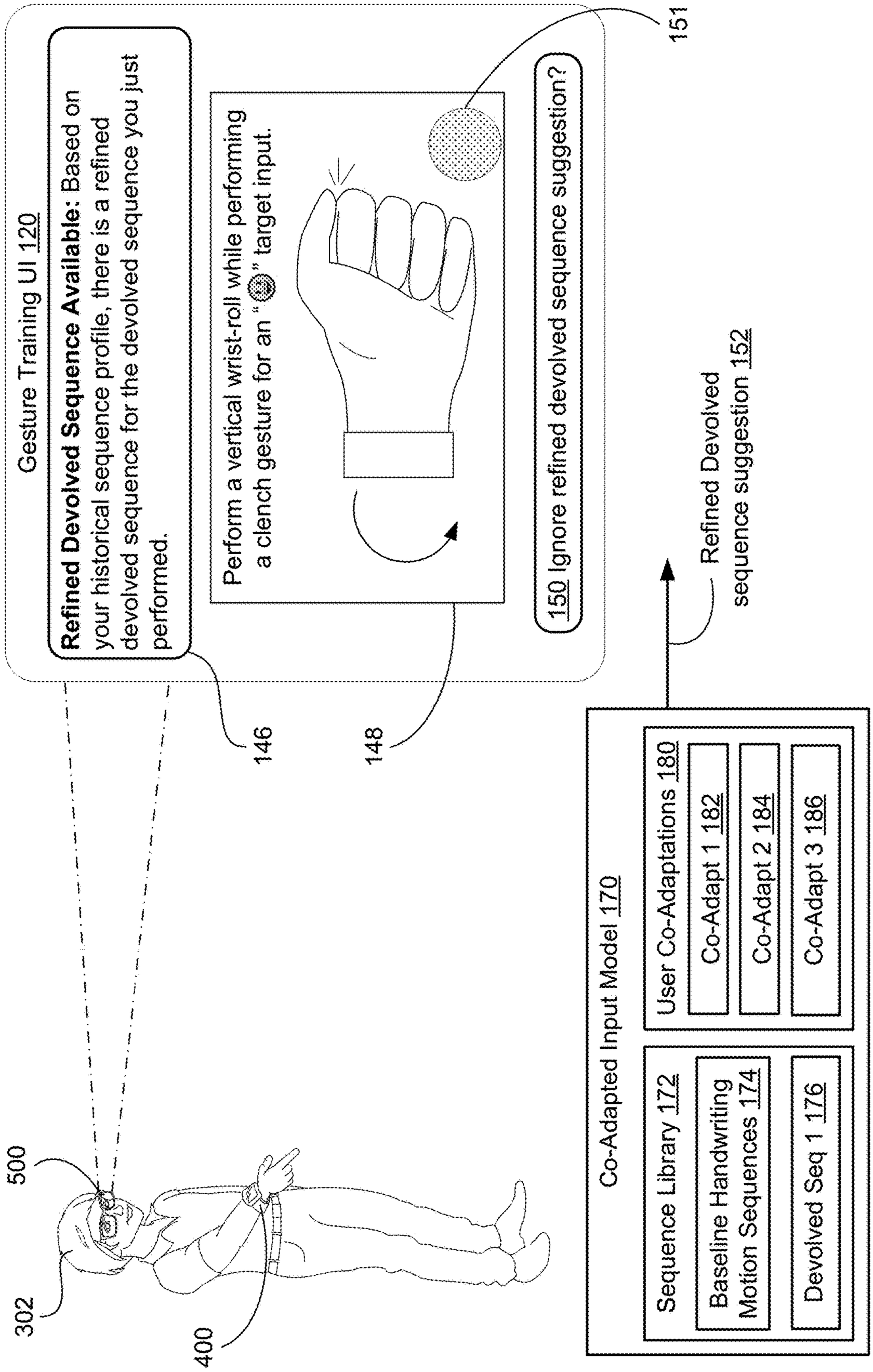

Gesture Training UI 120
Refined Devolved Sequence Available: Based on your historical sequence profile, there is a refined devolved sequence for the devolved sequence you just performed.
146
Perform a vertical wrist-roll while performing a clench gesture for an "●" target input.
148
150 Ignore refined devolved sequence suggestion?
151
Refined Devolved sequence suggestion 152
Co-Adapted Input Model 170
Sequence Library 172
Baseline Handwriting Motion Sequences 174
Devolved Seq 1 176
User Co-Adaptations 180
Co-Adapt 1 182
Co-Adapt 2 184
Co-Adapt 3 186
500
302
400

Figure 1E

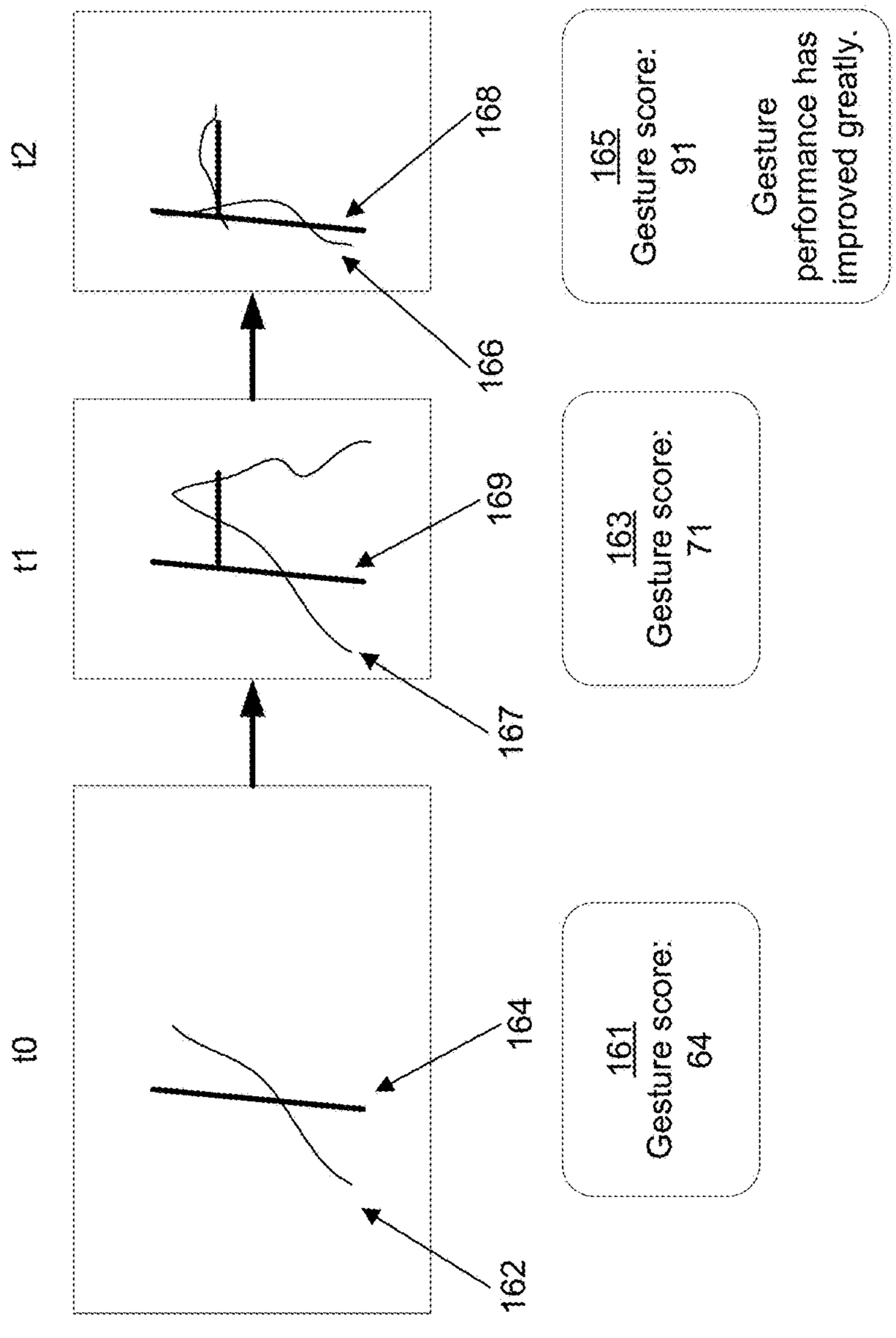
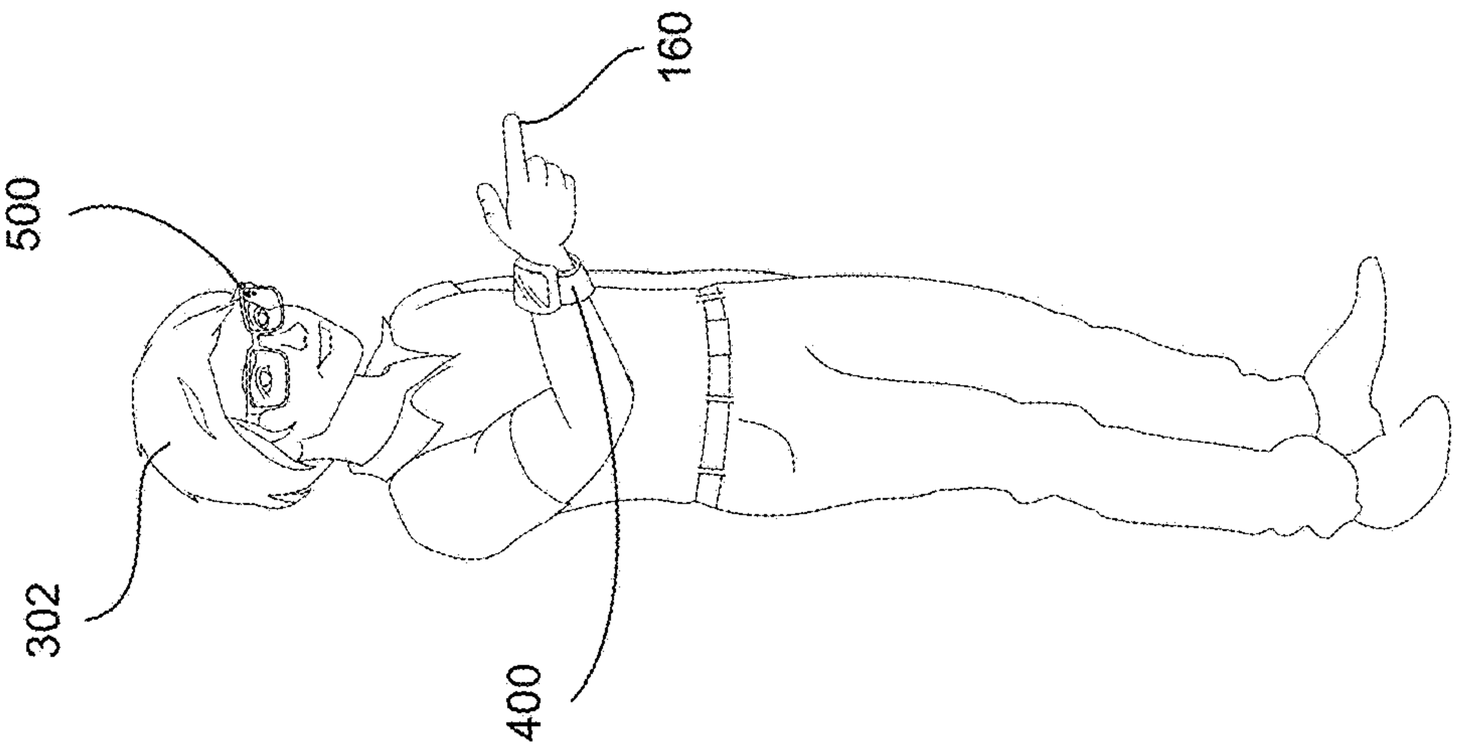

t2
168
166
165
Gesture score:
91
Gesture
performance has
improved greatly.
t1
169
167
163
Gesture score:
71
t0
164
162
161
Gesture score:
64

Figure 1F


AR system 300a
500
302
160
400

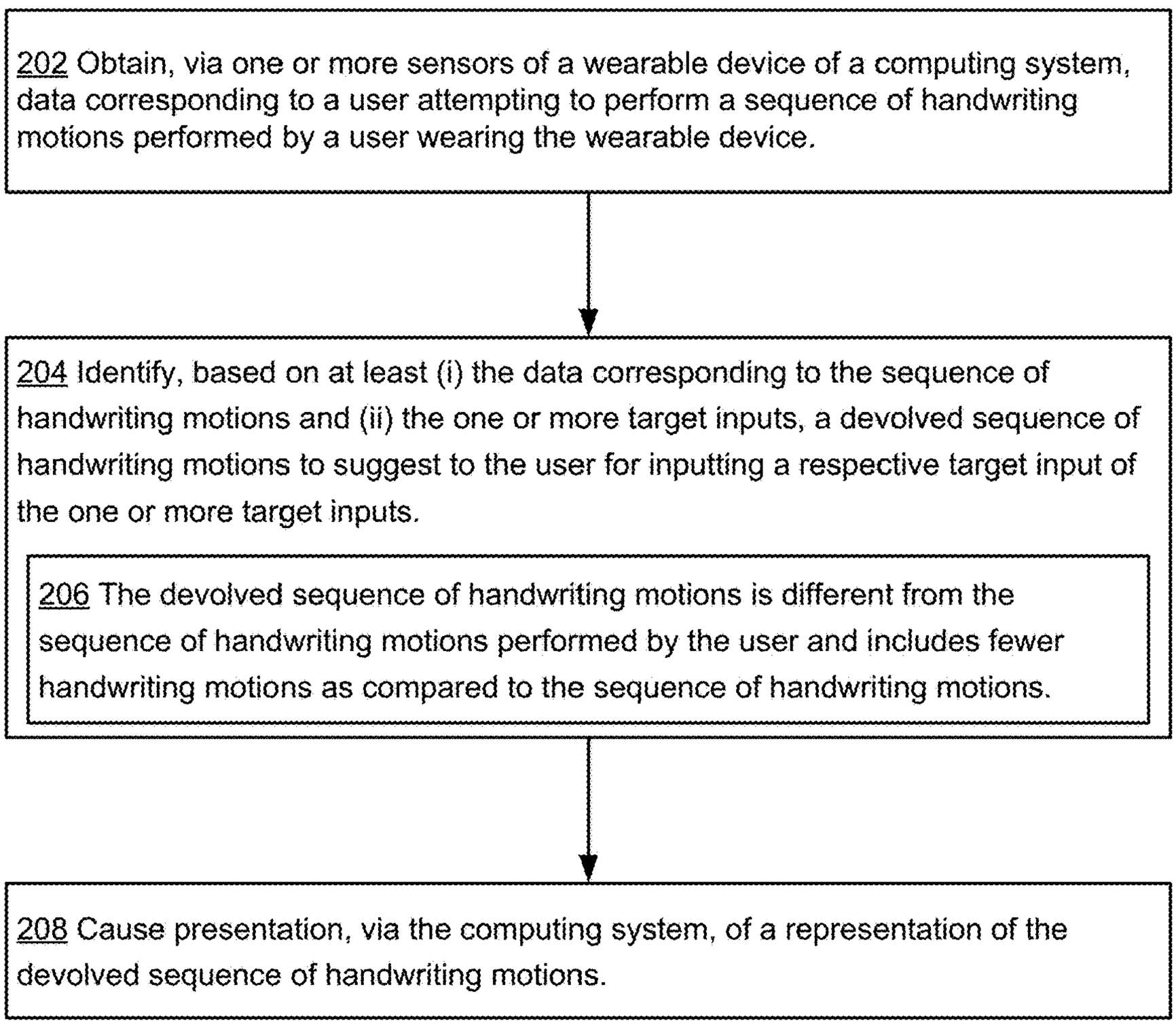

200
202 Obtain, via one or more sensors of a wearable device of a computing system, data corresponding to a user attempting to perform a sequence of handwriting motions performed by a user wearing the wearable device.
204 Identify, based on at least (i) the data corresponding to the sequence of handwriting motions and (ii) the one or more target inputs, a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs.
206 The devolved sequence of handwriting motions is different from the sequence of handwriting motions performed by the user and includes fewer handwriting motions as compared to the sequence of handwriting motions.
208 Cause presentation, via the computing system, of a representation of the devolved sequence of handwriting motions.

Figure 2A

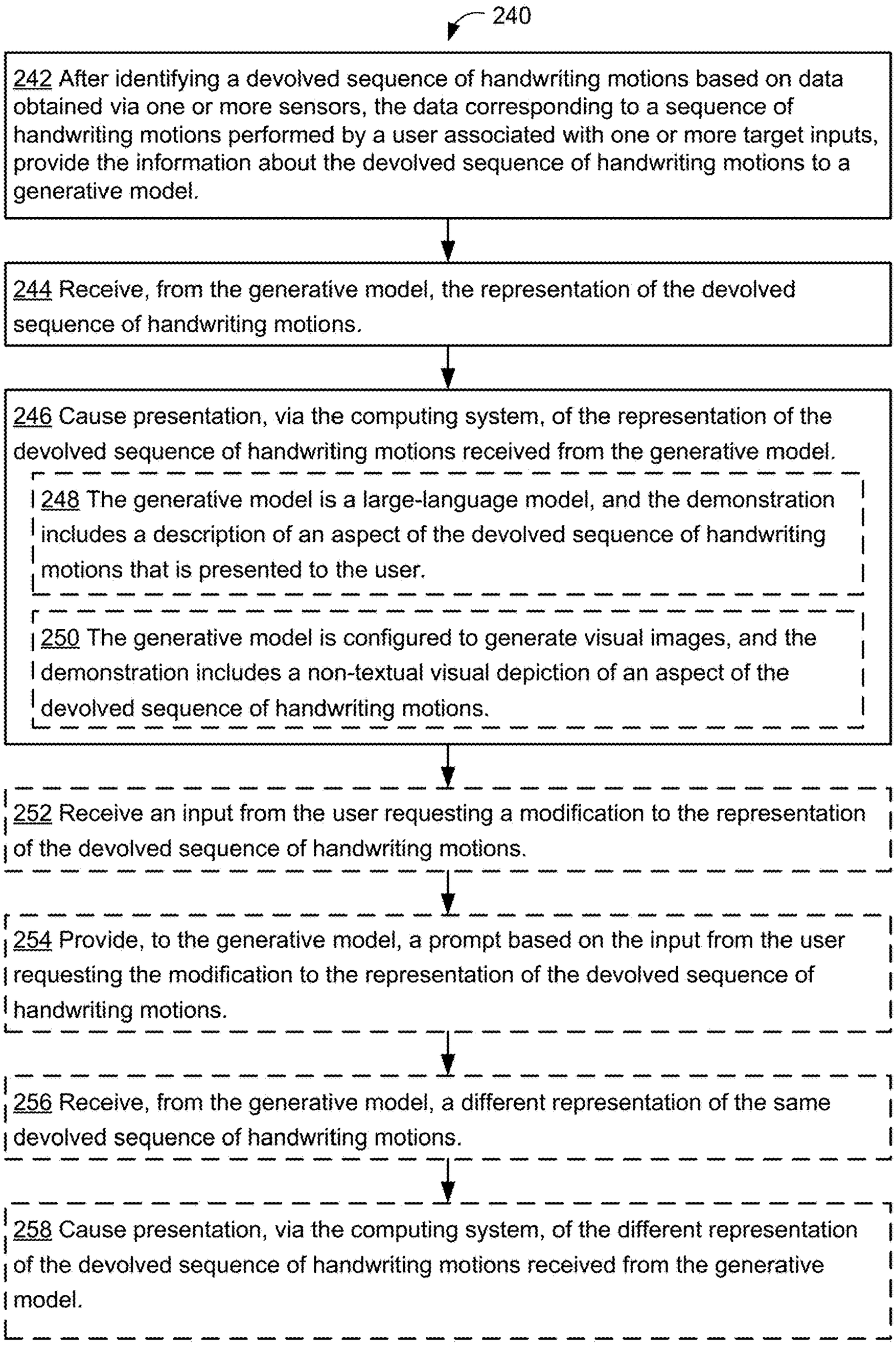

240
242 After identifying a devolved sequence of handwriting motions based on data obtained via one or more sensors, the data corresponding to a sequence of handwriting motions performed by a user associated with one or more target inputs, provide the information about the devolved sequence of handwriting motions to a generative model.
244 Receive, from the generative model, the representation of the devolved sequence of handwriting motions.
246 Cause presentation, via the computing system, of the representation of the devolved sequence of handwriting motions received from the generative model.
248 The generative model is a large-language model, and the demonstration includes a description of an aspect of the devolved sequence of handwriting motions that is presented to the user.
250 The generative model is configured to generate visual images, and the demonstration includes a non-textual visual depiction of an aspect of the devolved sequence of handwriting motions.
252 Receive an input from the user requesting a modification to the representation of the devolved sequence of handwriting motions.
254 Provide, to the generative model, a prompt based on the input from the user requesting the modification to the representation of the devolved sequence of handwriting motions.
256 Receive, from the generative model, a different representation of the same devolved sequence of handwriting motions.
258 Cause presentation, via the computing system, of the different representation of the devolved sequence of handwriting motions received from the generative model.

Figure 2B

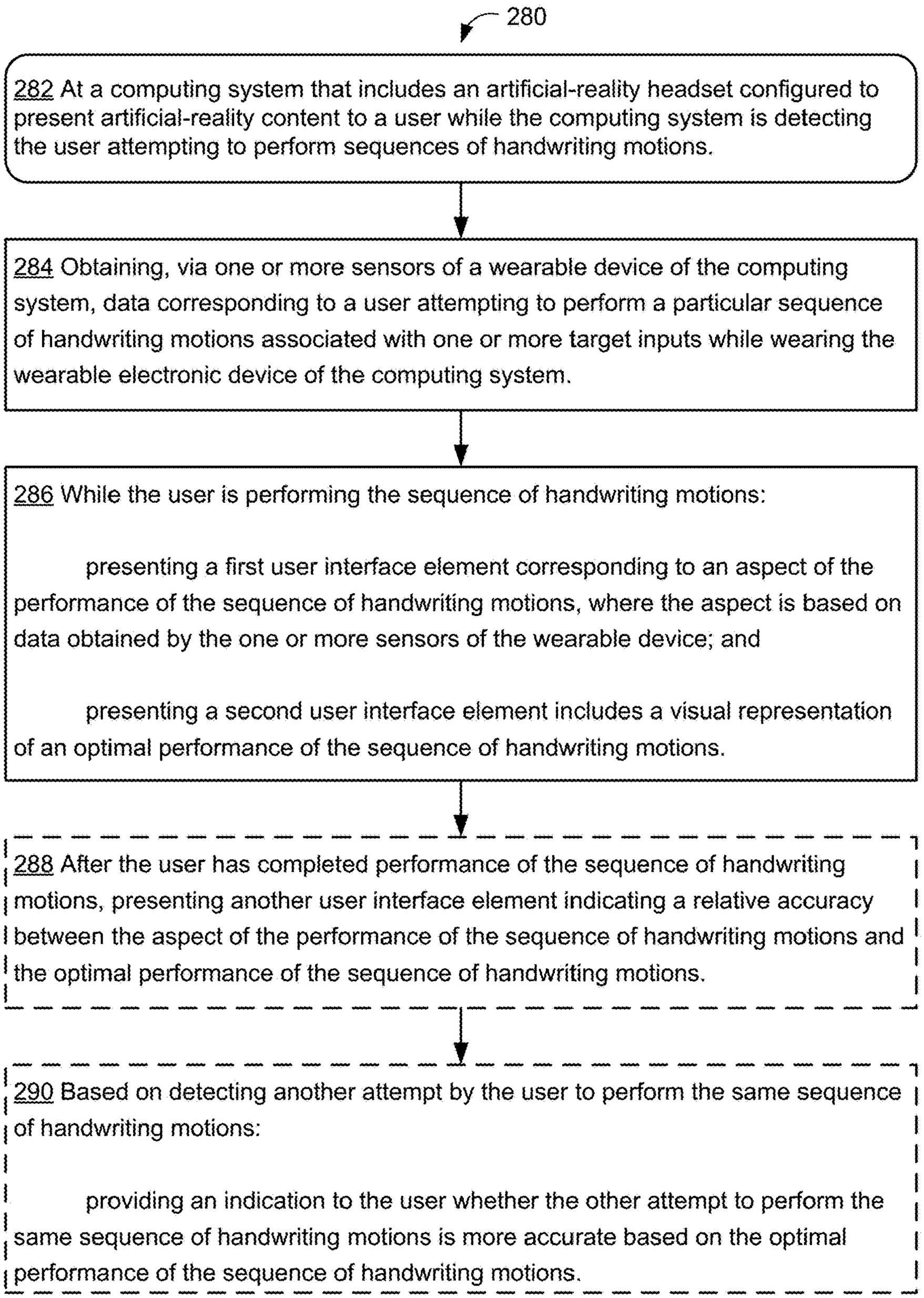

280
282 At a computing system that includes an artificial-reality headset configured to present artificial-reality content to a user while the computing system is detecting the user attempting to perform sequences of handwriting motions.
284 Obtaining, via one or more sensors of a wearable device of the computing system, data corresponding to a user attempting to perform a particular sequence of handwriting motions associated with one or more target inputs while wearing the wearable electronic device of the computing system.
286 While the user is performing the sequence of handwriting motions:
presenting a first user interface element corresponding to an aspect of the performance of the sequence of handwriting motions, where the aspect is based on data obtained by the one or more sensors of the wearable device; and
presenting a second user interface element includes a visual representation of an optimal performance of the sequence of handwriting motions.
288 After the user has completed performance of the sequence of handwriting motions, presenting another user interface element indicating a relative accuracy between the aspect of the performance of the sequence of handwriting motions and the optimal performance of the sequence of handwriting motions.
290 Based on detecting another attempt by the user to perform the same sequence of handwriting motions:
providing an indication to the user whether the other attempt to perform the same sequence of handwriting motions is more accurate based on the optimal performance of the sequence of handwriting motions.

Figure 2C

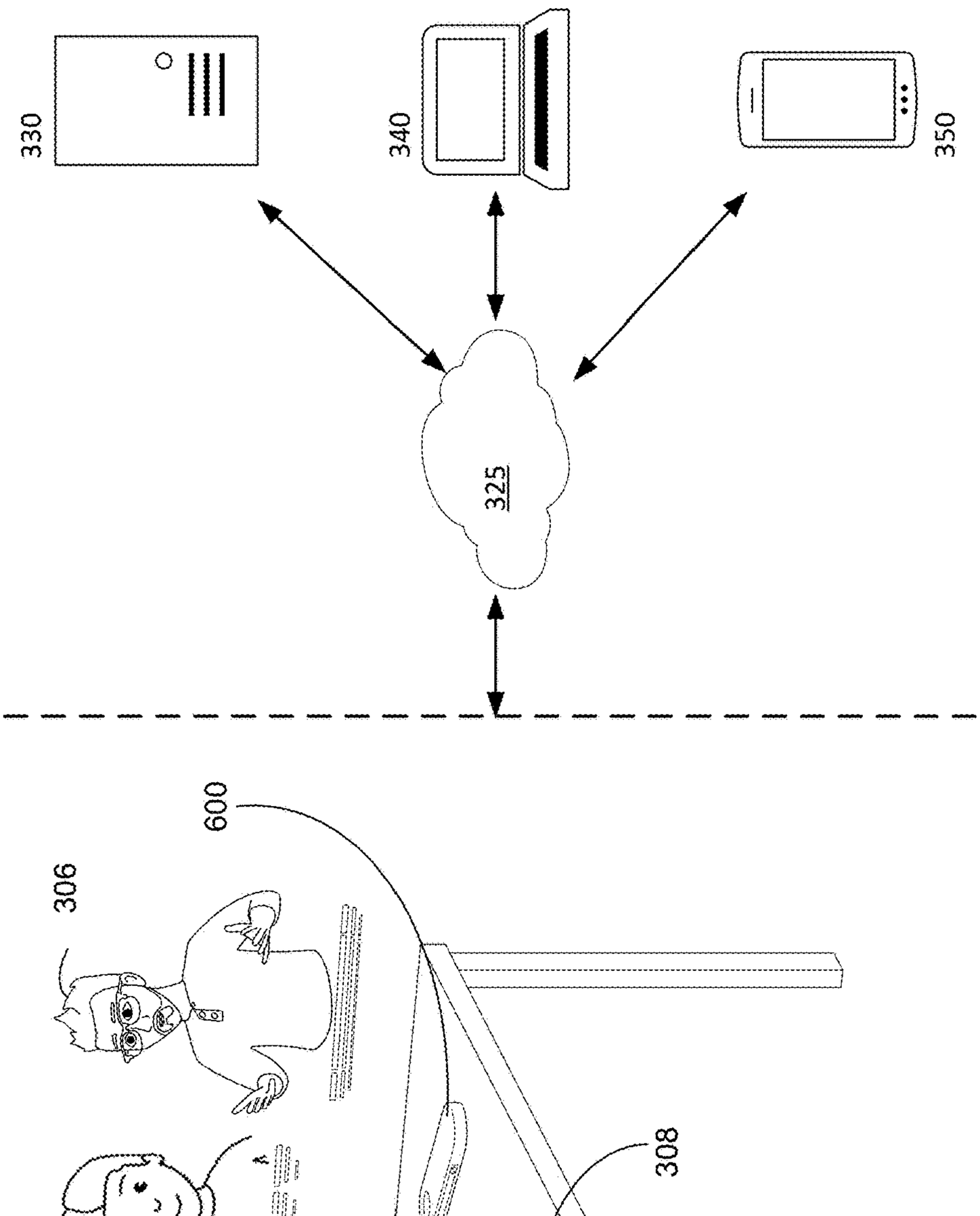
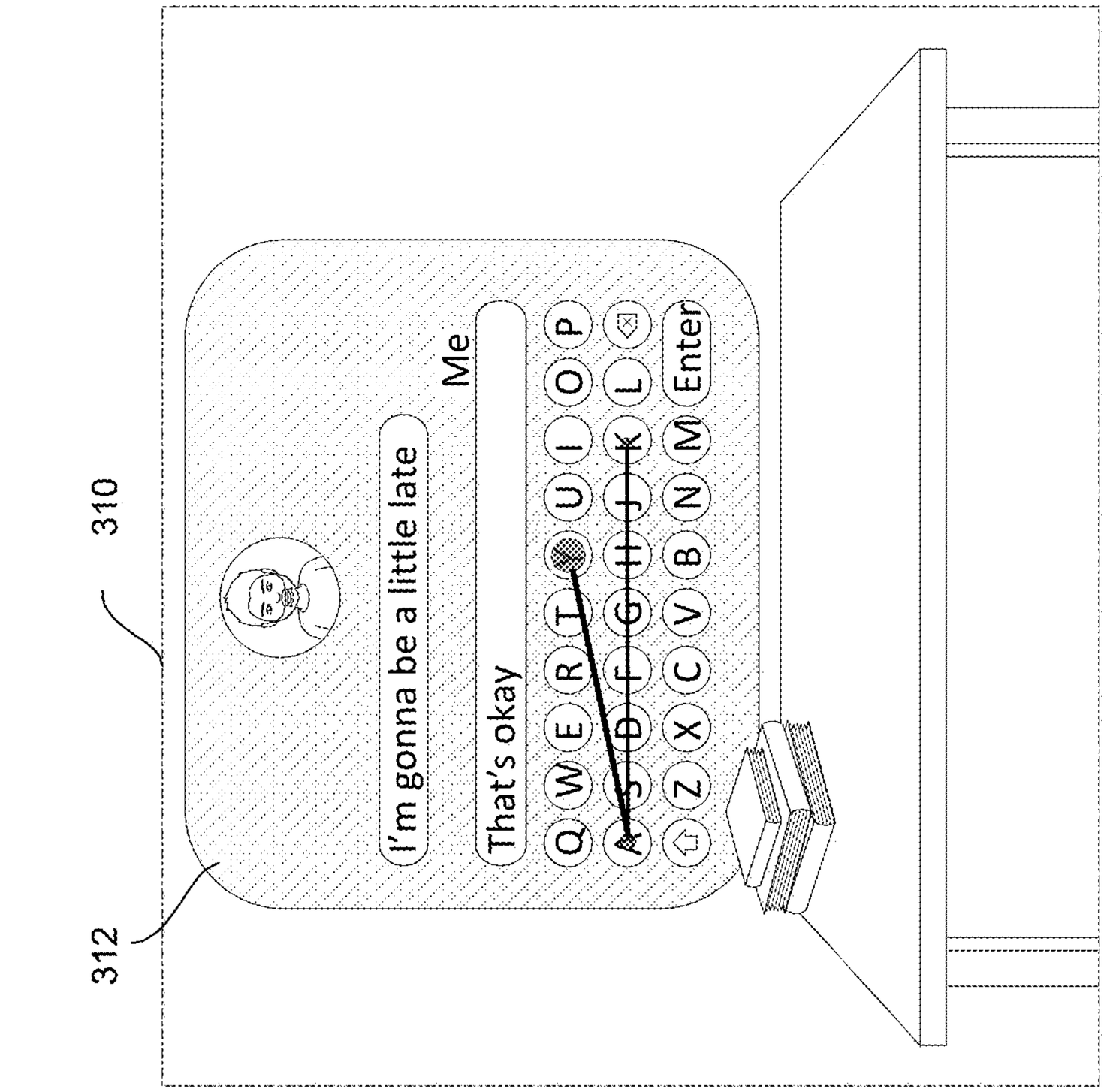


Figure 3A


310
312
I'm gonna be a little late
That's okay
Me
Enter

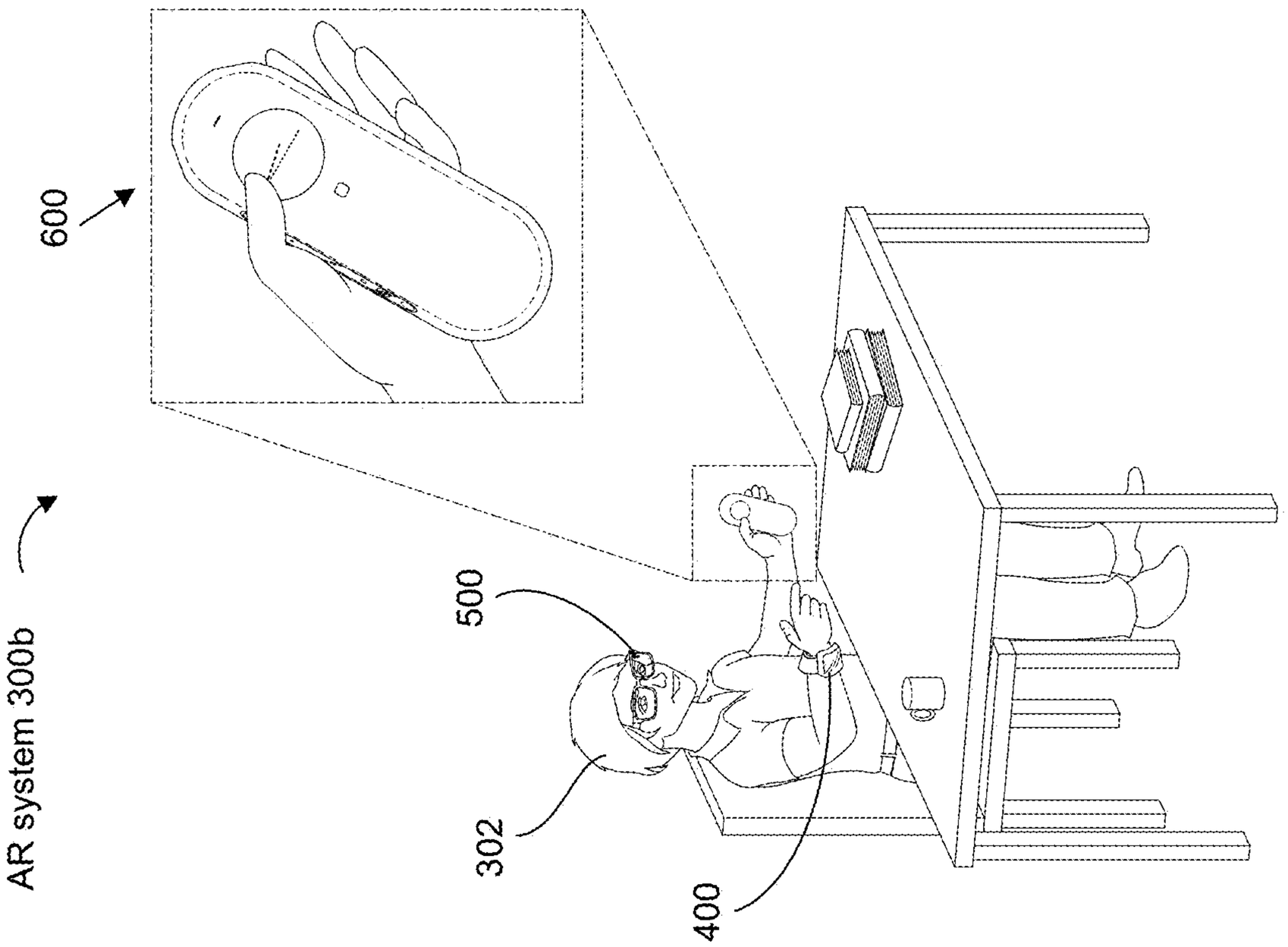

600
AR system 300b
500
302
400

Figure 3B

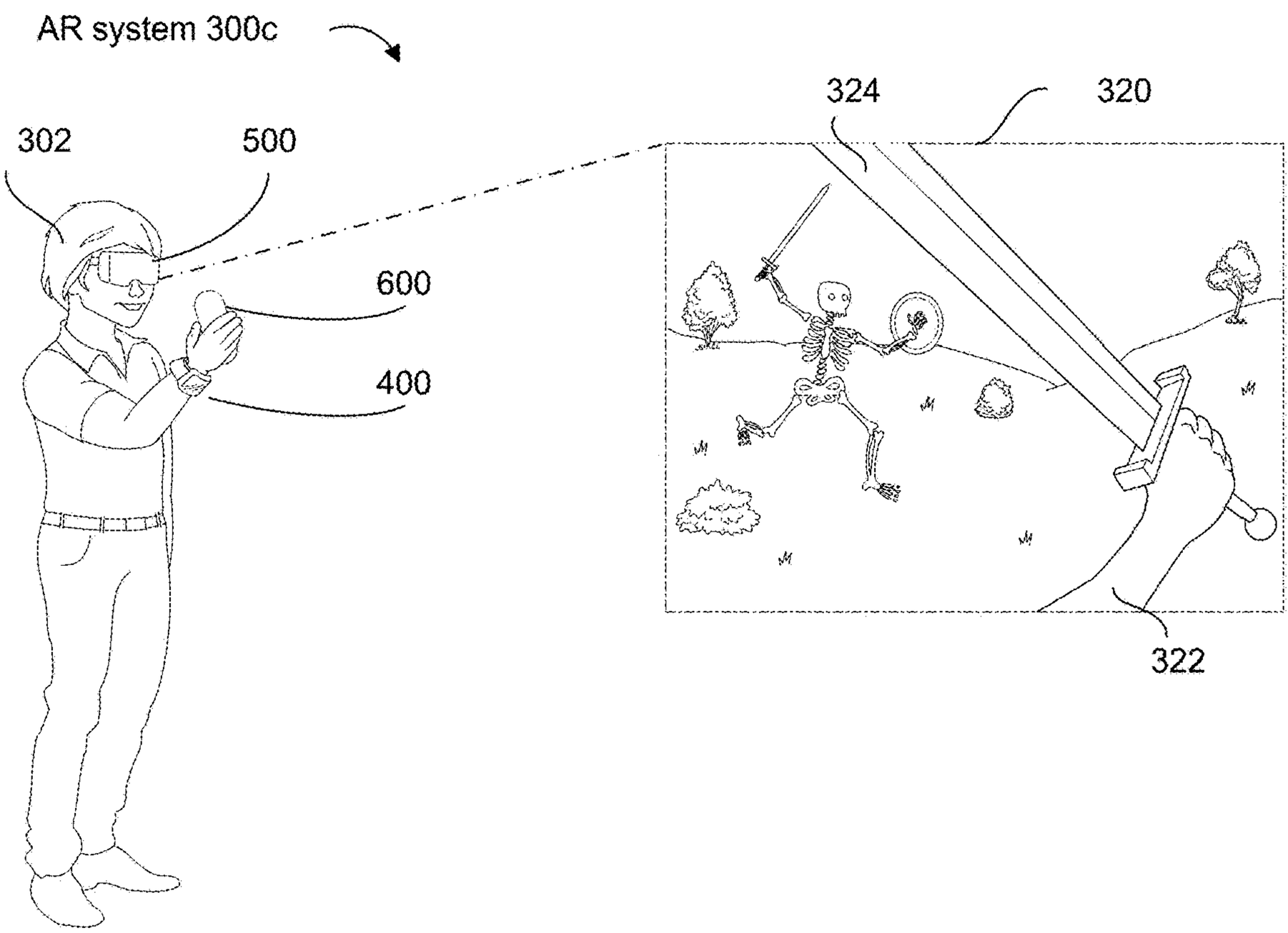


Figure 3C-1

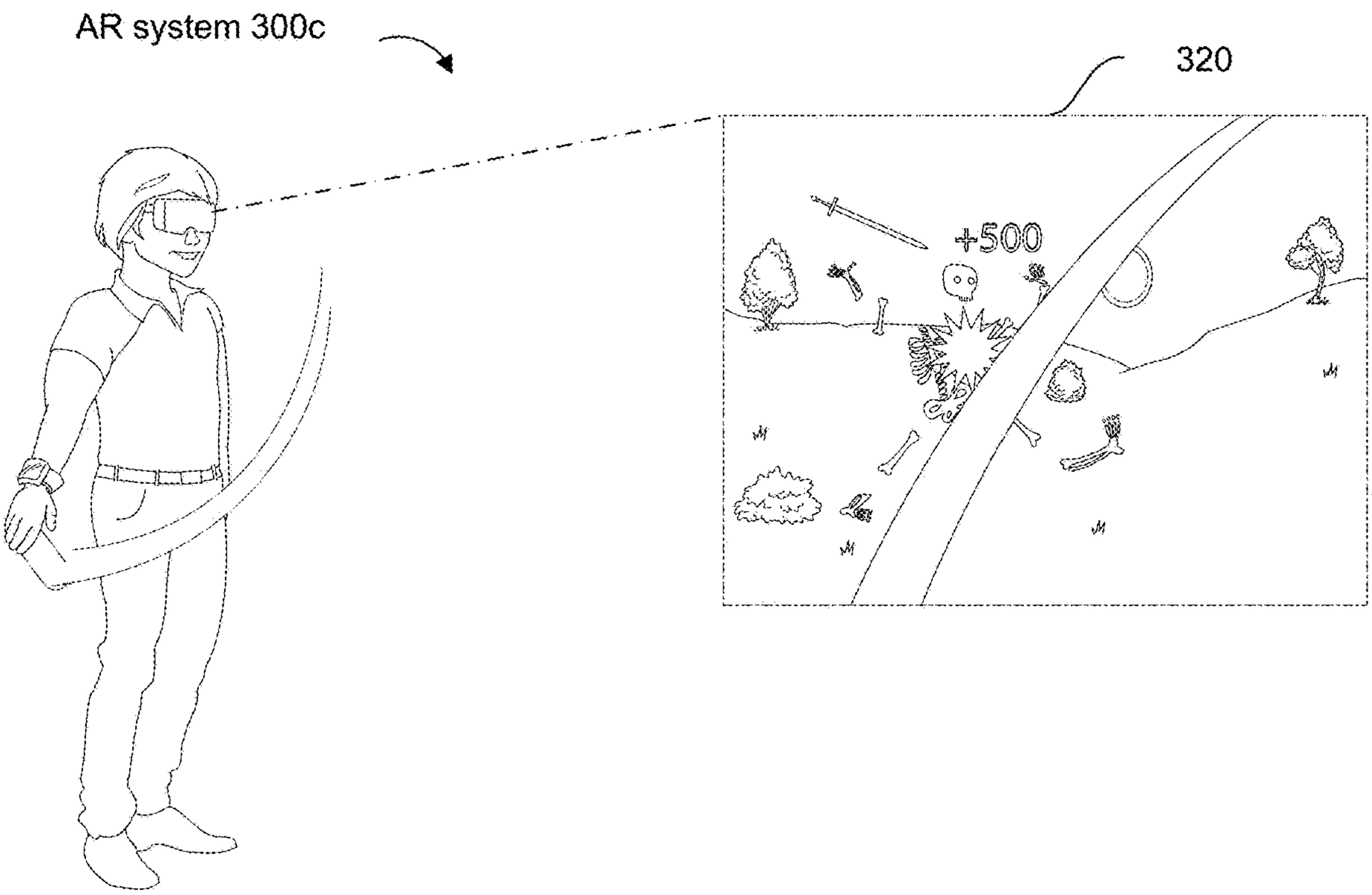


Figure 3C-2

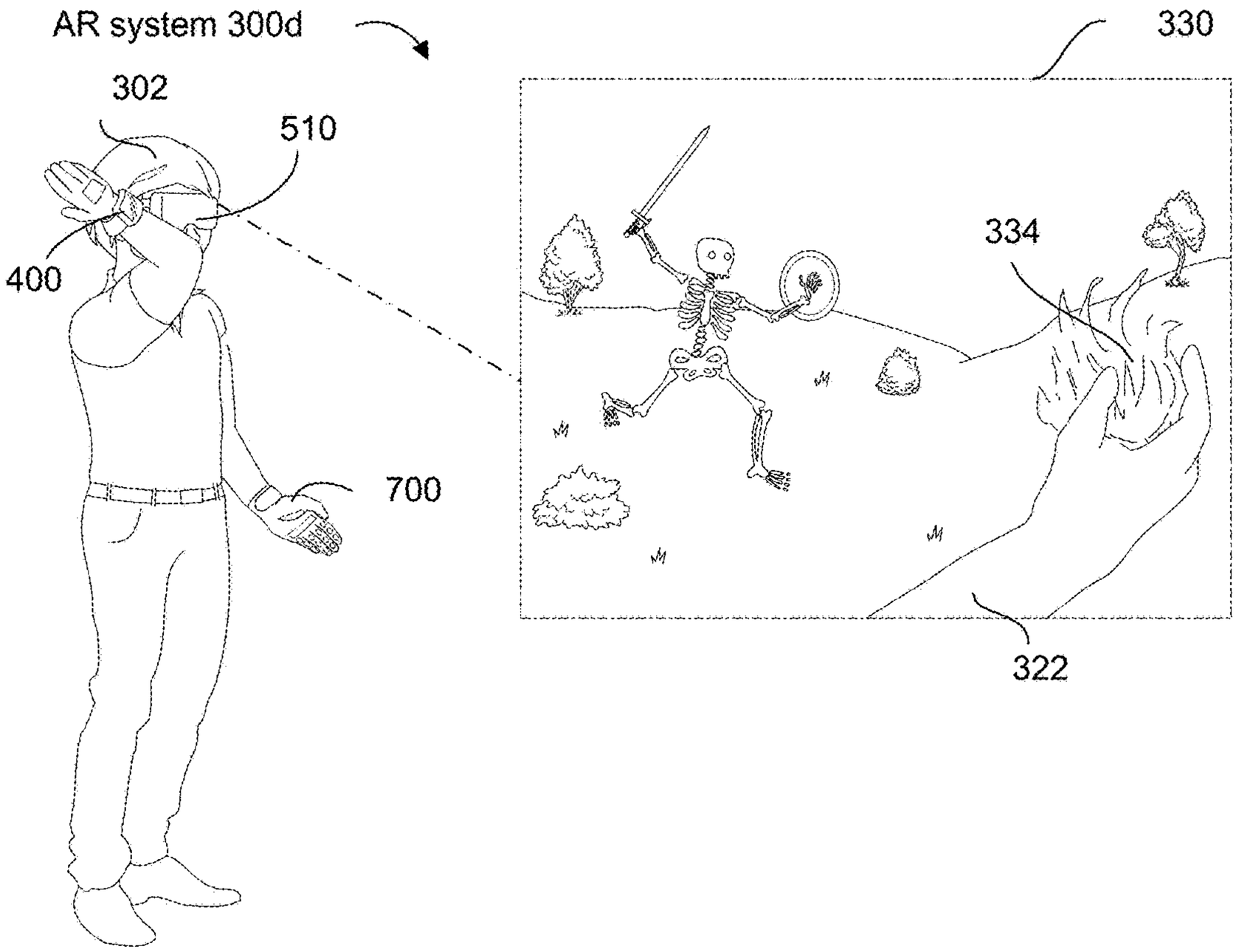


Figure 3D-1

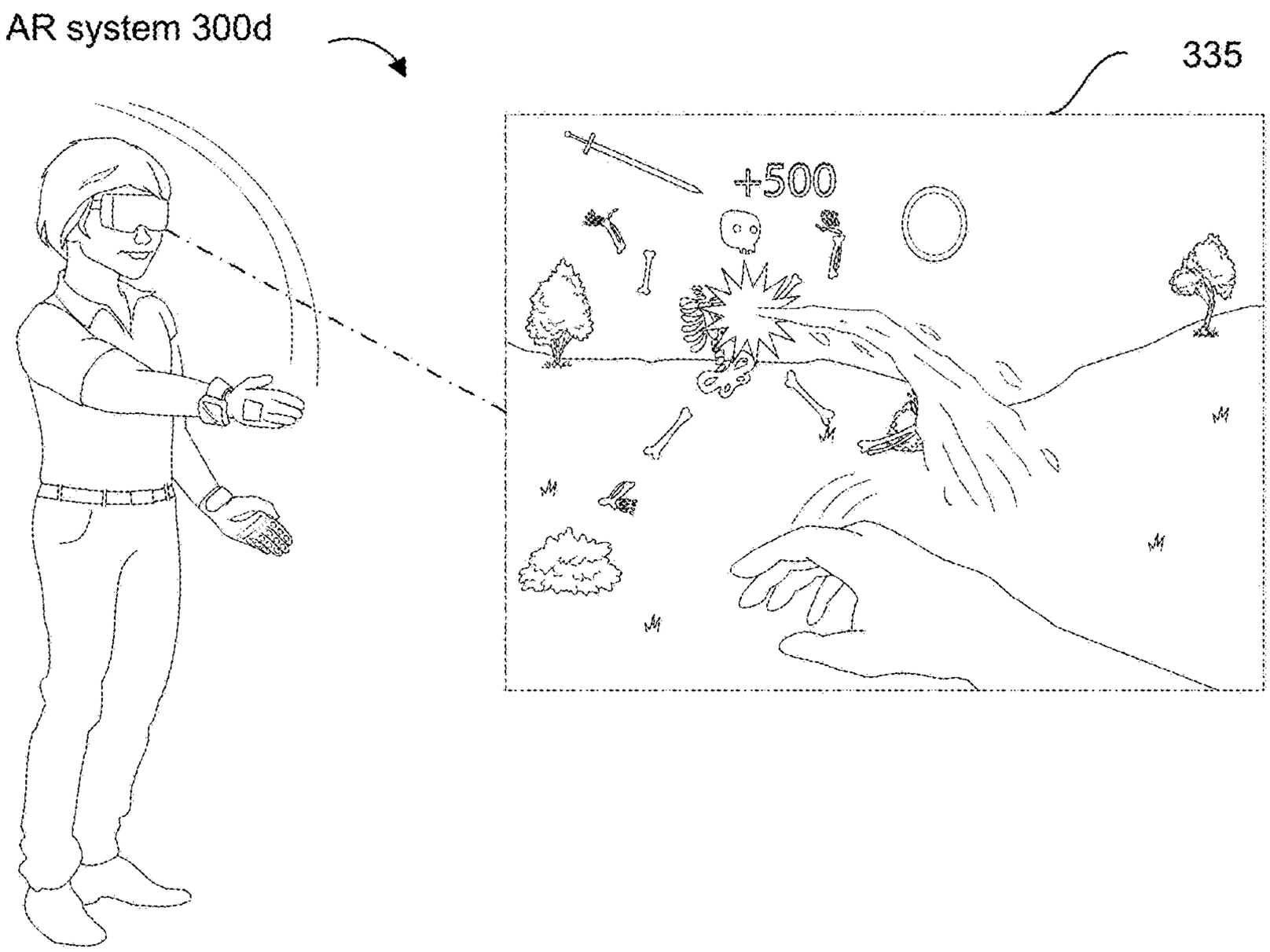


Figure 3D-2

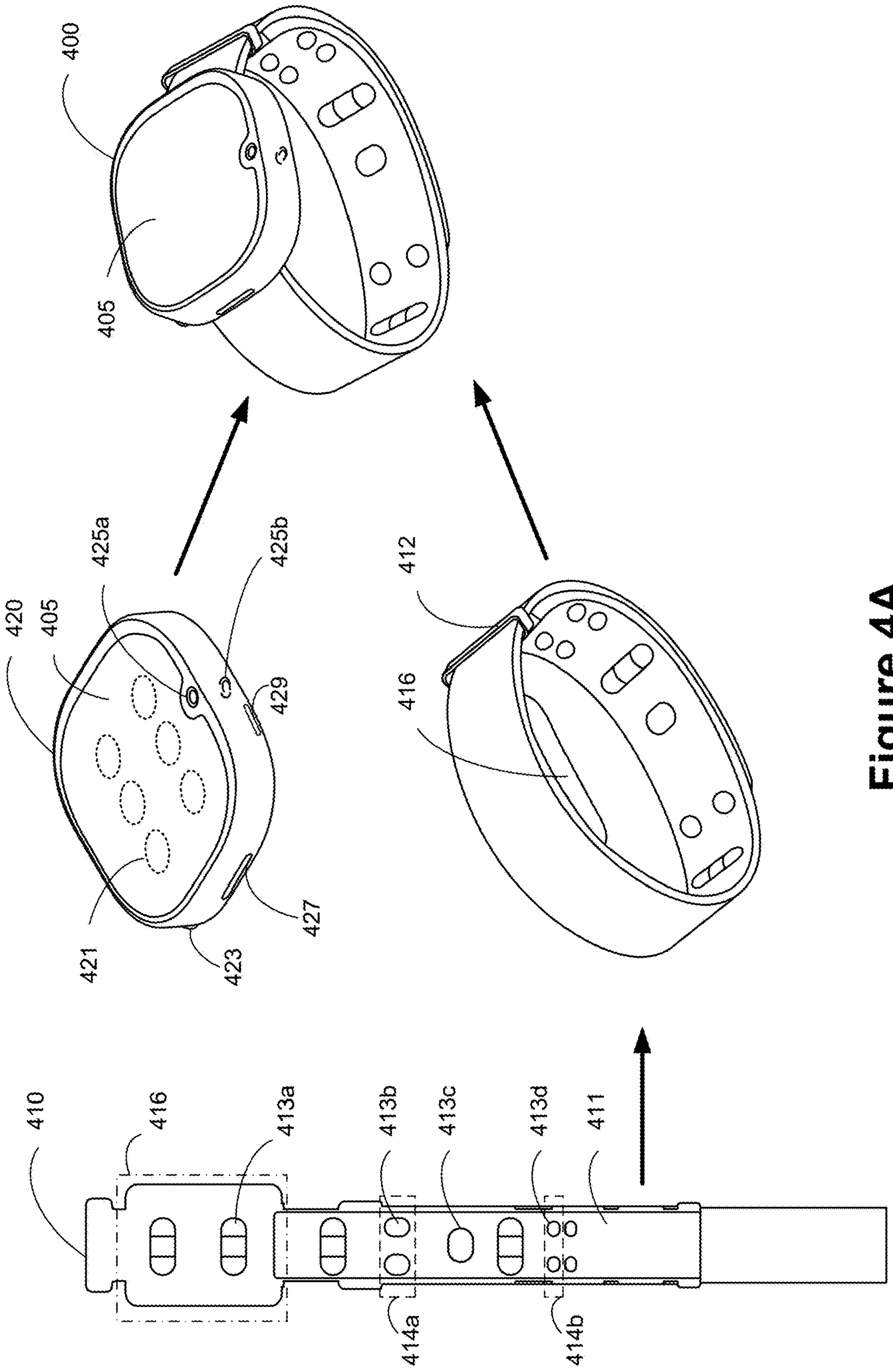

400
405
420
405
425a
425b
429
427
421
423
412
416
410
416
413a
413b
413c
413d
411
414a
414b

Figure 4A

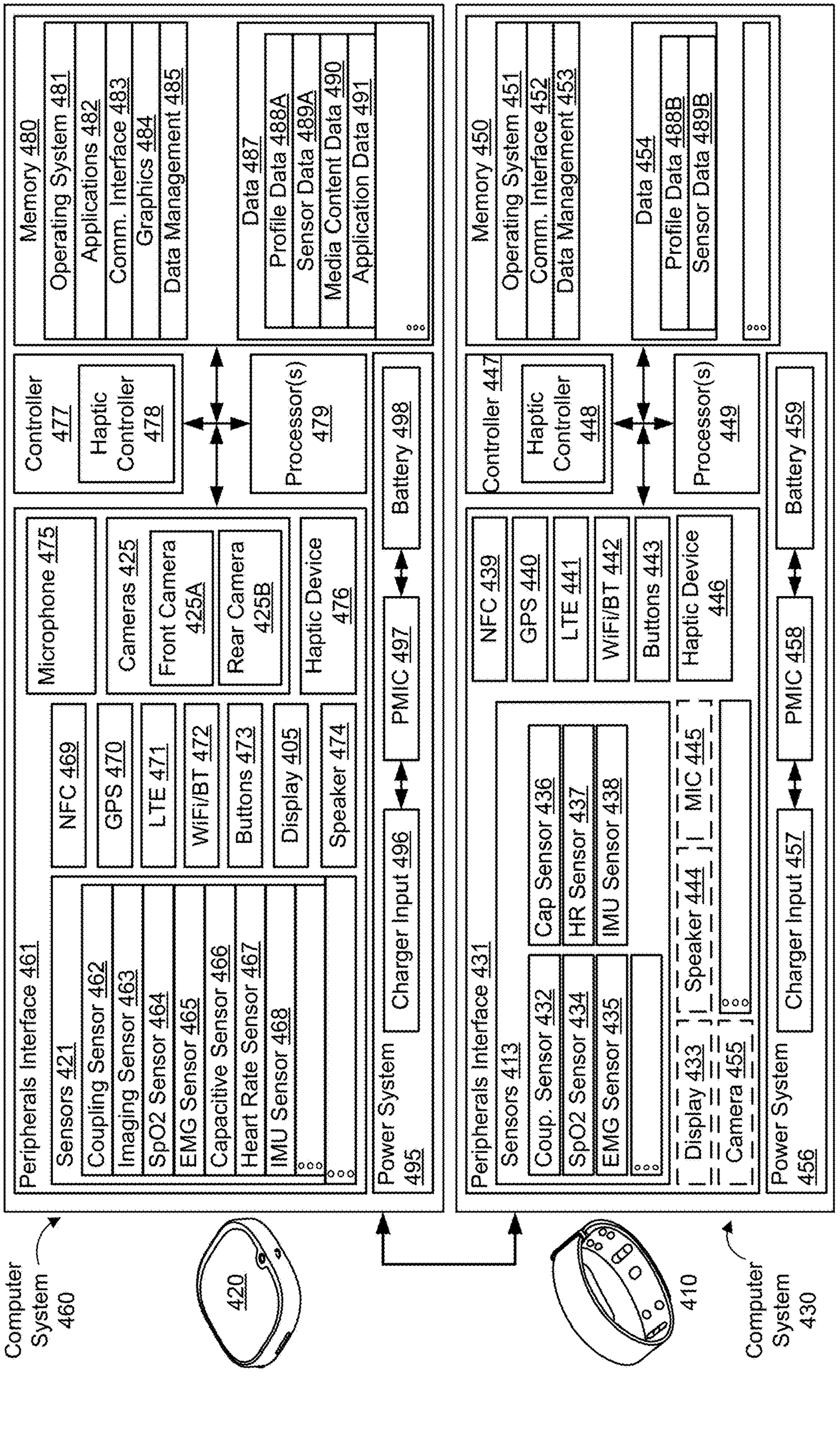

Computer System 460
Peripherals Interface 461
Sensors 421
Coupling Sensor 462
Imaging Sensor 463
SpO2 Sensor 464
EMG Sensor 465
Capacitive Sensor 466
Heart Rate Sensor 467
IMU Sensor 468
Power System 495
Charger Input 496
PMIC 497
Battery 498
Controller 477
Haptic Controller 478
Processor(s) 479
Memory 480
Operating System 481
Applications 482
Comm. Interface 483
Graphics 484
Data Management 485
Data 487
Profile Data 488A
Sensor Data 489A
Media Content Data 490
Application Data 491
Microphone 475
Cameras 425
Front Camera 425A
Rear Camera 425B
Haptic Device 476
NFC 469
GPS 470
LTE 471
WiFi/BT 472
Buttons 473
Display 405
Speaker 474
420
410
Computer System 430
Peripherals Interface 431
Sensors 413
Coup. Sensor 432
SpO2 Sensor 434
EMG Sensor 435
Cap Sensor 436
HR Sensor 437
IMU Sensor 438
Display 433
Camera 455
Speaker 444
MIC 445
Power System 456
Charger Input 457
PMIC 458
Battery 459
Controller 447
Haptic Controller 448
Processor(s) 449
Memory 450
Operating System 451
Comm. Interface 452
Data Management 453
Data 454
Profile Data 488B
Sensor Data 489B
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GPS 440
LTE 441
WiFi/BT 442
Buttons 443
Haptic Device 446

Figure 4B

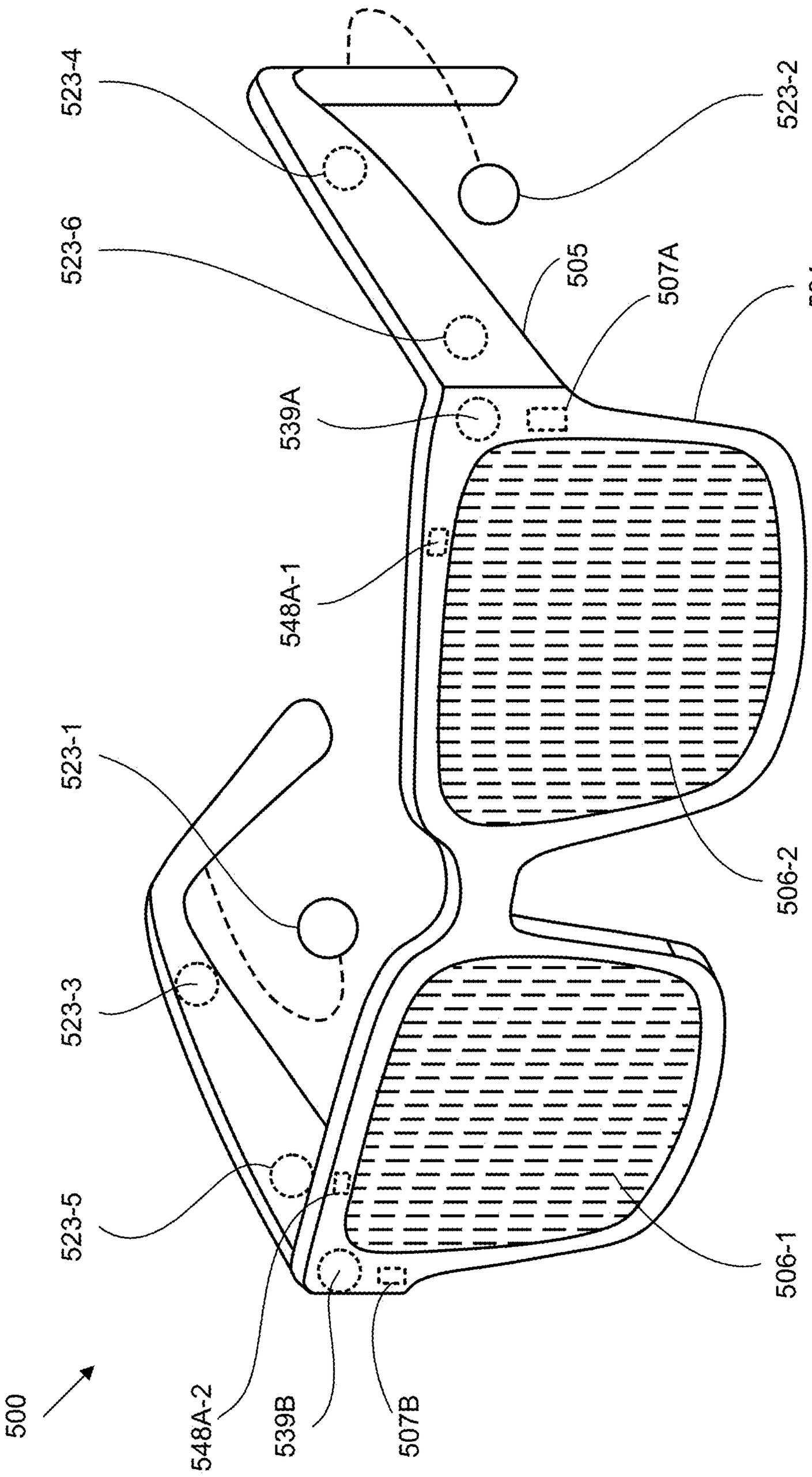

523-4
523-2
523-6
505
507A
504
539A
548A-1
523-1
523-3
506-2
523-5
506-1
500
548A-2
539B
507B

Figure 5A

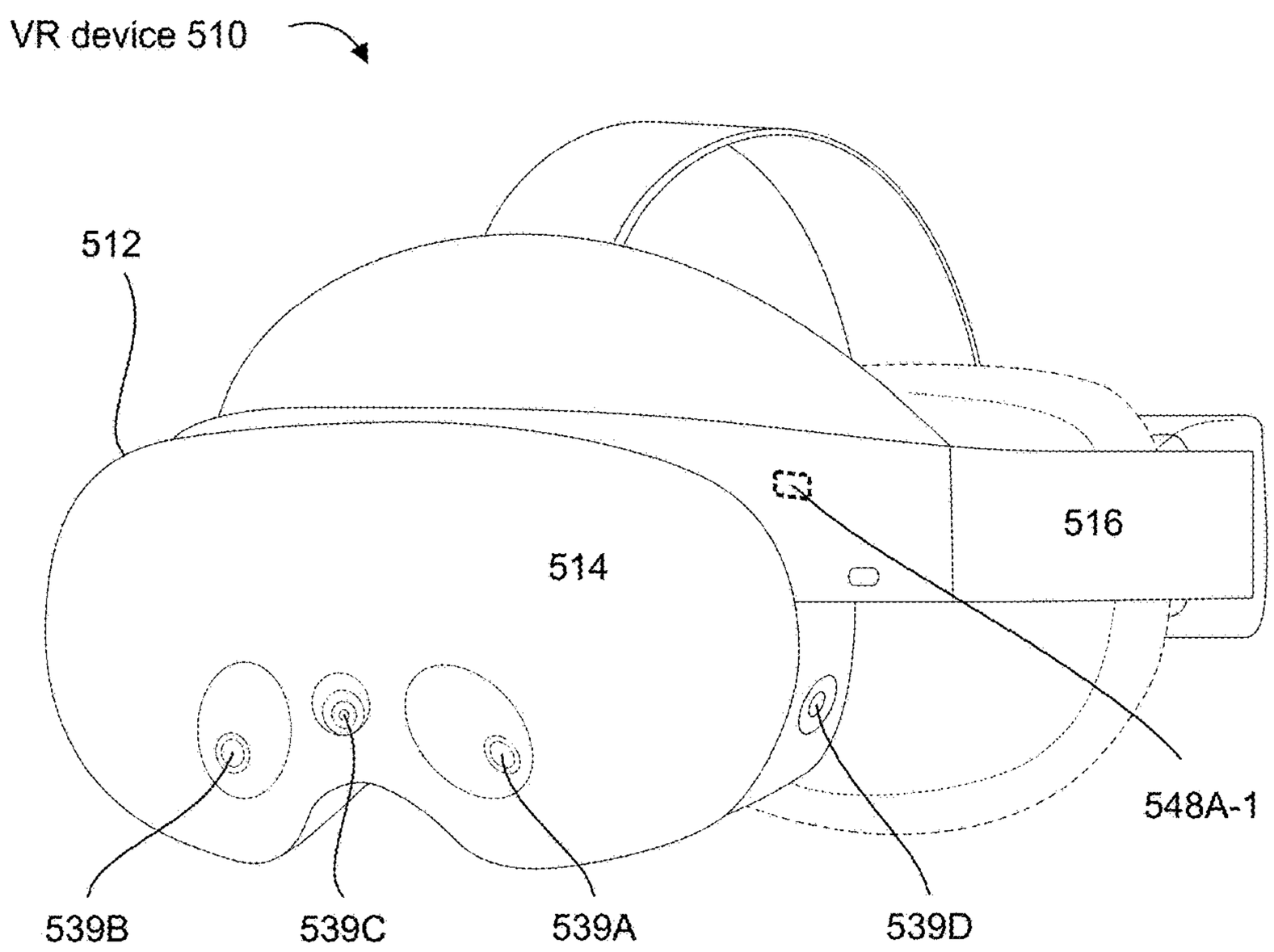


Figure 5B-1

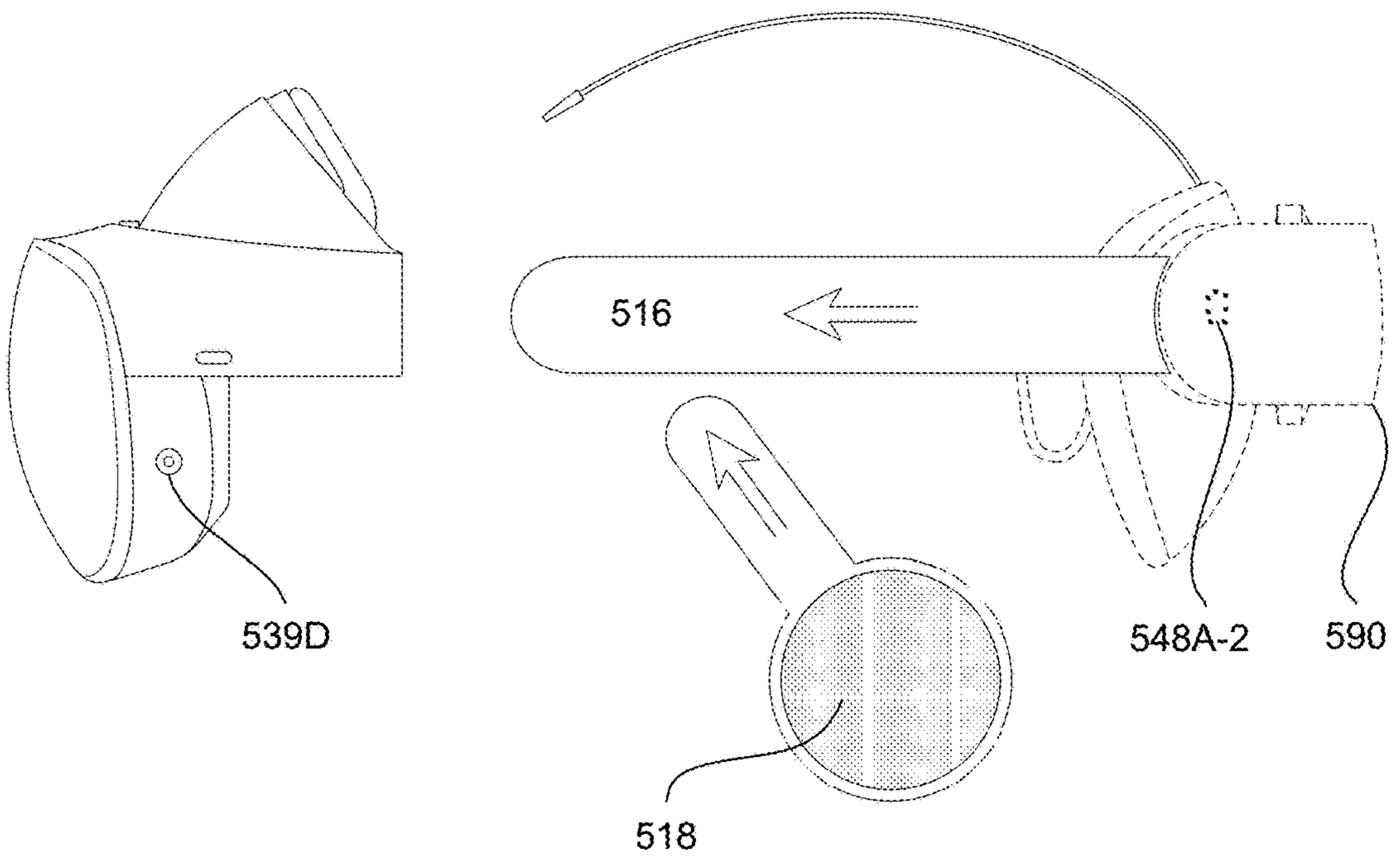


Figure 5B-2

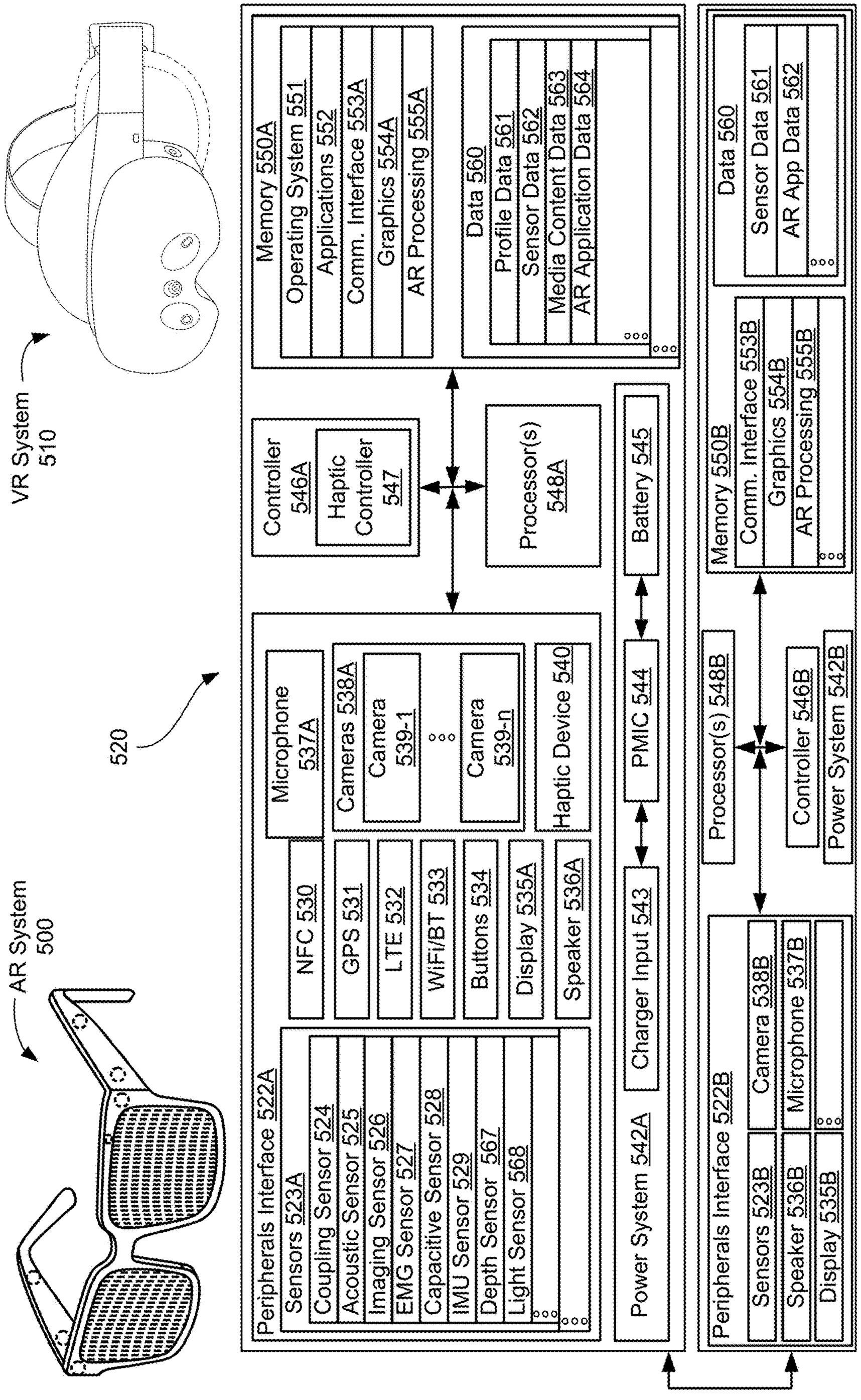
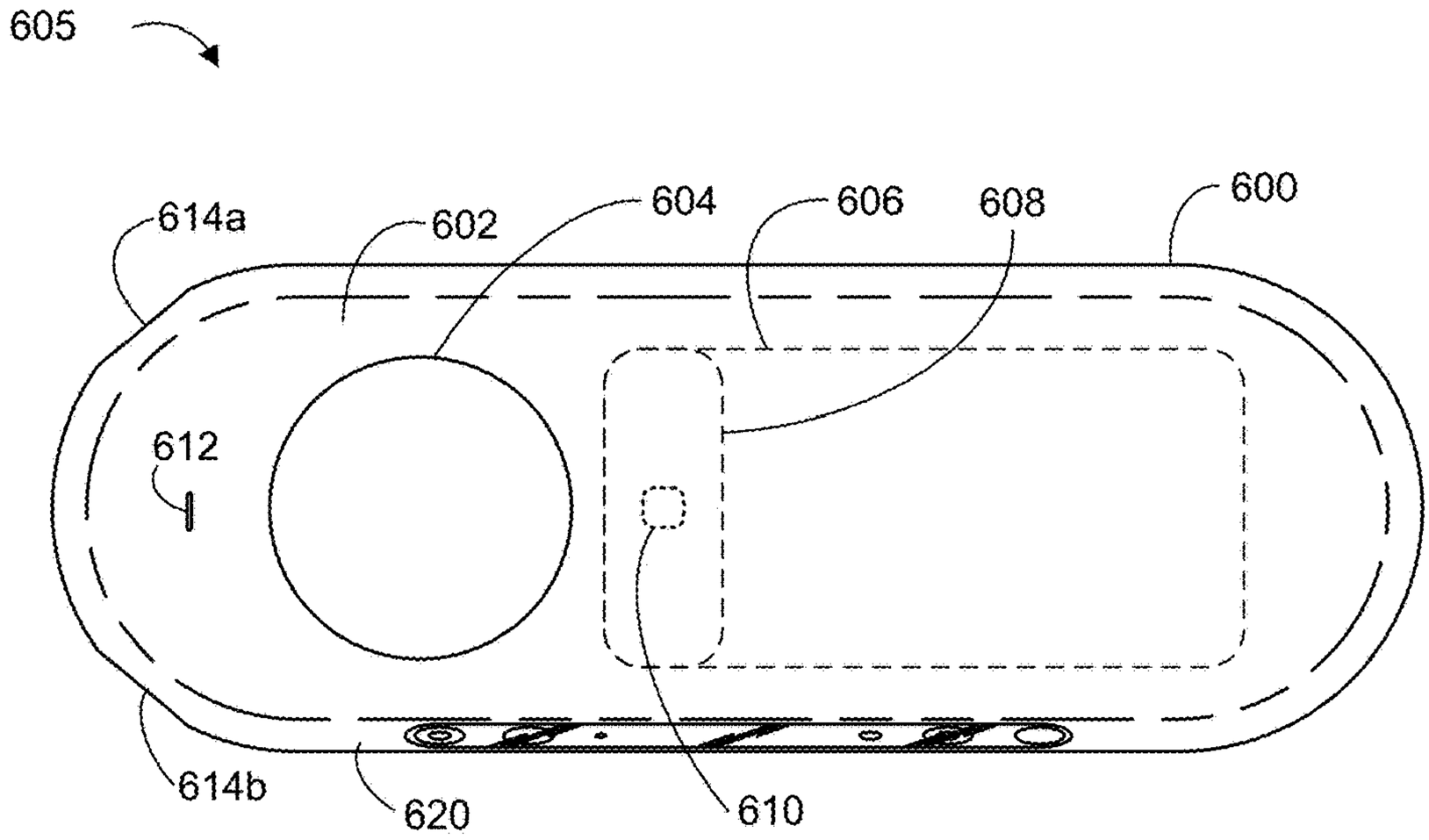

AR System 500
VR System 510
520
590
Memory 550A
Operating System 551
Applications 552
Comm. Interface 553A
Graphics 554A
AR Processing 555A
Data 560
Profile Data 561
Sensor Data 562
Media Content Data 563
AR Application Data 564
Controller 546A
Haptic Controller 547
Processor(s) 548A
Microphone 537A
Cameras 538A
Camera 539-1
Camera 539-n
Haptic Device 540
PMIC 544
Battery 545
Peripherals Interface 522A
Sensors 523A
Coupling Sensor 524
Acoustic Sensor 525
Imaging Sensor 526
EMG Sensor 527
Capacitive Sensor 528
IMU Sensor 529
Depth Sensor 567
Light Sensor 568
NFC 530
GPS 531
LTE 532
WiFi/BT 533
Buttons 534
Display 535A
Speaker 536A
Power System 542A
Charger Input 543
Data 560
Sensor Data 561
AR App Data 562
Memory 550B
Comm. Interface 553B
Graphics 554B
AR Processing 555B
Processor(s) 548B
Controller 546B
Power System 542B
Peripherals Interface 522B
Sensors 523B
Camera 538B
Speaker 536B
Microphone 537B
Display 535B

Figure 5C


605
614a
602
604
606
608
600
612
614b
620
610

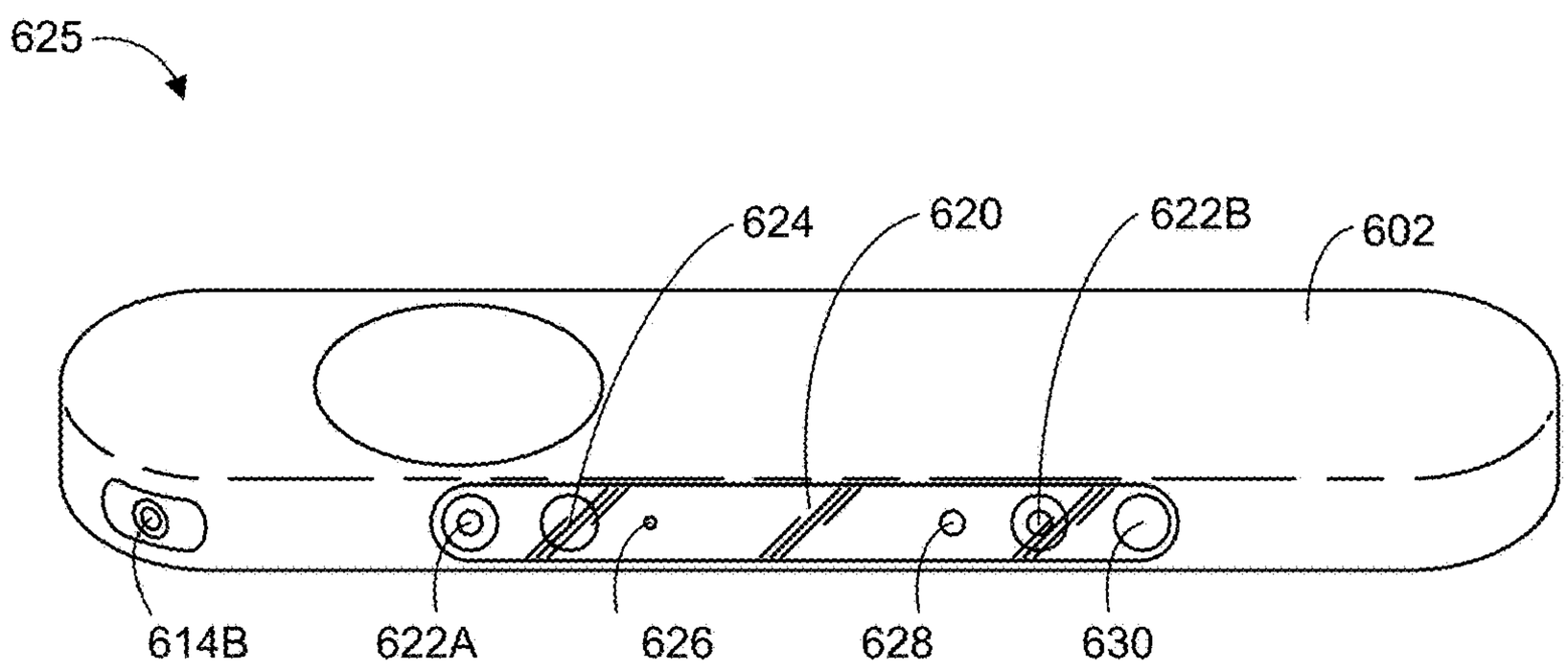

625
624
620
622B
602
614B
622A
626
628
630

Figure 6A

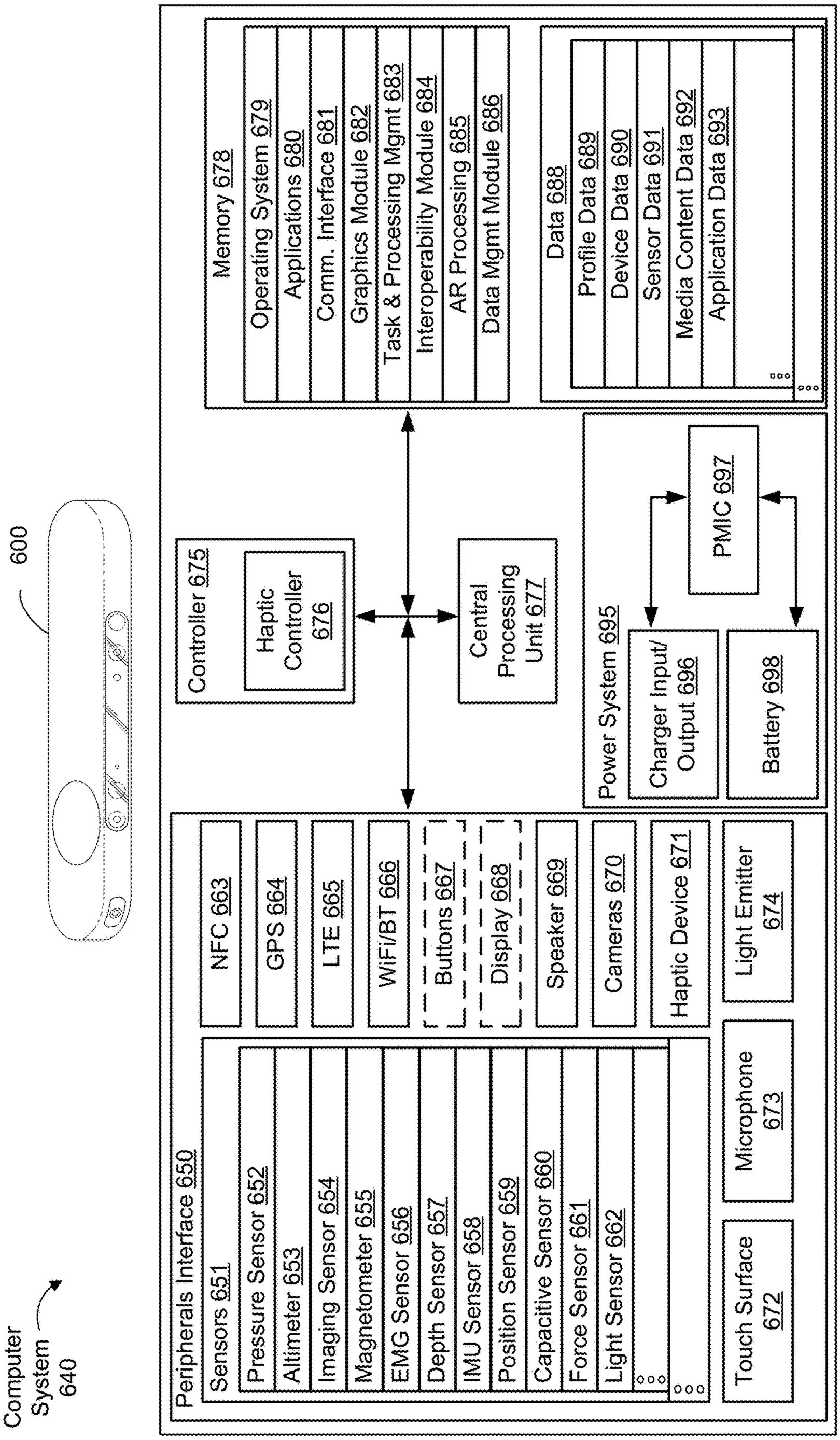

600
Computer System 640
Memory 678
Operating System 679
Applications 680
Comm. Interface 681
Graphics Module 682
Task & Processing Mgmt 683
Interoperability Module 684
AR Processing 685
Data Mgmt Module 686
Data 688
Profile Data 689
Device Data 690
Sensor Data 691
Media Content Data 692
Application Data 693
Controller 675
Haptic Controller 676
Central Processing Unit 677
Power System 695
Charger Input/ Output 696
PMIC 697
Battery 698
NFC 663
GPS 664
LTE 665
WiFi/BT 666
Buttons 667
Display 668
Speaker 669
Cameras 670
Haptic Device 671
Light Emitter 674
Peripherals Interface 650
Sensors 651
Pressure Sensor 652
Altimeter 653
Imaging Sensor 654
Magnetometer 655
EMG Sensor 656
Depth Sensor 657
IMU Sensor 658
Position Sensor 659
Capacitive Sensor 660
Force Sensor 661
Light Sensor 662
Touch Surface 672
Microphone 673

Figure 6B

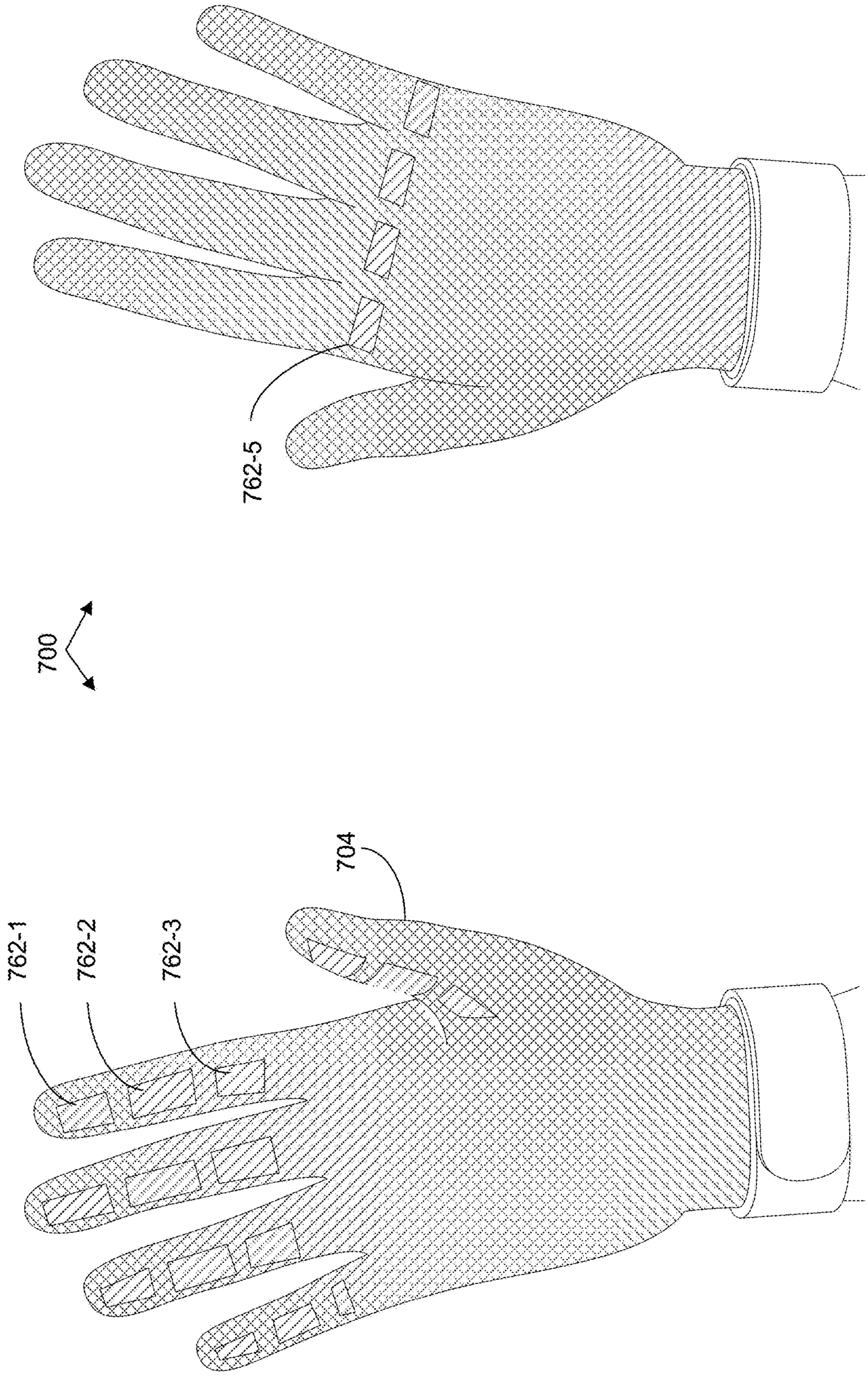
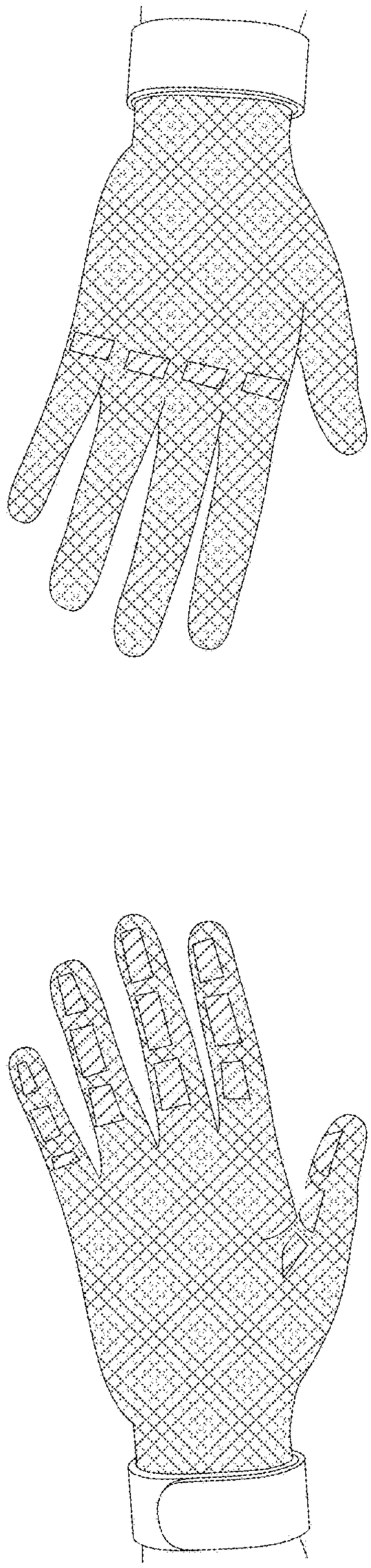


Figure 7A

Figure 7B



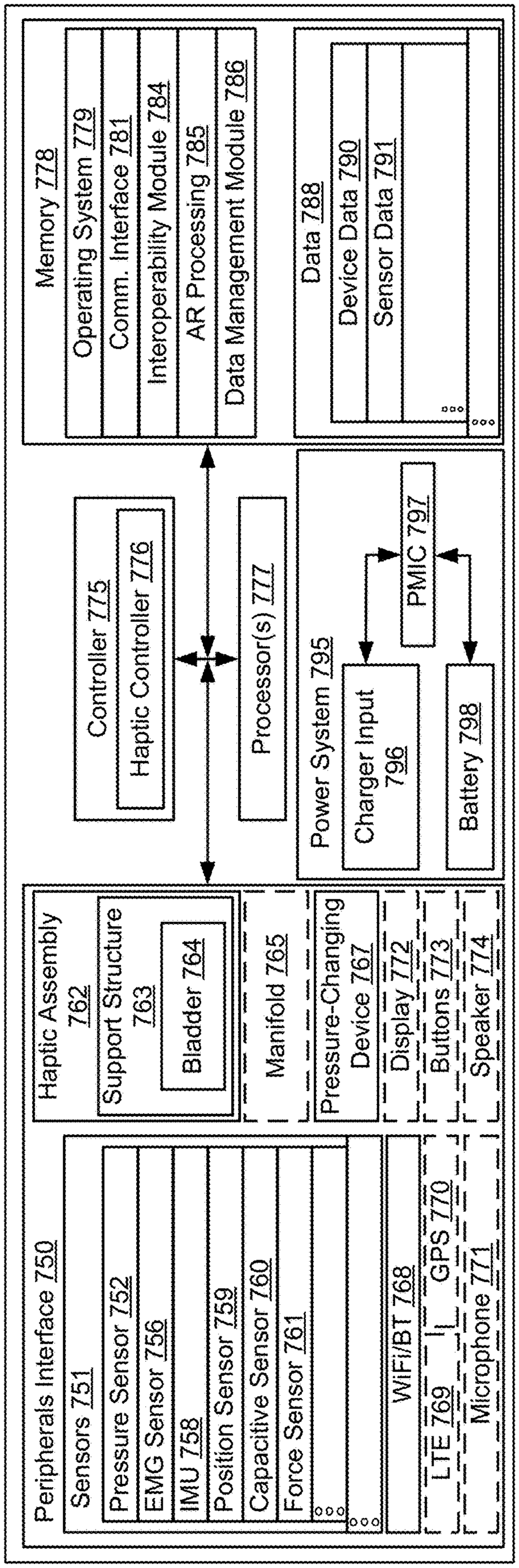

Memory 778
Operating System 779
Comm. Interface 781
Interoperability Module 784
AR Processing 785
Data Management Module 786
Data 788
Device Data 790
Sensor Data 791
Controller 775
Haptic Controller 776
Processor(s) 777
Power System 795
Charger Input 796
PMIC 797
Battery 798
Haptic Assembly 762
Support Structure 763
Bladder 764
Manifold 765
Pressure-Changing Device 767
Display 772
Buttons 773
Speaker 774
Peripherals Interface 750
Sensors 751
Pressure Sensor 752
EMG Sensor 756
IMU 758
Position Sensor 759
Capacitive Sensor 760
Force Sensor 761
WiFi/BT 768
LTE 769
GPS 770
Microphone 771
Computer System 740

Figure 7C

METHODS FOR IDENTIFYING DEVOLVED SEQUENCES OF HANDWRITING MOTIONS FOR GENERATING TARGET INPUTS USING A CO-ADAPTED INPUT-DETECTION MODEL, AND DEVICES AND SYSTEMS THEREFOR

RELATED APPLICATIONS

This application claims priority to U.S. Prov. App. No. 63/588,270, filed on Oct. 5, 2023, entitled "Methods for Identifying Devolved Sequences of Handwriting Motions for Generating Target Inputs using a Co-Adapted Input-Detection Model, and Devices and Systems therefor," which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates generally to wearable electronic devices (e.g., wrist-wearable devices and/or head-wearable devices) with sensors for detecting sequences of handwriting motions performed by a wearer, and more particularly to identifying devolved sequences of handwriting motions for generating target inputs (e.g., text characters and strings, emojis, gifs).

BACKGROUND

Conventional textual input systems allow users to produce content (e.g., generate targeted textual inputs) by pressing physical buttons (e.g., on a keyboard or remote controller) and/or a touch-sensitive display displaying virtual buttons within a user interface. These textual input systems typically require tedious user inputs using "hunt-and-peck" techniques for locating and entering characters of the target inputs that the user intends to produce. These input systems are not practically capable of allowing users to produce text at speeds the same or similar to, the users' speed of producing thought and/or speaking (e.g., 120 to 150 words per minute).

The existing textual input systems are also rigidly defined, and do not efficiently or intuitively facilitate co-adaptation between the users and their respective devices for detecting user inputs. And thus, existing textual input systems do not include or consider means for effectively tracking a user's progress to determine more efficient ways for the user to perform operations to achieve the same target input as by performing the precise inputs defined by the textual input system.

SUMMARY

The methods, devices, and systems described herein address the deficiencies described above. Namely, the techniques described herein allow users to produce one or more target inputs (e.g., textual characters, emojis, reactions) by performing devolved sequences of handwriting motions that are suggested to them by a co-adapted machine-learning model. For example, a user may perform one or more handwriting motions to produce (e.g., in a text message) letters in the word "this" (e.g., separately drawing "t," "h," "I," and "s"). A machine-learning model receiving data corresponding to the user's hand movements may determine a simpler "devolved" version of the sequence of handwriting motions (e.g., requiring less motor activity, is less constrained by legibility criteria) that the user can perform to produce the same textual elements. The devolved sequence of handwriting motions may be selected based on an objective of the machine-learning model to improve the user's speed of producing target inputs (e.g., words per minute).

A first example method of identifying devolved sequences of handwriting motions is described herein. The operations of the example method include obtaining, via one or more sensors of a wearable device of a computing system, data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs while wearing a wearable electronic device of a computing system. The method further includes identifying, based on at least (i) the data corresponding to the user attempting to perform the sequence of handwriting motions and (ii) the one or more target inputs associated with the sequence of handwriting motions, a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs. The devolved sequence of handwriting motions is a different sequence as compared to the sequence of handwriting motions and includes fewer handwriting motions as compared to the sequence of handwriting motions. And the method includes causing presentation, via the computing system, of a representation of the devolved sequence of handwriting motions.

Some of the embodiments of the first example described herein are technical improvements to the pen-and-paper methodology for producing text. For example, devolvement criteria for identifying devolved sequences of handwriting motions are based on removing aspects of handwriting that are based on a legibility constraint (e.g., formal and informal rules about how text must be produced to ensure the text is readable by other human observers), which are not necessary for a co-adapted input-detection model to identify the same target inputs.

A second example method of presenting representations of identified sequences of handwriting motions to a user by applying the sequences of handwriting motions to a generative model that is co-adapted to a user of the computing system is provided. The second example includes obtaining, via one or more sensors of a wearable device of a computing system, data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs while wearing the wearable electronic device of a computing system. The second example method includes identifying, based on at least (i) the data corresponding to the user attempting to perform the sequence of handwriting motions and (ii) the one or more target inputs associated with the sequence of handwriting motions, a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs, where the devolved sequence of handwriting motions is a different sequence as compared to the sequence of handwriting motions and includes fewer handwriting motions as compared to the sequence of handwriting motions. The second example method includes, after identifying the devolved sequence of handwriting motions, providing information about the devolved sequence of handwriting motions to a generative model. The second example method includes receiving, from the generative model, a representation of the devolved sequence of handwriting motions. And the second example method includes causing presentation, via the computing system, of the representation of the devolved sequence of handwriting motions received from the generative model.

The features and advantages described in the specification are not necessarily all-inclusive and, in particular, certain additional features and advantages will be apparent to one of

ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes.

Having summarized the above example aspects, a brief description of the drawings will not be presented.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the various described embodiments, reference should now be made to the Detailed description below in conjunction with the following drawings in which like reference numerals refer to corresponding parts throughout the figures.

FIGS. **1**A to **1**F illustrate an example AR system for determining target inputs based on sequences of handwriting motions performed by a user and identifying devolved sequences of handwriting motions, in accordance with some embodiments.

FIGS. **2**A to **2**C show example method flow charts for identifying devolved sequences of handwriting motions for generating target inputs using a co-adapted input-detection model, in accordance with some embodiments.

FIGS. **3**A, **3**B, **3**C-**1**, **3**C-**2**, **3**D-**1**, and **3**D-**2** illustrate example artificial-reality systems, in accordance with some embodiments.

FIGS. **4**A to **4**B illustrate an example wrist-wearable device, in accordance with some embodiments.

FIGS. **5**A, **5**B-**1**, **5**B-**2**, and **5**C illustrate example head-wearable devices, in accordance with some embodiments.

FIGS. **6**A to **6**B illustrate an example handheld intermediary processing device, in accordance with some embodiments.

FIGS. **7**A to **7**C illustrate an example smart textile-based garment, in accordance with some embodiments.

In accordance with customary practice, the various features illustrated in the drawings may not be drawn to scale. Accordingly, the dimensions of the various features may be arbitrarily expanded or reduced for clarity. In addition, some of the drawings may not depict all of the components of a given system, method, or device. Finally, like reference numerals may be used to denote like features throughout the specification and figures.

DETAILED DESCRIPTION

Numerous details are described herein to provide a thorough understanding of the example embodiments illustrated in the accompanying drawings. However, some embodiments may be practiced without many of the specific details, and the scope of the claims is only limited by those features and aspects specifically recited in the claims. Furthermore, well-known processes, components, and materials have not necessarily been described in exhaustive detail so as to avoid obscuring pertinent aspects of the embodiments described herein.

Embodiments of this disclosure can include or be implemented in conjunction with various types or embodiments of artificial-reality systems. Artificial reality (AR), as described herein, is any superimposed functionality and/or sensory-detectable presentation provided by an artificial-reality system within a user's physical surroundings. Such artificial realities can include and/or represent virtual reality (VR), augmented reality, mixed artificial reality (MAR), or some combination and/or variation of these. For example, a user can perform a swiping in-air hand gesture to cause a song to be skipped by a song-providing API providing playback at, for example, a home speaker. An AR environment, as described herein, includes, but is not limited to, VR environments (including non-immersive, semi-immersive, and fully immersive VR environments); augmented-reality environments (including marker-based augmented-reality environments, markerless augmented-reality environments, location-based augmented-reality environments, and projection-based augmented-reality environments); hybrid reality; and other types of mixed-reality environments.

Artificial-reality content can include completely generated content or generated content combined with captured (e.g., real-world) content. The artificial-reality content can include video, audio, haptic events, or some combination thereof, any of which can be presented in a single channel or in multiple channels (such as stereo video that produces a three-dimensional effect to a viewer). Additionally, in some embodiments, artificial reality can also be associated with applications, products, accessories, services, or some combination thereof, which are used, for example, to create content in an artificial reality and/or are otherwise used in (e.g., to perform activities in) an artificial reality.

A hand gesture, as described herein, can include an in-air gesture, a surface-contact gesture, and/or other gestures that can be detected and determined based on movements of a single hand (e.g., a one-handed gesture performed with a user's hand that is detected by one or more sensors of a wearable device (e.g., electromyography (EMG) and/or inertial measurement units (IMUs) of a wrist-wearable device) and/or detected via image data captured by an imaging device of a wearable device (e.g., a camera of a head-wearable device)) or a combination of the user's hands. In-air means, in some embodiments, that the user hand does not contact a surface, object, or portion of an electronic device (e.g., a head-wearable device or other communicatively coupled device, such as the wrist-wearable device), in other words, the gesture is performed in open air in 3D space and without contacting a surface, an object, or an electronic device. Surface-contact gestures (contacts at a surface, object, body part of the user, or electronic device) more generally are also contemplated in which a contact (or an intention to contact) is detected at a surface (e.g., a single- or double-finger tap on a table, on a user's hand or another finger, on the user's leg, a couch, a steering wheel, etc.). The different hand gestures disclosed herein can be detected using image data and/or sensor data (e.g., neuromuscular signals sensed by one or more biopotential sensors (e.g., EMG sensors) or other types of data from other sensors, such as proximity sensors, time-of-flight sensors, sensors of an inertial measurement unit, etc.) detected by a wearable device worn by the user and/or other electronic devices in the user's possession (e.g., smartphones, laptops, imaging devices, intermediary devices, and/or other devices described herein).

As described herein, a baseline sequence of handwriting motions includes a sequence of hand motions performed by a user (e.g., in-air, near-surface, and/or surface-contact hand gestures) that directly corresponds to the motions (e.g., strokes) that the user would need to perform to produce the same text (e.g., target inputs) using pen-and-paper handwriting.

As described herein, devolved sequences of handwriting motions are sequences of handwriting motions that can be performed by the user to produce the same target inputs as would be produced by baseline sequences of handwriting motions, but which are in some way optimized (e.g., involving fewer handwriting motions than the corresponding base-

line sequences of handwriting motions) for the user **302** to perform and/or for the computing system to detect.

As described herein, co-adaptation refers to a process of concurrently adapting (i) a model (e.g., a generative model, such as a LLM) and (ii) a user's behavior based on the respective tendencies of the model and the user, respectively. In other words, a co-adapted model becomes personalized based on aspects of a user's interactions with the model. In some embodiments, co-adaptation between a user and a generative model can be considered bi-directional (e.g., the model is capable of providing instructions to the user for adapting the user's performance of certain handwriting motions such that they are more likely to be correctly interpreted by the model).

FIGS. **1**A to **1**F illustrate an example AR system **300***a* (which is described in more detail with respect to FIG. **3**A) that is causing operations to be performed for determining target inputs based on a sequence of handwriting motions **102** performed by a user **302** and identifying devolved sequences of handwriting motions (e.g., a devolved sequence suggestion **130** shown in FIG. **1**B), in accordance with some embodiments.

FIG. **1**A shows the user **302** performing the sequence of handwriting motions **102** while wearing wrist-wearable device **400** (which is described in more detail with respect to FIGS. **4**A and **4**B). The wrist-wearable device **400** is part of a computing system **300***a* that also includes a head-wearable device being worn by the user **302** (e.g., AR headset **500**, VR headset **510**). But a skilled artisan will appreciate that computing systems including various different combinations of one or more different components can be used for performing some or all of the operations described herein (e.g., AR system **300***b*, AR system **300***c*, AR system **300***d*).

The sequence of handwriting motions **102** corresponds to a set of target inputs for the phrase "Happy:)." Specifically, the sequence of handwriting motions **102** that the user **302** is performing in FIG. **1**A is described herein as a baseline sequence of handwriting motions, in that it includes respective handwriting motions that directly correspond to the same motions that the user **302** would need to perform to produce handwritten characters corresponding to the one or more target inputs (e.g., pen-and-paper sequences of letters and other characters). For example, a baseline sequence of handwriting motions corresponding to the letter "H" would include two vertical lines and a horizontal line that spatially connects the two vertical lines.

In accordance with some embodiments, the input model **170** includes a sequence library **172** that includes data (e.g., algorithms, detection models) for identifying one or more target inputs that the user **302** is attempting to produce by performing the sequence of handwriting motions **102**. In some embodiments, the sequence library **172** is preconfigured with data for detecting sets of characters (e.g., alphanumeric text, numbers, and a select set of emojis) based on baseline sequences of handwriting motions. In accordance with some embodiments, the input model **170** is calibrated, or otherwise co-adapted, for the user **302** based on, for example, historical data, including data obtained while the user **302** was performing sequences of handwriting motions.

In some embodiments, the input model **170** receives data (e.g., the handwriting sequence data **110** and target input data **112** indicating the one or more target inputs that the user **302** is attempting to perform via the sequence of handwriting motions **102**) from one or more data input devices of the computing system (e.g., biopotential-signal-sensing components, such as EMG sensors **465** of the wrist-wearable device **400** and/or imaging sensor **526**, such as cameras, that are located on the wrist-wearable device **400** or the head-wearable device **500**). In some embodiments, the input model utilizes sensor fusion to combine data from a variety of sources (e.g., data from the EMG sensor **756** and image data from the imaging sensor **526**). In some embodiments, the input model **170** includes and/or is coupled with a generative model configured to perform various operations related to devolved sequences of handwriting motions. For example, a generative model may be used to identify a devolved sequence of handwriting motions to suggest to the user **302** based on a sequence of handwriting motions detected by the input model **170**. In some embodiments, the same or a different generative model (e.g., a large-language model) may be used to generate a representation of the identified devolved sequence of handwriting motions (e.g., an instructional demonstration and/or textual output instructing the user **302** how to perform the devolved sequence of handwriting motions). In some embodiments, the input model **170** is co-adapted to the user **302**. That is, the input model **170** may be uniquely personalized to the user **302** based on preferences and/or tendencies of the user related to their performance of gestures (e.g., sequences of handwriting motions) to produce target inputs.

While the user **302** performs the sequence of handwriting motions **102**, a user interface **104** (e.g., a gesture calibration user interface) is presented by an electronic device of the computing system **300***a* (e.g., a display **405** of the wrist-wearable device **400**, a display **535**A of the AR device **500**). The user interface **104** presents information (e.g., real-time data obtained by the wrist-wearable device **400**) while the user **302** attempts to perform sequences of handwriting motions. For example, the user interface includes a user interface element **106**, which includes a representation of data being obtained by one or more biopotential-signal-sensing components of the wrist-wearable device **400**, in accordance with some embodiments.

In conjunction with presenting the real-time data with the user interface element **106**, the user interface **104** includes another user interface element **108**, which includes a representation of data that would be produced within the user interface element **106** if the user **302** had performed a maximally efficient sequence of handwriting motions for the same one or more target inputs. In some embodiments, the maximally efficient sequence of handwriting motions shown by the user interface element **108** includes the same baseline sequence of handwriting motions that the user **302** attempted to perform via the sequence of handwriting motions **102**. In some embodiments, the maximally efficient sequence of handwriting motions includes a devolved sequence of handwriting motions that has already been stored within the sequence library **172** (e.g., providing a reminder to the user that the devolved sequence of handwriting motions is available for obtaining the one or more target inputs). In accordance with some embodiments, the input model **170** is further configured to include a user co-adaptations module **180**, which includes a set of co-adaptations that are specific to the user **302**. For example, a particular co-adaptation may indicate that the user **302** is more likely to learn devolved sequences of handwriting motions that include particular types of handwriting motions.

FIG. **1**B shows the AR system **300***a* after the user **302** has finished performing the sequence of handwriting motions **102** shown in FIG. **1**A. Another user interface **120** is being presented to the user **302**, the user interface **120** including an alert that a devolved sequence of handwriting motions is available to be performed for the same one or more target

inputs that the sequence of handwriting motions **102** corresponds to (e.g., a devolved sequence suggestion **130**). The alert user interface element **122** includes an indication: "Alert: There is a devolved sequence of handwriting motions available to use instead of the baseline sequence of handwriting motions for the same target inputs." The alert user interface element **122** also includes information about how to perform the suggested devolved sequence of handwriting motions (e.g., "Suggested Devolved Sequence: Perform the gesture without including the second 'p' to improve words per minute speed (detection accuracy will be substantially unchanged)."). That is, in accordance with some embodiments, a devolved sequence of handwriting motions corresponding to one or more target inputs (e.g., the word "Happy") may include substantially the same set of handwriting motions for each of the individual letters, except that the devolved sequence of handwriting motions may omit a particular portion of the sequence of handwriting motions **102** (e.g., "dropping" a double letter).

The user interface **120** also includes a user interface element **126**, which includes a suggestion for how the user **302** can improve performance of the sequence of handwriting motions **102** that the user **302** performed in FIG. **1**A (stating: "EMG Optimization Suggestion: Your performance of the letter 'H' includes sub-optimal EMG signal."), in accordance with some embodiments. The user interface element **126** includes a selectable user interface element **128** that the user can select (e.g., using a directed tap input) to cause a demonstration of the sequence optimization. In some embodiments, the AR system **300***a* includes a neural network (e.g., a large-language model) that is configured to generate representations of particular suggestions provided by the input model **170**. For example, after the input model identifies a devolved sequence suggestion **130** to suggest to the user **302**, a large language model may receive information about the devolved sequence suggestion **130** and generate a visual demonstration (e.g., written instructions, a visual animation) of the devolved sequence suggestion **130** to present to the user **302**.

FIG. **1**C shows the AR system **300***a* after the user **302** has input a selection not to add the devolved sequence suggestion **130** to the sequence library **172** of the input model **170**. Based on the user input not to add the devolved sequence suggestion **130** to the sequence library **172**, the user interface **120** is presenting new user interface elements corresponding to additional devolved sequence suggestions for the user **302** based on the sequence of handwriting motions **102** (an informational user interface element **132** stating: "Sequence Optimization UI Element: There are several ways to improve performance of the letter 'h' based on your historical user-specific sequence data to improve decoder accuracy and gesture performance and speed."). The user interface **120** includes demonstration user interface elements **134** and **136** that illustrate respective representations (e.g., demonstrations) for the other devolved sequence suggestions. In accordance with some embodiments, based on the user **302** forgoing adding the devolved sequence of handwriting motions suggested to the user as part of the devolved sequence suggestion **130**, a particular co-adaptation **182** is added to the user co-adaptations module **180** of the co-adapted input model **170**, which may be used to determine future devolved sequence suggestions to present to the user **302**.

The demonstration user interface element **134** includes a visual depiction of a handwriting motion corresponding to one of the letters of the target inputs that the user intended to produce by performing the sequence of handwriting motions **102** shown in FIG. **1**A (stating: "Draw the tail of the 'h' in a third plane," and including a visual depiction of the devolved sequence suggestion **140** that includes a three-dimensional plane). That is, in accordance with some embodiments, a devolved sequence of handwriting motions can include a portion of a sequence of handwriting motions that is performed in an additional dimensional plane that was not implicated by the original sequence of handwriting motions. The other demonstration user interface element **136** includes a visual depiction of a devolved sequence of handwriting motions that includes an EMG-detectable substitute gesture (e.g., a pinch gesture) that the user **302** can perform instead of the portion of the sequence of handwriting motions corresponding a particular target input (or set of target inputs). In some embodiments, EMG-detectable substitute gestures may be suggested for particular target inputs that the user **302** commonly performs.

In accordance with some embodiments, the input model **170** may include one or more user co-adaptations modules **180** based on actions performed by the user. That is the input model **170** may be or include a co-adaptive component that is configured to cause the input model **170** to co-adapt to the user **302** (e.g., based on user-specific aspects of handwriting motion data, user preferences related to learning new sequences of handwriting motions, and/or user-specific learning styles or learning rates for learning devolved sequences of handwriting motions). For example, the user co-adaptations module **180** may include a particular co-adaptation **182** based on the user foregoing to add the devolved sequence suggestion **130** to the sequence library **172**. The user **302** is performing a gesture corresponding to a user selection **135** of the demonstration user interface element **134**.

In some embodiments, multiple devolved sequences of handwriting motions may be suggested to the user **302** as part of a multipart devolved sequence suggestion, where each of the respective devolved sequence suggestions of the multipart devolved sequence suggestion correspond to different respective target inputs of the one or more target inputs. In some embodiments, one or more devolvement criteria are used to determine which of a plurality of candidate devolved sequences of handwriting motions to suggest to the user **302**. For example, a particular devolvement criterion may be based on a reduction in the amount of exertion that the user is required to exert in performing the devolved sequence of handwriting motions.

FIG. **1**D shows the AR system **300***a* while the user **302** is performing the devolved sequence of handwriting motions corresponding to the devolved sequence information **176** selected by user selection **135** in FIG. **1**C for the same set of target inputs (e.g., the phrase "Happy:)"). While the user **302** is performing the devolved sequence of handwriting motions **144**, the user interface **104** presents similar content for the devolved sequence of handwriting motions **144** as it did for the sequence of handwriting motions **102** shown in FIG. **1**A. Based on the user selection in FIG. **1**C selecting the devolved sequence of handwriting motions, devolved sequence information **176** is added to the sequence library **172** for the user **302**, and another particular co-adaptation **184** is added to the user co-adaptations module **180** based on the user **302** choosing to learn the devolved sequence of handwriting motions presented by the demonstration user interface element **134**.

FIG. **1**E shows AR system **300***a* after the user has performed the devolved sequence of handwriting motions **144** based on the devolved sequence suggestion selected in FIG. **1**C. Based on the performance of the devolved

sequence of handwriting motions **144** by the user **302** in FIG. **1**D, the user interface **120** is presenting information to the user about a refined devolved sequence of handwriting motions based on the performance of the devolved sequence of handwriting motions **144** (an informational user interface element **146**, stating: "Refined Devolved Sequence Available: Based on your historical sequence profile, there is a refined devolved sequence for the devolved sequence you just performed."). A demonstration user interface element **148** is presenting a visual demonstration of a refined devolved sequence suggestion **152** that is suggested to the user **302** based on the performance of the devolved sequence of handwriting motions **144**. Based on a user selection **151** of the refined devolved sequence suggestion **152** that is presented by the user interface element **148**, another particular co-adaptation **186** is added to the user co-adaptations module **180** of the input model **170** that is associated with the user **302**.

FIG. **1**F shows the AR system **300***a* while the user **302** performs various iterations of a sequence of handwriting motion and is receiving feedback (e.g., instantaneous or near-instantaneous feedback) about the performance of a sequence of handwriting motions **160** that the user **302** is performing over a span of time (e.g., the span of time denoted by t**0**, t**1**, and t**2**). For example, at time t**0** the user **302** is performing a first iteration of the sequence of handwriting motions. A first feedback element **162** is a representation of a respective handwriting motion of the sequence of handwriting motions **160** that the user **302** is performing at time to, and a second feedback element **164** is a representation of an optimized handwriting motion corresponding to the same handwriting motion that the user **302** is attempting to perform at the time t**0**. A user interface element **161** provides a gesture score to the user **302** (e.g., a gesture score of 64), indicating a relative accuracy of performance of that portion of the sequence of handwriting motions **160** by the user **302**.

At a second time, t**1**, based on the user **302** performing another sequence of handwriting motions **160** (e.g., after a notification provided to the user **302** from the AR device **500** requesting the user **302** to perform gesture optimization training, and/or as part of a continuation of the sequence of handwriting motions that user **302** performed at time t**0**), another user interface element is displayed that includes another first feedback element **167** of a respective handwriting motion of the second sequence of handwriting motions performed by the user **302**, and another second feedback element **169** is another representation of the optimized handwriting motion for performing the set of target inputs that the user **302** is attempting to produce using the sequence of handwriting motions **160**. Another user interface element **163** provides a gesture score to the user **302** (e.g., a gesture score of 71), indicating a relative accuracy of the performance of the sequence of handwriting motions by the user **302**.

At a third time, t**2**, based on the user **302** performing yet another sequence of handwriting motions (e.g., as part of a training sequence for co-adapting the user **302** to the input model **170**), a third set of first and second feedback elements **166** and **168**, respectively, is presented within a user interface, and another user interface element **165** is presented that includes an indication that the user **302** performed the sequence of handwriting motions corresponding to time t**2** with a substantially higher level of accuracy, including a gesture score of 91 and a textual element within the user interface element **165** stating, "Gesture performance has improved greatly."

Example Embodiments

FIGS. **2**A to **2**C illustrate various embodiments of techniques related to devolving sequences of handwriting motions performed by users of computing systems that include components described herein. In particular: (i) FIG. **2**A illustrates an example method **200** of identifying devolved sequences of handwriting motions based on users' attempts to perform sequences of handwriting motions corresponding to target inputs; (ii) FIG. **2**B illustrates another example method **240** of presenting representations of identified sequences of handwriting motions to a user by applying the sequences of handwriting motions to a generative model that is co-adapted to a user of the computing system; and (iii) FIG. **2**C illustrates yet another example method **280** of presenting user interfaces to users that include representations of aspects of the users' performances of sequences of handwriting motions.

For explanatory purposes, the various blocks of the processes **200**, **240**, and **280** are described herein with reference to FIGS. **1**A to **1**F, and the associated components and/or processes described herein with respect to FIGS. **3**A to **6**B. For example, operations (e.g., steps) of the methods **200**, **240**, and/or **280** can be performed by one or more processors (e.g., processor **479** and/or a microcontroller unit) of the system **300***a*. Some of the operations of the example methods shown in FIGS. **2**A to **2**C correspond to instructions stored in a computer memory or computer-readable storage medium (e.g., memory **450** of the computer system **430** associated with the wearable band **410**).

Operations of the example methods shown in FIGS. **2**A to **2**C can be performed by a single device alone or in conjunction with one or more processors and/or hardware components of another communicatively coupled device (e.g., the wrist-wearable device **400** in conjunction with the head-wearable device **500**) and/or instructions stored in memory or computer-readable media of the other device communicatively coupled to the system. In some embodiments, the various operations of any of the methods shown in FIGS. **2**A to **2**C are interchangeable and/or optional, and respective operations of the methods can be performed by any of the devices and/or constituent components of the components described herein. For convenience, the method operations will be described below as being performed by particular components or devices but should not be construed as limiting the performance of the operation to the particular device in all embodiments.

The one or more blocks of methods **200**, **240**, and **280** may be implemented, for example, by one or more computing devices of the AR system **300***a* including, for example, the wrist-wearable device **400** and/or the AR device **500**. In some embodiments, two or more electronic devices within a respective computing system can operate in tandem (e.g., as part of a device constellation) to perform the operations described herein. For example, respective sensors of the wrist-wearable device **400** and/or the AR device **500** may collect data related to a user's performance of a sequence of handwriting motions (e.g., a baseline sequence of handwriting motions, a devolved sequence of handwriting motions), and the respective sensor data can be provided to an intermediary processing device (e.g., the handheld intermediary processing device (HIPD) **600**, a remote server (e.g., a respective server of the one or more servers **330**)).

Concept 1. Devolving Handwriting Through Co-Adaptation of a Gesture-Detection Model

(A1) FIG. **2**A shows a flow chart of the example method **200** of identifying devolved sequences of handwriting

motions to suggest to a user based on detected attempts to perform sequences of handwriting motions (e.g., baseline handwriting motions for one or more characters of alphanumeric text).

As part of the AR system **300***a* performing the method **200**, the wrist-wearable device **400** obtains (**202**), via one or more sensors of the wrist-wearable device **400** (e.g., EMG sensors **465**), data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs (e.g., alphanumeric text and/or special characters, such as emojis) while wearing the wrist-wearable device **400**. For example, in FIG. **1**A, data may be obtained by one or more EMG sensors **465** of the wrist-wearable device **400**. In some embodiments, the data corresponding to the user **302** attempting to perform the sequence of handwriting motions is obtained, at least in part, by one or more imaging sensors (e.g., external-facing cameras, such as the left camera **539**A and/or the right camera **539**B) of the AR device **500**. In some embodiments, first data collected by one or more sensors of a first device (e.g., the wrist-wearable device **400**), and second data collected by one or more sensors of a second device (e.g., the AR system **500**) are provided to the same input model **170** (e.g., as part of a sensor fusion operation) in order to increase the confidence of detection of the sequence of handwriting motions.

Performance of the method **200** includes identifying (**204**), based on at least (i) the data corresponding to the sequence of handwriting motions and (ii) the one or more target inputs, a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs (e.g., the devolved sequence suggestion **130** shown in FIG. **1**B). The devolved sequence of handwriting motions is different from the sequence of handwriting motions performed by the user and includes fewer handwriting motions (e.g., less muscular activations by the user's hand or forearm) as compared to the sequence of handwriting motions (**206**). In some embodiments, one or more portions of the devolved sequence of handwriting motions are the same as the sequence of handwriting motions that the user **302** originally performed. For example, the devolved sequence suggestion **130** shown in FIG. **1**B includes all of the same handwriting motions for the individual letters and characters but involves dropping the second "p" in the word "happy." In contrast, some devolved sequences of handwriting motions may include handwriting motions that do not correspond to any baseline sequences of handwriting motions (e.g., a "thumbs-up" hand gesture may be a devolved sequence of handwriting motions for the word "yes").

Finally, the AR system **300***a* causes (**208**) presentation (e.g., using the display **535**A of the AR system **500**) of a representation of the devolved sequence of handwriting motions. For example, as described in more detail with respect to the method **240** discussed with respect to FIG. **2**B, data related to the devolved sequence of handwriting motions may be provided to a generative model (e.g., a large-language model (LLM)), and the generative model may generate an output that includes a demonstration that includes one or more textual, visual, audial, and/or haptic components related to representing the devolved sequence of handwriting motions.

(A2) In some embodiments of A1, one or more sensors of the wearable device (e.g., the wrist-wearable device **400**) obtain other data corresponding to the user **302** attempting to perform the devolved sequence of handwriting motions associated with the respective target input of the one or more target inputs. For example, in FIG. **1**D, sensors of the wrist-wearable device **400** are used to detect that the user **302** is performing the devolved sequence of handwriting motions **144**. The AR system **300***a* identifies, based on at least (i) the other data corresponding to the user attempting to perform the devolved sequence of handwriting motions and (ii) the respective target input of the one or more target inputs, a refined devolved sequence of handwriting motions to suggest to the user for inputting the respective target input (e.g., the refined devolved sequence suggestion **152**). The refined devolved sequence of handwriting motions is a different sequence as compared to the devolved sequence of handwriting motions identified based on the sequence of handwriting motions and includes fewer handwriting motions than the sequence of handwriting motions (e.g., the sequence of handwriting motions **102** in FIG. **1**A). And the AR system **300***a* causes presentation, via the computing system, of a representation of the refined devolved sequence of handwriting motions.

That is, the systems, devices, and methods described herein provide for dynamic fine-tuning of devolved sequences of handwriting motions and baseline sequences of handwriting motions that are continuously co-adapted based on the user's usage and/or efficiency in performing particular sequences of handwriting motions and/or based on the user's historical rate of learning new devolved sequences of handwriting motions. For example, a particular set of devolved sequences of handwriting motions may be based on an objective of reducing sequences of handwriting motions to singular strokes at particular angles relative to the user, and each refinement and/or devolvement of the sequence of handwriting motions may be based on achieving the objective of providing a library of single-stroke gestures to the user (e.g., to be stored in the sequence library **172**).

(A3) In some embodiments of A2, the devolved sequence of handwriting motions is selected from a predefined set of devolved sequences corresponding to particular target inputs, and the refined devolved sequence is identified via a self-supervised model that is co-adapted based on sequences of handwriting motions performed by the user (e.g., stored as user co-adaptation within the user co-adaptations module **180** shown in FIGS. **1**A to **1**E). In other words, the AR system **300***a* can identify suggestions of devolved sequences based on a combination of (i) a pre-configured library and/or supervised learning techniques for suggesting devolved sequences (e.g., based on pre-defined devolvement objectives) and (ii) an unsupervised learning technique that suggests devolved sequences based on, for example, real-time criteria about the user **302**'s performance of respective sequences of handwriting motions and/or other devolved sequences of handwriting motions.

(A4) In some embodiments of any one of A1 to A3, the AR system **300***a* identifies another devolved sequence of handwriting motions to suggest to the user **302** for inputting a different respective target input of the or more target inputs (e.g., in conjunction with identifying the devolved sequence of handwriting motions). In some embodiments, the devolved sequence of handwriting motions and the other devolved sequence of handwriting motions individually, and collectively, include fewer handwriting motions as compared to the sequence of handwriting motions. For example, in identifying a devolved sequence of handwriting motions to suggest to the user **302** based on the user **302** performing a baseline sequence of handwriting

motions for each of the individual letters in the word "happy," the AR system **300***a* may provide a first devolved sequence of handwriting motions that includes a different sequence of handwriting motions for the letter "h," and a devolved sequence for performing the double-p character sequence (e.g., suggesting a "dropped" letter).

(A5) In some embodiments of A4, the devolved sequence of handwriting motions and the other devolved sequence of handwriting motions together form a multipart set of devolved sequences corresponding to the one or more target inputs, and the multipart set of devolved sequences is selected based on comparing the multipart set of devolved sequences of handwriting motions to the devolved sequence of handwriting motions based on one or more devolvement criteria related to the respective sequences. That is, the systems, devices, and methods described herein can be used to determine that a combination of different devolved sequences would be most effective, intuitive, and/or efficient for suggesting to the user, instead of a single devolved sequence of handwriting motions for performing all of the one or more target inputs.

(A6) In some embodiments, the one or more devolvement criteria include respective criteria related to minimizing a legibility constraint for identifying the one or more target inputs based on the devolved sequence of handwriting motions (e.g., distinguishing or otherwise disambiguating the one or more intended target inputs based on the sequence of handwriting motions). In some embodiments, the legibility constraint is based on a discriminability of the sequence of handwriting motions (e.g., an estimated accuracy of distinguishing the one or more target inputs from other target inputs that include similar handwriting motions). In some embodiments, the one or more devolvement criteria include respective criteria related to reducing an amount of exertion required for performing the devolved sequence of handwriting motions (e.g., motor activity, an amount of arm movements, and/or a cumulative difficulty of performing the set of handwriting motions). In some embodiments, the one or more devolvement criteria include respective criteria related to increasing an estimated speed of producing the one or more target inputs (e.g., words per minute).

In some embodiments, determining which of a plurality of devolved sequences to provide to the user (and/or whether to provide any devolved sequences of handwriting motions to the user) includes comparing a respective value of one particular criterion against a different value of the same or a different particular criterion (e.g., an amount of reduction of exertion for performing the devolved sequence of handwriting motions). For example, the devolved sequence suggestion **130** may have been presented to the user **302** in FIG. **1**B instead of the other devolved sequence suggestions **140** and **142** shown in FIG. **1**C based on comparing the respective devolved sequences of handwriting motions corresponding to the devolved sequence suggestions **130**, **140**, and **142** based on relative satisfaction of respective devolvement criteria.

(A7) In some embodiments of A6, determining whether respective criteria related to the legibility constraint are satisfied includes (i) comparing a historical accuracy of an input-detection model for detecting the sequence of handwriting motions to a predicted accuracy of the input-detection model for detecting respective devolved sequences of handwriting motions and (ii) determining whether the respective devolved sequences of handwriting motions result in increasing detection accuracy for the one or more target inputs by more than a threshold error reduction rate (e.g., a five percent reduction in the rate of false positives detected by the input-detection model).

In some embodiments, the input-detection model is configured to receive feedback indicating that a respective set of one or more handwriting motions performed by the user was incorrectly identified as corresponding to a different textual element (e.g., a textual element that includes commonly confusing characters (e.g., h vs. n, b vs. p)). In some implementations, the feedback is provided by the user (e.g., providing an indication that the generated input is different than the target input intended by the user). In some implementations, the devolved sequence of handwriting motions is identified based on a determination that a portion of the sequence that corresponds to a respective target input of the one or more target inputs has been mistakenly identified by the input-detection model at or above a threshold error rate.

(A8) In some embodiments of A6 or A7, determining whether respective criteria related to the speed of producing the one or more target inputs are satisfied includes identifying one or more portions of the sequence of handwriting motions that the user performed with ballistic movement. As described herein, ballistic movement is defined as one or more muscular activations that exhibit maximum velocities and accelerations over a brief period of time (e.g., exhibiting high firing rates, high force production, and very brief contraction times).

(A9) In some embodiments of any one of A1 to A8, in accordance with determining that removing one or more handwriting motions of the sequence of handwriting motions would reduce an accuracy of detecting target inputs by less than a threshold error rate (e.g., a predicted accuracy of the input-detection model would be reduced by less than five percent, eight percent, ten percent, etc.), the AR system **300***a* identifying the devolved sequence of handwriting motions includes determining the devolved sequence of handwriting motions by removing the one or more handwriting motions from the sequence of handwriting motions that was performed by the user. For example, the system may determine that an input-detection model (e.g., a machine-learning model) for detecting which target inputs a user is intending to perform based on a particular sequence of handwriting motions would be only 0.5% less accurate at correctly inferring which target inputs the user is intending to perform without the user performing a portion of the sequence corresponding to a particular character or portion of the particular character. Based on determining that the difference in accuracy is less than a threshold error rate for suggesting the devolved sequence of handwriting motions, the system may present the devolved sequence of handwriting motions.

In some embodiments, the determination to present the devolved sequence to the user is made in conjunction with a separate determination that the devolved sequence of handwriting motions satisfies one or more devolvement criteria (e.g., increases speed of performing the one or more target inputs that is sufficient to offset any decreased efficiency caused by the reduced accuracy).

(A10) In some embodiments of any one of A1 to A9, the AR system **300***a* identifies, based on the data corresponding to the sequence of handwriting motions from

the one or more sensors of the wearable device (e.g., the wrist-wearable device **400** or the AR device **500**), a plurality of devolved sequences of handwriting motions to suggest to the user for inputting the respective target input, including the devolved sequence of handwriting motions (e.g., based on modifications (e.g., co-adaptions) applied to a gesture-recommendation module in accordance with the user performing respective previous sequences of handwriting motions). And the AR system **300***a* causes presentation (e.g., at the AR device **500**) of a plurality of representations, each of the representations corresponding to one of the plurality of devolved sequences of handwriting motions. In some embodiments, each of the plurality of devolved sequences of handwriting motions is identified for suggesting to the user based on a determination that each of the respective devolved sequences satisfies one or more devolvement criteria.

(A11) In some embodiments of A10, after presenting the devolved sequence of handwriting motions, the AR system **300***a* detects a user input, the user input corresponding to an operation for presenting alternative devolved sequences. And, responsive to the user input, the AR system **300***a* presents the plurality of representations, including presenting at least one of the plurality of representations corresponding to a respective devolved sequence of the plurality of devolved sequences that is different than the devolved sequence of handwriting motions. For example, while the demonstration user interface elements **134** and **136** representing selectable options are being presented to the user **302** in FIG. **1**C, a selection of the demonstration user interface element **136** may cause additional devolved sequences corresponding to the same target input and/or a different target input of the one or more target inputs that the user **302** performed sequences of handwriting motions corresponding to motions in FIG. **1**A. In some embodiments, the user input to present alternative devolved sequences is provided as an indication to a gesture-suggestion model (e.g., indicating that the user did not select the representation of the devolved sequence of handwriting motions).

(A12) In some embodiments of any one of A1 to A11, based on the data corresponding to the sequence of handwriting motions, the AR system **300***a* applies a co-adaptation to an input-detection model used to identify the devolved sequence of handwriting motions, wherein the co-adaptation is based on user-specific aspects of performance of one or more respective handwriting motions of the sequence of handwriting motions. And the AR system **300***a* uses the co-adaptation to the input-detection model to detect a different sequence of handwriting motions corresponding to one or more different target inputs. In other words, a co-adaptation applied to the input-detection model based on one particular sequence of handwriting motions may be used during detection of a different sequence of handwriting motions.

For example, the co-adapted large-language model may determine that there is a specific set of characters that the input-detection model persistently detects with a lower accuracy (and/or that the user performs slower compared to other users), and the co-adapted large language model may suggest one or more devolved hand sequences to reduce inaccuracy and or increase the user's speed of text generation based on the user-specific aspects of the historical handwriting motion sequence data related to those characters.

(A13) In some embodiments of any one of A1 to A12, after identifying the devolved sequence of handwriting motions, the AR system **300***a* provides information about the devolved sequence of handwriting motions to a generative model (e.g., a large-language model, or another artificial intelligence model that generates a particular medium of content). In some embodiments, the AR system **300***a* provides the information about the devolved sequence of handwriting motions in conjunction with a conditional prompt that includes instructions for the large-language model to generate a demonstration. And the AR system **300***a* receives, from the generative model, the representation of the devolved sequence of handwriting motions (e.g., including visual and/or non-visual demonstration components).

In some embodiments, the representation can be a demonstration to the user as to how the devolved sequence of handwriting motions should be performed, and this demonstration can be generated by a generative (artificial-intelligence) model, such as a LLM. In some embodiments, the demonstration is presented at the wearable electronic device (e.g., a wrist-wearable device). In some implementations, the demonstration is presented at a different wearable electronic device (e.g., a head-wearable device). By leveraging the generative model, the techniques described herein provide technical improvements by presenting instructions to a user by using a generative model to generate personalized instructions based on (e.g., unsupervised) learning by the model. Further, the devolved sequences of handwriting motions that are suggested to the user may include sequences of handwriting motions that are not predefined within any sequence library or other data storage associated with the handwriting motions of the user's available handwriting motions. (A14) In some embodiments of any one of A1 to A13, the one or more sensors in operable communication with the computing system include a biopotential-signal-sensing component, and the biopotential-signal-sensing component is configured to detect hand motions performed by the user (e.g., including sequences of handwriting motions). For example, the wrist-wearable device **102** shown in FIGS. **1**A to **1**F may be detecting the sequences of hand motions performed by the user **302**, at least in part, based on data from one or more EMG sensors **465** of the wrist-wearable device **400**.

(A15) In some embodiments of A14, the devolved sequence of handwriting motions includes a stationary action (e.g., a hand gesture that includes one or more neuromuscular activations but does not include any handwriting motions) detected via data from the biopotential-signal-sensing component (e.g., a pinch or flexure of a finger of the user) to replace one or more handwriting motions of the sequence of handwriting motions associated with the one or more target inputs (e.g., the trailing vertical line of the letter "h"). In some implementations, the neuromuscular proxy can be used to cause a particular letter to be capitalized or as a replacement for a particular common trigram (e.g., "the").

(A16) In some embodiments of any one of A1 to A15, the sequence of handwriting motions corresponding to the one or more target inputs consists of a two-dimensional movement profile (e.g., within 15 to 30 degrees of a particular defined two-dimensional plane where the user is performing the motion). The devolved sequence

of handwriting motions includes a handwriting motion in a third-dimensional plane distinct from respective planes defining the substantially two-dimensional movement profile. In some embodiments, the third-dimensional plane is substantially orthogonal to a plane defined by the two-dimensional movement profile (e.g., the three-dimensional movement profile shown within the demonstration user interface element **134** in FIG. **1**C). In some embodiments, attempts to perform the devolved sequence of handwriting motions that include hand movements within thirty degrees of the third-dimensional plane. In some embodiments, the portion of the devolved sequence of handwriting motions that includes movement in the third-dimensional plane is estimated to increase the discriminability of the one or more target inputs. For example, suggesting a motion for the tail of "h" in the third-dimensional plane may help to distinguish from a sequence of handwriting motions that includes "n" by increasing the discriminability of the distinct aspect of the sequence of handwriting motions for the target input.

(A17) In some embodiments of any one of A1 to A16, the AR system **300***a* causes storage, in a vector space, of a plurality of vector representations for respective target inputs, wherein respective vector representations of the plurality of vector representations include data profiles for sequences of handwriting movements associated with the respective target inputs. And, responsive to obtaining the data corresponding to the sequence of handwriting motions, the AR system **300***a* causes generation of a new vector representation of the sequence of handwriting motions. The vector representation of the data corresponding to the sequence of handwriting motions is embedded into the vector space. And based on a relationship between the new vector representation and the respective vector representations of the plurality of vector representations, a corresponding vector representation is caused to be identified (e.g., by the AR system **300***a* and/or a remote server in operable communication with the AR system **300***a*).

(A18) In some embodiments of any one of A1 to A17, while the user is performing the sequence of handwriting motions, the AR system **300***a* presents a first dynamic user interface element including real-time data that is based on the data from the one or more sensors (e.g., a two-dimensional or three-dimensional visual representation of the motions detected based on biopotential-signal data). And the AR system **300***a* presents (e.g., via the AR device **500**) a second dynamic user interface element including a corresponding visualization of a co-adapted performance of the sequence of handwriting motions corresponding to the one or more target inputs. For example, FIGS. **1**A and **1**D illustrate examples where the user interface **104** is presenting a user interface element **106** that includes a visual depiction of neuromuscular activations of a hand of the user **302** while the user **302** is performing various sequences of handwriting motions (e.g., the sequence of handwriting motions **102**). And the user interface **104** also includes the user interface element **108** that includes a visual depiction of prophetic neuromuscular activations that would be detected if the user **302** optimized their performance of the respective sequences of handwriting motions **102** and **144**. In some embodiments, devolved sequences of handwriting motions are suggested to the user **302** based on the user performing one or more portions of sequences of handwriting motions having an optimization score below a particular threshold. That is, the devolved sequences of handwriting motions can be identified based on respective sequences of handwriting motions that the user **302** has performed poorly.

Concept 2. Using a Generative Model (e.g., a Large-Language Model) to Produce Instructions for Performing Devolved Sequences of Handwriting Motions

(B1) FIG. **2**B shows a flow chart of the example method **240** of presenting representations of identified sequences of handwriting motions to a user by applying the sequences of handwriting motions to a generative model that is co-adapted to a user of the computing system.

As part of performing the method **240**, after identifying a devolved sequence of handwriting motions based on data obtained via one or more sensors, the data corresponding to a sequence of handwriting motions performed by a user associated with one or more target inputs, the AR system **300***a* provides (**242**) the information about the devolved sequence of handwriting motions to a generative model. In accordance with some embodiments, the AR system **300***a* receives (**244**), from the generative model, the representation of the devolved sequence of handwriting motions. For example, the input model **170** may provide the devolved sequence suggestion **130** shown in FIG. **1**B and/or the devolved sequence suggestions **140** and **142** to a generative model.

After receiving the representation of the devolved sequence of handwriting motions from the generative model, the AR system **300***a* causes (**246**) presentation, via the computing system, of the representation of the devolved sequence of handwriting motions received from the generative model. For example, the demonstration user interface elements **134** and **136**, shown in FIG. **1**C, may be generated using a generative model (e.g., a generative model that includes a large language model).

(B2) In some embodiments of B1, the generative model is a large-language model, and the demonstration includes a description of an aspect of the devolved sequence of handwriting motions that is presented to the user (**248**) (e.g., the textual element within the demonstration user interface element **134** stating, "Draw the tail of the 'h' in a third plane").

(B3) In some embodiments of B1, the generative model is configured to generate visual images, and the demonstration includes a non-textual visual depiction of an aspect of the devolved sequence of handwriting motions (**250**) (e.g., the visual element within the demonstration user interface element **134** that includes the three-dimensional plane and the orientations of the respective sequences of handwriting motions within the three-dimensional plane).

(B4) In some embodiments of any one of B1 to B3, the AR system **300***a* receives (**252**) an input from the user requesting a modification to the representation of the devolved sequence of handwriting motions. After the AR system **300***a* receives the input from the user, the AR system **300***a* provides (**254**), to the generative model, a prompt based on the input from the user requesting the modification to the representation of the devolved sequence of handwriting motions. The AR system **300***a* then receives (**256**), from the generative model, a different representation of the same devolved

sequence of handwriting motions. And the AR system **300***a* causes (**258**) presentation, via the computing system, of the different representation of the devolved sequence of handwriting motions received from the generative model.

Concept 3. Using a Co-Adapted Artificial Intelligence Model to Teach the User of a Computing System how to Optimize Performance of Sequences of Handwriting Motions

(C1) FIG. **2**C shows a flow chart of the example method **280** of presenting user interfaces to users that include representations of aspects of the users' performances of sequences of handwriting motions.

The operations of the method **280** are performed at a computing system (e.g., AR system **300***a*) that includes an artificial-reality headset configured to present artificial-reality content to a user while the computing system is detecting the user attempting to perform sequences of handwriting motions (**282**).

In accordance with embodiments of the example method **280**, the AR system **300***a* obtains (**284**), via one or more sensors of a wearable device of the computing system, data corresponding to a user attempting to perform a particular sequence of handwriting motions associated with the one or more target inputs while wearing the wearable electronic device of the computing system.

And in accordance with embodiments of the example method **280**, while the user **302** is performing the sequence of handwriting motions, the AR system **300***a* presents a first user interface element corresponding to an aspect of the performance of the sequence of handwriting motions, where the aspect is based on data obtained by the one or more sensors of the wearable electronic device, and presents a second user interface element that includes a visual representation of an optimal performance of the sequence of handwriting motions (**286**).

(C2) In some embodiments C1, after the user has completed performance of the sequence of handwriting motions, the AR system **300***a* (**288**) presents another user interface element indicating a relative accuracy between the aspect of the performance of the sequence of handwriting motions and the optimal performance of the sequence of handwriting motions.

(C3) In some embodiments of C1 or C2, based on detecting another attempt by the user to perform the same sequence of handwriting motions (**290**), the AR system provides an indication to the user **302** whether the other attempt to perform the same sequence of handwriting motions is more accurate based on the optimal performance of the sequence of handwriting motions.

The devices described above are further detailed below, including systems, wrist-wearable devices, headset devices, and smart textile-based garments. Specific operations described above may occur as a result of specific hardware; such hardware is described in further detail below. The devices described below are not limiting and features on these devices can be removed or additional features can be added to these devices. The different devices can include one or more analogous hardware components. For brevity, analogous devices and components are described below. Any differences in the devices and components are described below in their respective sections.

As described herein, a processor (e.g., a central processing unit (CPU) or microcontroller unit (MCU)), is an electronic component that is responsible for executing instructions and controlling the operation of an electronic device (e.g., a wrist-wearable device **400**, a head-wearable device, an HIPD **600**, a smart textile-based garment **700**, or other computer system). There are several distinct types of processors that may be used interchangeably or specifically required by embodiments described herein. For example, a processor may be (i) a general processor designed to perform a wide range of tasks, such as running software applications, managing operating systems, and performing arithmetic and logical operations; (ii) a microcontroller designed for specific tasks such as controlling electronic devices, sensors, and motors; (iii) a graphics processing unit (GPU) designed to accelerate the creation and rendering of images, videos, and animations (e.g., virtual-reality animations, such as three-dimensional modeling); (iv) a field-programmable gate array (FPGA) that can be programmed and reconfigured after manufacturing and/or customized to perform specific tasks, such as signal processing, cryptography, and machine learning; (v) a digital signal processor (DSP) designed to perform mathematical operations on signals such as audio, video, and radio waves. One of skill in the art will understand that one or more processors of one or more electronic devices may be used in various embodiments described herein.

As described herein, controllers are electronic components that manage and coordinate the operation of other components within an electronic device (e.g., controlling inputs, processing data, and/or generating outputs). Examples of controllers can include (i) microcontrollers, including small, low-power controllers that are commonly used in embedded systems and Internet of Things (IoT) devices; (ii) programmable logic controllers (PLCs) that may be configured to be used in industrial automation systems to control and monitor manufacturing processes; (iii) system-on-a-chip (SoC) controllers that integrate multiple components such as processors, memory, I/O interfaces, and other peripherals into a single chip; and/or DSPs. As described herein, a graphics module is a component or software module that is designed to manage graphical operations and/or processes, and can include a hardware module and/or a software module.

As described herein, memory refers to electronic components in a computer or electronic device that store data and instructions for the processor to access and manipulate. The devices described herein can include volatile and non-volatile memory. Examples of memory can include (i) random access memory (RAM), such as DRAM, SRAM, DDR RAM or other random access solid state memory devices, configured to store data and instructions temporarily; (ii) read-only memory (ROM) configured to store data and instructions permanently (e.g., one or more portions of system firmware and/or boot loaders); (iii) flash memory, magnetic disk storage devices, optical disk storage devices, other non-volatile solid state storage devices, which can be configured to store data in electronic devices (e.g., universal serial bus (USB) drives, memory cards, and/or solid-state drives (SSDs)); and (iv) cache memory configured to temporarily store frequently accessed data and instructions. Memory, as described herein, can include structured data (e.g., SQL databases, MongoDB databases, GraphQL data, or JSON data). Other examples of memory can include: (i) profile data, including user account data, user settings, and/or other user data stored by the user; (ii) sensor data detected and/or otherwise obtained by one or more sensors; (iii) media content data including stored image data, audio data, documents, and the like; (iv) application data, which

can include data collected and/or otherwise obtained and stored during use of an application; and/or any other types of data described herein.

As described herein, a power system of an electronic device is configured to convert incoming electrical power into a form that can be used to operate the device. A power system can include various components, including (i) a power source, which can be an alternating current (AC) adapter or a direct current (DC) adapter power supply; (ii) a charger input that can be configured to use a wired and/or wireless connection (which may be part of a peripheral interface, such as a USB, micro-USB interface, near-field magnetic coupling, magnetic inductive and magnetic resonance charging, and/or radio frequency (RF) charging); (iii) a power-management integrated circuit, configured to distribute power to various components of the device and ensure that the device operates within safe limits (e.g., regulating voltage, controlling current flow, and/or managing heat dissipation); and/or (iv) a battery configured to store power to provide usable power to components of one or more electronic devices.

As described herein, peripheral interfaces are electronic components (e.g., of electronic devices) that allow electronic devices to communicate with other devices or peripherals and can provide a means for input and output of data and signals. Examples of peripheral interfaces can include (i) USB and/or micro-USB interfaces configured for connecting devices to an electronic device; (ii) Bluetooth interfaces configured to allow devices to communicate with each other, including Bluetooth low energy (BLE); (iii) near-field communication (NFC) interfaces configured to be short-range wireless interfaces for operations such as access control; (iv) POGO pins, which may be small, spring-loaded pins configured to provide a charging interface; (v) wireless charging interfaces; (vi) global-position system (GPS) interfaces; (vii) Wi-Fi interfaces for providing a connection between a device and a wireless network; and (viii) sensor interfaces.

As described herein, sensors are electronic components (e.g., in and/or otherwise in electronic communication with electronic devices, such as wearable devices) configured to detect physical and environmental changes and generate electrical signals. Examples of sensors can include (i) imaging sensors for collecting imaging data (e.g., including one or more cameras disposed on a respective electronic device); (ii) biopotential-signal sensors; (iii) inertial measurement unit (e.g., IMUs) for detecting, for example, angular rate, force, magnetic field, and/or changes in acceleration; (iv) heart rate sensors for measuring a user's heart rate; (v) SpO2 sensors for measuring blood oxygen saturation and/or other biometric data of a user; (vi) capacitive sensors for detecting changes in potential at a portion of a user's body (e.g., a sensor-skin interface) and/or the proximity of other devices or objects; and (vii) light sensors (e.g., time-of-flight sensors, infrared light sensors, or visible light sensors), and/or sensors for sensing data from the user or the user's environment. As described herein biopotential-signal-sensing components are devices used to measure electrical activity within the body (e.g., biopotential-signal sensors). Some types of biopotential-signal sensors include: (i) electroencephalography (EEG) sensors configured to measure electrical activity in the brain to diagnose neurological disorders; (ii) electrocardiography (ECG or EKG) sensors configured to measure electrical activity of the heart to diagnose heart problems; (iii) electromyography (EMG) sensors configured to measure the electrical activity of muscles and diagnose neuromuscular disorders; (iv) electrooculography (EOG) sensors configured to measure the electrical activity of eye muscles to detect eye movement and diagnose eye disorders.

As described herein, an application stored in memory of an electronic device (e.g., software) includes instructions stored in the memory. Examples of such applications include (i) games; (ii) word processors; (iii) messaging applications; (iv) media-streaming applications; (v) financial applications; (vi) calendars; (vii) clocks; (viii) web browsers; (ix) social media applications, (x) camera applications, (xi) web-based applications; (xii) health applications; (xiii) artificial-reality (AR) applications, and/or any other applications that can be stored in memory. The applications can operate in conjunction with data and/or one or more components of a device or communicatively coupled devices to perform one or more operations and/or functions.

As described herein, communication interface modules can include hardware and/or software capable of data communications using any of a variety of custom or standard wireless protocols (e.g., IEEE 802.15.4, Wi-Fi, ZigBee, 6LoWPAN, Thread, Z-Wave, Bluetooth Smart, ISA100.11a, WirelessHART, or MiWi), custom or standard wired protocols (e.g., Ethernet or HomePlug), and/or any other suitable communication protocol, including communication protocols not yet developed as of the filing date of this document. A communication interface is a mechanism that enables different systems or devices to exchange information and data with each other, including hardware, software, or a combination of both hardware and software. For example, a communication interface can refer to a physical connector and/or port on a device that enables communication with other devices (e.g., USB, Ethernet, HDMI, or Bluetooth). In some embodiments, a communication interface can refer to a software layer that enables different software programs to communicate with each other (e.g., application programming interfaces (APIs) and protocols such as HTTP and TCP/IP).

As described herein, a graphics module is a component or software module that is designed to manage graphical operations and/or processes, and can include a hardware module and/or a software module.

As described herein, non-transitory computer-readable storage media are physical devices or storage medium that can be used to store electronic data in a non-transitory form (e.g., such that the data is stored permanently until it is intentionally deleted or modified).

Example AR Systems **3**A-**3**D-**2**

FIGS. **3**A, **3**B, **3**C-**1**, **3**C-**2**, **3**D-**1**, and **3**D-**2** illustrate example AR systems, in accordance with some embodiments. FIG. **3**A shows a first AR system **300***a* and first example user interactions using a wrist-wearable device **400**, a head-wearable device (e.g., AR device **500**), and/or a handheld intermediary processing device (HIPD) **600**. FIG. **3**B shows a second AR system **300***b* and second example user interactions using a wrist-wearable device **400**, AR device **500**, and/or an HIPD **600**. FIGS. **3**C-**1** and **3**C-**2** show a third AR system **300***c* and third example user interactions using a wrist-wearable device **400**, a head-wearable device (e.g., virtual-reality (VR) device **510**), and/or an HIPD **600**. FIGS. **3**D-**1** and **3**D-**2** show a fourth AR system **300***d* and fourth example user interactions using a wrist-wearable device **400**, VR device **510**, and/or a smart textile-based garment **700** (e.g., wearable gloves, haptic gloves). As the skilled artisan will appreciate upon reading the descriptions provided herein, the above-example AR systems (described

in detail below) can perform various functions and/or operations described above with reference to FIGS. **1**A to **1**F.

The wrist-wearable device **400** and its constituent components are described below in reference to FIGS. **4**A-**4**B, the head-wearable devices and their constituent components are described below in reference to FIGS. **5**A-**5**D, and the HIPD **600** and its constituent components are described below in reference to FIGS. **6**A-**6**B. The smart textile-based garment **700** and its one or more components are described below in reference to FIGS. **7**A-**7**C. The wrist-wearable device **400**, the head-wearable devices, and/or the HIPD **600** can communicatively couple via a network **325** (e.g., cellular, near field, Wi-Fi, personal arca network, or wireless LAN). Additionally, the wrist-wearable device **400**, the head-wearable devices, and/or the HIPD **600** can also communicatively couple with one or more servers **330**, computers **340** (e.g., laptops or computers), mobile devices **350** (e.g., smartphones or tablets), and/or other electronic devices via the network **325** (e.g., cellular, near field, Wi-Fi, personal area network, or wireless LAN). Similarly, the smart textile-based garment **700**, when used, can also communicatively couple with the wrist-wearable device **400**, the head-wearable devices, the HIPD **600**, the one or more servers **330**, the computers **340**, the mobile devices **350**, and/or other electronic devices via the network **325**.

Turning to FIG. **3**A, a user **302** is shown wearing the wrist-wearable device **400** and the AR device **500**, and having the HIPD **600** on their desk. The wrist-wearable device **400**, the AR device **500**, and the HIPD **600** facilitate user interaction with an AR environment. In particular, as shown by the first AR system **300***a*, the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** cause presentation of one or more avatars **304**, digital representations of contacts **306**, and virtual objects **308**. As discussed below, the user **302** can interact with the one or more avatars **304**, digital representations of the contacts **306**, and virtual objects **308** via the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**.

The user **302** can use any of the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** to provide user inputs. For example, the user **302** can perform one or more hand gestures that are detected by the wrist-wearable device **400** (e.g., using one or more EMG sensors and/or IMUs, described below in reference to FIGS. **4**A-**4**B) and/or AR device **500** (e.g., using one or more image sensors or cameras, described below in reference to FIGS. **5**A-**5**B) to provide a user input. Alternatively, or additionally, the user **302** can provide a user input via one or more touch surfaces of the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**, and/or voice commands captured by a microphone of the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**. In some embodiments, the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** include a digital assistant to help the user in providing a user input (e.g., completing a sequence of operations, suggesting different operations or commands, providing reminders, or confirming a command). In some embodiments, the user **302** can provide a user input via one or more facial gestures and/or facial expressions. For example, cameras of the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** can track the user **302**'s eyes for navigating a user interface.

The wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** can operate alone or in conjunction to allow the user **302** to interact with the AR environment. In some embodiments, the HIPD **600** is configured to operate as a central hub or control center for the wrist-wearable device **400**, the AR device **500**, and/or another communicatively coupled device. For example, the user **302** can provide an input to interact with the AR environment at any of the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**, and the HIPD **600** can identify one or more back-end and front-end tasks to cause the performance of the requested interaction and distribute instructions to cause the performance of the one or more back-end and front-end tasks at the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**. In some embodiments, a back-end task is a background-processing task that is not perceptible by the user (e.g., rendering content, decompression, or compression), and a front-end task is a user-facing task that is perceptible to the user (e.g., presenting information to the user or providing feedback to the user). As described below in reference to FIGS. **6**A-**6**B, the HIPD **600** can perform the back-end tasks and provide the wrist-wearable device **400** and/or the AR device **500** operational data corresponding to the performed back-end tasks such that the wrist-wearable device **400** and/or the AR device **500** can perform the front-end tasks. In this way, the HIPD **600**, which has more computational resources and greater thermal headroom than the wrist-wearable device **400** and/or the AR device **500**, performs computationally intensive tasks and reduces the computer resource utilization and/or power usage of the wrist-wearable device **400** and/or the AR device **500**.

In the example shown by the first AR system **300***a*, the HIPD **600** identifies one or more back-end tasks and front-end tasks associated with a user request to initiate an AR video call with one or more other users (represented by the avatar **304** and the digital representation of the contact **306**) and distributes instructions to cause the performance of the one or more back-end tasks and front-end tasks. In particular, the HIPD **600** performs back-end tasks for processing and/or rendering image data (and other data) associated with the AR video call and provides operational data associated with the performed back-end tasks to the AR device **500** such that the AR device **500** performs front-end tasks for presenting the AR video call (e.g., presenting the avatar **304** and the digital representation of the contact **306**).

In some embodiments, the HIPD **600** can operate as a focal or anchor point for causing the presentation of information. This allows the user **302** to be generally aware of where information is presented. For example, as shown in the first AR system **300***a*, the avatar **304** and the digital representation of the contact **306** are presented above the HIPD **600**. In particular, the HIPD **600** and the AR device **500** operate in conjunction to determine a location for presenting the avatar **304** and the digital representation of the contact **306**. In some embodiments, information can be presented within a predetermined distance from the HIPD **600** (e.g., within five meters). For example, as shown in the first AR system **300***a*, virtual object **308** is presented on the desk some distance from the HIPD **600**. Similar to the above example, the HIPD **600** and the AR device **500** can operate in conjunction to determine a location for presenting the virtual object **308**. Alternatively, in some embodiments, presentation of information is not bound by the HIPD **600**. More specifically, the avatar **304**, the digital representation of the contact **306**, and the virtual object **308** do not have to be presented within a predetermined distance of the HIPD **600**.

User inputs provided at the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** are coordinated such that the user can use any device to initiate, continue, and/or complete an operation. For example, the user **302** can provide a user input to the AR device **500** to cause the AR

device **500** to present the virtual object **308** and, while the virtual object **308** is presented by the AR device **500**, the user **302** can provide one or more hand gestures via the wrist-wearable device **400** to interact and/or manipulate the virtual object **308**.

FIG. **3**B shows the user **302** wearing the wrist-wearable device **400** and the AR device **500**, and holding the HIPD **600**. In the second AR system **300***b*, the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** are used to receive and/or provide one or more messages to a contact of the user **302**. In particular, the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** detect and coordinate one or more user inputs to initiate a messaging application and prepare a response to a received message via the messaging application.

In some embodiments, the user **302** initiates, via a user input, an application on the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** that causes the application to initiate on at least one device. For example, in the second AR system **300***b*, the user **302** performs a hand gesture associated with a command for initiating a messaging application (represented by messaging user interface **312**), the wrist-wearable device **400** detects the hand gesture, and, based on a determination that the user **302** is wearing AR device **500**, causes the AR device **500** to present a messaging user interface **312** of the messaging application. The AR device **500** can present the messaging user interface **312** to the user **302** via its display (e.g., as shown by user **302**'s field of view **310**). In some embodiments, the application is initiated and can be run on the device (e.g., the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**) that detects the user input to initiate the application, and the device provides another device operational data to cause the presentation of the messaging application. For example, the wrist-wearable device **400** can detect the user input to initiate a messaging application, initiate and run the messaging application, and provide operational data to the AR device **500** and/or the HIPD **600** to cause presentation of the messaging application. Alternatively, the application can be initiated and run at a device other than the device that detected the user input. For example, the wrist-wearable device **400** can detect the hand gesture associated with initiating the messaging application and cause the HIPD **600** to run the messaging application and coordinate the presentation of the messaging application.

Further, the user **302** can provide a user input provided at the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** to continue and/or complete an operation initiated at another device. For example, after initiating the messaging application via the wrist-wearable device **400** and while the AR device **500** presents the messaging user interface **312**, the user **302** can provide an input at the HIPD **600** to prepare a response (e.g., shown by the swipe gesture performed on the HIPD **600**). The user **302**'s gestures performed on the HIPD **600** can be provided and/or displayed on another device. For example, the user **302**'s swipe gestures performed on the HIPD **600** are displayed on a virtual keyboard of the messaging user interface **312** displayed by the AR device **500**.

In some embodiments, the wrist-wearable device **400**, the AR device **500**, the HIPD **600**, and/or other communicatively coupled devices can present one or more notifications to the user **302**. The notification can be an indication of a new message, an incoming call, an application update, a status update, etc. The user **302** can select the notification via the wrist-wearable device **400**, the AR device **500**, or the HIPD **600** and cause presentation of an application or operation associated with the notification on at least one device. For example, the user **302** can receive a notification that a message was received at the wrist-wearable device **400**, the AR device **500**, the HIPD **600**, and/or other communicatively coupled device and provide a user input at the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** to review the notification, and the device detecting the user input can cause an application associated with the notification to be initiated and/or presented at the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600**.

While the above example describes coordinated inputs used to interact with a messaging application, the skilled artisan will appreciate upon reading the descriptions that user inputs can be coordinated to interact with any number of applications including, but not limited to, gaming applications, social media applications, camera applications, web-based applications, financial applications, etc. For example, the AR device **500** can present to the user **302** game application data and the HIPD **600** can use a controller to provide inputs to the game. Similarly, the user **302** can use the wrist-wearable device **400** to initiate a camera of the AR device **500**, and the user can use the wrist-wearable device **400**, the AR device **500**, and/or the HIPD **600** to manipulate the image capture (e.g., zoom in or out or apply filters) and capture image data.

Turning to FIGS. **3**C-**1** and **3**C-**2**, the user **302** is shown wearing the wrist-wearable device **400** and a VR device **510**, and holding the HIPD **600**. In the third AR system **300***c*, the wrist-wearable device **400**, the VR device **510**, and/or the HIPD **600** are used to interact within an AR environment, such as a VR game or other AR application. While the VR device **510** presents a representation of a VR game (e.g., first AR game environment **320**) to the user **302**, the wrist-wearable device **400**, the VR device **510**, and/or the HIPD **600** detect and coordinate one or more user inputs to allow the user **302** to interact with the VR game.

In some embodiments, the user **302** can provide a user input via the wrist-wearable device **400**, the VR device **510**, and/or the HIPD **600** that causes an action in a corresponding AR environment. For example, the user **302** in the third AR system **300***c* (shown in FIG. **3**C-**1**) raises the HIPD **600** to prepare for a swing in the first AR game environment **320**. The VR device **510**, responsive to the user **302** raising the HIPD **600**, causes the AR representation of the user **322** to perform a similar action (e.g., raise a virtual object, such as a virtual sword **324**). In some embodiments, each device uses respective sensor data and/or image data to detect the user input and provide an accurate representation of the user **302**'s motion. For example, imaging sensors **654** (e.g., SLAM cameras or other cameras discussed below in FIGS. **6**A and **6**B) of the HIPD **600** can be used to detect a position of the **600** relative to the user **302**'s body such that the virtual object can be positioned appropriately within the first AR game environment **320**; sensor data from the wrist-wearable device **400** can be used to detect a velocity at which the user **302** raises the HIPD **600** such that the AR representation of the user **322** and the virtual sword **324** are synchronized with the user **302**'s movements; and image sensors **526** (FIGS. **5**A-**5**C) of the VR device **510** can be used to represent the user **302**'s body, boundary conditions, or real-world objects within the first AR game environment **320**.

In FIG. **3**C-**2**, the user **302** performs a downward swing while holding the HIPD **600**. The user **302**'s downward swing is detected by the wrist-wearable device **400**, the VR device **510**, and/or the HIPD **600** and a corresponding action is performed in the first AR game environment **320**. In some

embodiments, the data captured by each device is used to improve the user's experience within the AR environment. For example, sensor data of the wrist-wearable device **400** can be used to determine a speed and/or force at which the downward swing is performed and image sensors of the HIPD **600** and/or the VR device **510** can be used to determine a location of the swing and how it should be represented in the first AR game environment **320**, which, in turn, can be used as inputs for the AR environment (e.g., game mechanics, which can use detected speed, force, locations, and/or aspects of the user **302**'s actions to classify a user's inputs (e.g., user performs a light strike, hard strike, critical strike, glancing strike, miss) or calculate an output (e.g., amount of damage)).

While the wrist-wearable device **400**, the VR device **510**, and/or the HIPD **600** are described as detecting user inputs, in some embodiments, user inputs are detected at a single device (with the single device being responsible for distributing signals to the other devices for performing the user input). For example, the HIPD **600** can operate an application for generating the first AR game environment **320** and provide the VR device **510** with corresponding data for causing the presentation of the first AR game environment **320**, as well as detect the **302**'s movements (while holding the HIPD **600**) to cause the performance of corresponding actions within the first AR game environment **320**. Additionally, or alternatively, in some embodiments, operational data (e.g., sensor data, image data, application data, device data, and/or other data) of one or more devices is provide to a single device (e.g., the HIPD **600**) to process the operational data and cause respective devices to perform an action associated with processed operational data.

In FIGS. **3**D-**1** and **3**D-**2**, the user **302** is shown wearing the wrist-wearable device **400**, the VR device **510**, and smart textile-based garments **700**. In the fourth AR system **300***d*, the wrist-wearable device **400**, the VR device **510**, and/or the smart textile-based garments **700** are used to interact within an AR environment (e.g., any AR system described above in reference to FIGS. **3**A-**3**C-**2**). While the VR device **510** presents a representation of a VR game (e.g., second AR game environment **331**) to the user **302**, the wrist-wearable device **400**, the VR device **510**, and/or the smart textile-based garments **700** detect and coordinate one or more user inputs to allow the user **302** to interact with the AR environment.

In some embodiments, the user **302** can provide a user input via the wrist-wearable device **400**, the VR device **510**, and/or the smart textile-based garments **700** that causes an action in a corresponding AR environment. For example, the user **302** in the fourth AR system **300***d* (shown in FIG. **3**D-**1**) raises a hand wearing the smart textile-based garments **700** to prepare to cast a spell or throw an object within the second AR game environment **331**. The VR device **510**, responsive to the user **302** holding up their hand (wearing smart textile-based garments **700**), causes the AR representation of the user **322** to perform a similar action (e.g., hold a virtual object or throw a fireball **334**). In some embodiments, each device uses respective sensor data and/or image data to detect the user input and provides an accurate representation of the user **302**'s motion.

In FIG. **3**D-**2**, the user **302** performs a throwing motion while wearing the smart textile-based garment **700**. The user **302**'s throwing motion is detected by the wrist-wearable device **400**, the VR device **510**, and/or the smart textile-based garments **700**, and a corresponding action is performed in the second AR game environment **331**. As described above, the data captured by each device is used to improve the user's experience within the AR environment. Although not shown, the smart textile-based garments **700** can be used in conjunction with an AR device **510** and/or an HIPD **600**.

Having discussed example AR systems, devices for interacting with such AR systems, and other computing systems more generally, devices and components will now be discussed in greater detail below. Some definitions of devices and components that can be included in some or all of the example devices discussed below are defined here for case of reference. A skilled artisan will appreciate that certain types of the components described below may be more suitable for a particular set of devices and less suitable for another particular set of devices. But subsequent references to the components defined here should be considered to be encompassed by the definitions provided.

In some embodiments discussed below, example devices and systems, including electronic devices and systems, will be discussed. Such example devices and systems are not intended to be limiting, and one of skill in the art will understand that alternative devices and systems to the example devices and systems described herein may be used to perform the operations and construct the systems and devices that are described herein.

As described herein, an electronic device is a device that uses electrical energy to perform a specific function. It can be any physical object that contains electronic components such as transistors, resistors, capacitors, diodes, and integrated circuits. Examples of electronic devices include smartphones, laptops, digital cameras, televisions, gaming consoles, and music players, as well as the example electronic devices discussed herein. As described herein, an intermediary electronic device is a device that sits between two other electronic devices and/or a subset of components of one or more electronic devices, which facilitates communication, and/or data processing, and/or data transfer between the respective electronic devices and/or electronic components.

Example Wrist-Wearable Devices

FIGS. **4**A and **4**B illustrate an example wrist-wearable device **400**, in accordance with some embodiments. The wrist-wearable device **400** is an instance of the wrist-wearable device **400** described in reference to FIGS. **1**A to **1**F herein, such that the wrist-wearable device should be understood to have the features of the wrist-wearable device **400** and vice versa. FIG. **4**A illustrates components of the wrist-wearable device **400**, which can be used individually or in combination, including combinations that include other electronic devices and/or electronic components.

FIG. **4**A shows a wearable band **410** and a watch body **420** (or capsule) being coupled, as discussed below, to form the wrist-wearable device **400**. The wrist-wearable device **400** can perform various functions and/or operations associated with navigating through user interfaces and selectively opening applications, as well as the functions and/or operations described above with reference to FIGS. **1**A to **1**F (e.g., detecting attempts by the user **302** to perform sequences of handwriting motions and/or presenting user interfaces to the user related to attempts to perform sequences of handwriting motions).

As will be described in more detail below, operations executed by the wrist-wearable device **400** can include (i) presenting content to a user (e.g., displaying visual content via a display **405**); (ii) detecting (e.g., sensing) user input (e.g., sensing a touch on peripheral button **423** and/or at a

touch screen of the display **405**, a hand gesture detected by sensors (e.g., biopotential sensors)); (iii) sensing biometric data via one or more sensors **413** (e.g., neuromuscular signals, heart rate, temperature, or sleep); messaging (e.g., text, speech, or video); image capture via one or more imaging devices or cameras **425**; wireless communications (e.g., cellular, near field, Wi-Fi, or personal area network); location determination; financial transactions; providing haptic feedback; alarms; notifications; biometric authentication; health monitoring; and/or sleep monitoring.

The above-example functions can be executed independently in the watch body **420**, independently in the wearable band **410**, and/or via an electronic communication between the watch body **420** and the wearable band **410**. In some embodiments, functions can be executed on the wrist-wearable device **400** while an AR environment is being presented (e.g., via one of the AR systems **300***a* to **300***d*). As the skilled artisan will appreciate upon reading the descriptions provided herein, the novel wearable devices described herein can be used with other types of AR environments.

The wearable band **410** can be configured to be worn by a user such that an inner (or inside) surface of the wearable structure **411** of the wearable band **410** is in contact with the user's skin. When worn by a user, sensors **413** contact the user's skin. The sensors **413** can sense biometric data such as a user's heart rate, saturated oxygen level, temperature, sweat level, neuromuscular-signal sensors, or a combination thereof. The sensors **413** can also sense data about a user's environment, including a user's motion, altitude, location, orientation, gait, acceleration, position, or a combination thereof. In some embodiments, the sensors **413** are configured to track a position and/or motion of the wearable band **410**. The one or more sensors **413** can include any of the sensors defined above and/or discussed below with respect to FIG. **4**B.

The one or more sensors **413** can be distributed on an inside and/or an outside surface of the wearable band **410**. In some embodiments, the one or more sensors **413** are uniformly spaced along the wearable band **410**. Alternatively, in some embodiments, the one or more sensors **413** are positioned at distinct points along the wearable band **410**. As shown in FIG. **4**A, the one or more sensors **413** can be the same or distinct. For example, in some embodiments, the one or more sensors **413** can be shaped as a pill (e.g., sensor **413***a*), an oval, a circle a square, an oblong (e.g., sensor **413***c*), and/or any other shape that maintains contact with the user's skin (e.g., such that neuromuscular signal and/or other biometric data can be accurately measured at the user's skin). In some embodiments, the one or more sensors **413** are aligned to form pairs of sensors (e.g., for sensing neuromuscular signals based on differential sensing within each respective sensor). For example, sensor **413***b* is aligned with an adjacent sensor to form sensor pair **414***a*, and sensor **413***d* is aligned with an adjacent sensor to form sensor pair **414***b*. In some embodiments, the wearable band **410** does not have a sensor pair. Alternatively, in some embodiments, the wearable band **410** has a predetermined number of sensor pairs (one pair of sensors, three pairs of sensors, four pairs of sensors, six pairs of sensors, or sixteen pairs of sensors).

The wearable band **410** can include any suitable number of sensors **413**. In some embodiments, the amount, and arrangements of sensors **413** depend on the particular application for which the wearable band **410** is used. For instance, a wearable band **410** configured as an armband, wristband, or chest-band may include a plurality of sensors **413** with a different number of sensors **413** and different arrangement for each use case, such as medical use cases, compared to gaming or general day-to-day use cases.

In accordance with some embodiments, the wearable band **410** further includes an electrical ground electrode and a shielding electrode. The electrical ground and shielding electrodes, like the sensors **413**, can be distributed on the inside surface of the wearable band **410** such that they contact a portion of the user's skin. For example, the electrical ground and shielding electrodes can be at an inside surface of coupling mechanism **416** or an inside surface of a wearable structure **411**. The electrical ground and shielding electrodes can be formed and/or use the same components as the sensors **413**. In some embodiments, the wearable band **410** includes more than one electrical ground electrode and more than one shielding electrode.

The sensors **413** can be formed as part of the wearable structure **411** of the wearable band **410**. In some embodiments, the sensors **413** are flush (or substantially flush within fault tolerances of the relevant materials) with the wearable structure **411** such that they do not extend beyond the surface of the wearable structure **411**. While flush with the wearable structure **411**, the sensors **413** are still configured to contact the user's skin (e.g., via a skin-contacting surface). Alternatively, in some embodiments, the sensors **413** extend beyond the wearable structure **411** a predetermined distance (e.g., 0.1 mm to 2 mm) to make contact and depress into the user's skin. In some embodiments, the sensors **413** are coupled to an actuator (not shown) configured to adjust an extension height (e.g., a distance from the surface of the wearable structure **411**) of the sensors **413** such that the sensors **413** make contact and depress into the user's skin. In some embodiments, the actuators adjust the extension height between 0.01 mm to 1.2 mm. This allows the user to customize the positioning of the sensors **413** to improve the overall comfort of the wearable band **410** when worn while still allowing the sensors **413** to contact the user's skin. In some embodiments, the sensors **413** are indistinguishable from the wearable structure **411** when worn by the user.

The wearable structure **411** can be formed of an elastic material, elastomers, etc., configured to be stretched and fitted to be worn by the user. In some embodiments, the wearable structure **411** is a textile or woven fabric. As described above, the sensors **413** can be formed as part of a wearable structure **411**. For example, the sensors **413** can be molded into the wearable structure **411** or be integrated into a woven fabric (e.g., the sensors **413** can be sewn into the fabric and mimic the pliability of fabric (e.g., the sensors **413** can be constructed from a series of woven strands of fabric)).

The wearable structure **411** can include flexible electronic connectors that interconnect the sensors **413**, the electronic circuitry, and/or other electronic components (as described below in reference to FIG. **4**B) that are enclosed in the wearable band **410**. In some embodiments, the flexible electronic connectors are configured to interconnect the sensors **413**, the electronic circuitry, and/or other electronic components of the wearable band **410** with respective sensors and/or other electronic components of another electronic device (e.g., watch body **420**). The flexible electronic connectors are configured to move with the wearable structure **411** such that the user adjustment to the wearable structure **411** (e.g., resizing, pulling, or folding) does not stress or strain the electrical coupling of components of the wearable band **410**.

As described above, the wearable band **410** is configured to be worn by a user. In particular, the wearable band **410** can be shaped or otherwise manipulated to be worn by a

user. For example, the wearable band **410** can be shaped to have a substantially circular shape such that it can be configured to be worn on the user's lower arm or wrist. Alternatively, the wearable band **410** can be shaped to be worn on another body part of the user, such as the user's upper arm (e.g., around a bicep), forearm, chest, legs, etc. The wearable band **410** can include a retaining mechanism **412** (e.g., a buckle or a hook and loop fastener) for securing the wearable band **410** to the user's wrist or other body part. While the wearable band **410** is worn by the user, the sensors **413** sense data (referred to as sensor data) from the user's skin. In particular, the sensors **413** of the wearable band **410** obtain (e.g., sense and record) neuromuscular signals.

The sensed data (e.g., sensed neuromuscular signals) can be used to detect and/or determine the user's intention to perform certain motor actions. In particular, the sensors **413** sense and record neuromuscular signals from the user as the user performs muscular activations (e.g., movements or gestures). The detected and/or determined motor action (e.g., phalange (or digits) movements, wrist movements, hand movements, and/or other muscle intentions) can be used to determine control commands or control information (instructions to perform certain commands after the data is sensed) for causing a computing device to perform one or more input commands. For example, the sensed neuromuscular signals can be used to control certain user interfaces displayed on the display **405** of the wrist-wearable device **400** and/or can be transmitted to a device responsible for rendering an AR environment (e.g., a head-mounted display) to perform an action in an associated AR environment, such as to control the motion of a virtual device displayed to the user. The muscular activations performed by the user can include static gestures, such as placing the user's hand palm down on a table; dynamic gestures, such as grasping a physical or virtual object; and covert gestures that are imperceptible to another person, such as slightly tensing a joint by co-contracting opposing muscles or using sub-muscular activations. The muscular activations performed by the user can include symbolic gestures (e.g., gestures mapped to other gestures, interactions, or commands, for example, based on a gesture vocabulary that specifies the mapping of gestures to commands).

The sensor data sensed by the sensors **413** can be used to provide a user with an enhanced interaction with a physical object (e.g., devices communicatively coupled with the wearable band **410**) and/or a virtual object in an AR application generated by an AR system (e.g., user interface objects presented on the display **405** or another computing device (e.g., a smartphone)).

In some embodiments, the wearable band **410** includes one or more haptic devices **446** (FIG. **4**B; e.g., a vibratory haptic actuator) that are configured to provide haptic feedback (e.g., a cutaneous and/or kinesthetic sensation) to the user's skin. The sensors **413** and/or the haptic devices **446** can be configured to operate in conjunction with multiple applications including, without limitation, health monitoring, social media, games, and AR (e.g., the applications associated with AR).

The wearable band **410** can also include a coupling mechanism **416** (e.g., a cradle or a shape of the coupling mechanism can correspond to the shape of the watch body **420** of the wrist-wearable device **400**) for detachably coupling a capsule (e.g., a computing unit) or watch body **420** (via a coupling surface of the watch body **420**) to the wearable band **410**. In particular, the coupling mechanism **416** can be configured to receive a coupling surface proximate to the bottom side of the watch body **420** (e.g., a side opposite to a front side of the watch body **420** where the display **405** is located), such that a user can push the watch body **420** downward into the coupling mechanism **416** to attach the watch body **420** to the coupling mechanism **416**. In some embodiments, the coupling mechanism **416** can be configured to receive a top side of the watch body **420** (e.g., a side proximate to the front side of the watch body **420** where the display **405** is located) that is pushed upward into the cradle, as opposed to being pushed downward into the coupling mechanism **416**. In some embodiments, the coupling mechanism **416** is an integrated component of the wearable band **410** such that the wearable band **410** and the coupling mechanism **416** are a single unitary structure. In some embodiments, the coupling mechanism **416** is a type of frame or shell that allows the watch body **420** coupling surface to be retained within or on the wearable band **410** coupling mechanism **416** (e.g., a cradle, a tracker band, a support base, or a clasp).

The coupling mechanism **416** can allow for the watch body **420** to be detachably coupled to the wearable band **410** through a friction fit, a magnetic coupling, a rotation-based connector, a shear-pin coupler, a retention spring, one or more magnets, a clip, a pin shaft, a hook-and-loop fastener, or a combination thereof. A user can perform any type of motion to couple the watch body **420** to the wearable band **410** and to decouple the watch body **420** from the wearable band **410**. For example, a user can twist, slide, turn, push, pull, or rotate the watch body **420** relative to the wearable band **410**, or a combination thereof, to attach the watch body **420** to the wearable band **410** and to detach the watch body **420** from the wearable band **410**. Alternatively, as discussed below, in some embodiments, the watch body **420** can be decoupled from the wearable band **410** by actuation of the release mechanism **429**.

The wearable band **410** can be coupled with a watch body **420** to increase the functionality of the wearable band **410** (e.g., converting the wearable band **410** into a wrist-wearable device **400**, adding an additional computing unit and/or battery to increase computational resources and/or a battery life of the wearable band **410**, or adding additional sensors to improve sensed data). As described above, the wearable band **410** (and the coupling mechanism **416**) is configured to operate independently (e.g., execute functions independently) from watch body **420**. For example, the coupling mechanism **416** can include one or more sensors **413** that contact a user's skin when the wearable band **410** is worn by the user and provide sensor data for determining control commands.

A user can detach the watch body **420** (or capsule) from the wearable band **410** in order to reduce the encumbrance of the wrist-wearable device **400** to the user. For embodiments in which the watch body **420** is removable, the watch body **420** can be referred to as a removable structure, such that in these embodiments the wrist-wearable device **400** includes a wearable portion (e.g., the wearable band **410**) and a removable structure (the watch body **420**).

Turning to the watch body **420**, the watch body **420** can have a substantially rectangular or circular shape. The watch body **420** is configured to be worn by the user on their wrist or on another body part. More specifically, the watch body **420** is sized to be easily carried by the user, attached on a portion of the user's clothing, and/or coupled to the wearable band **410** (forming the wrist-wearable device **400**). As described above, the watch body **420** can have a shape corresponding to the coupling mechanism **416** of the wearable band **410**. In some embodiments, the watch body **420** includes a single release mechanism **429** or multiple release

mechanisms (e.g., two release mechanisms **429** positioned on opposing sides of the watch body **420**, such as spring-loaded buttons) for decoupling the watch body **420** and the wearable band **410**. The release mechanism **429** can include, without limitation, a button, a knob, a plunger, a handle, a lever, a fastener, a clasp, a dial, a latch, or a combination thereof.

A user can actuate the release mechanism **429** by pushing, turning, lifting, depressing, shifting, or performing other actions on the release mechanism **429**. Actuation of the release mechanism **429** can release (e.g., decouple) the watch body **420** from the coupling mechanism **416** of the wearable band **410**, allowing the user to use the watch body **420** independently from wearable band **410** and vice versa. For example, decoupling the watch body **420** from the wearable band **410** can allow the user to capture images using rear-facing camera **425***b*. Although the coupling mechanism **416** is shown positioned at a corner of watch body **420**, the release mechanism **429** can be positioned anywhere on watch body **420** that is convenient for the user to actuate. In addition, in some embodiments, the wearable band **410** can also include a respective release mechanism for decoupling the watch body **420** from the coupling mechanism **416**. In some embodiments, the release mechanism **429** is optional and the watch body **420** can be decoupled from the coupling mechanism **416**, as described above (e.g., via twisting or rotating).

The watch body **420** can include one or more peripheral buttons **423** and **427** for performing various operations at the watch body **420**. For example, the peripheral buttons **423** and **427** can be used to turn on or wake (e.g., transition from a sleep state to an active state) the display **405**, unlock the watch body **420**, increase or decrease volume, increase, or decrease brightness, interact with one or more applications, interact with one or more user interfaces. Additionally, or alternatively, in some embodiments, the display **405** operates as a touch screen and allows the user to provide one or more inputs for interacting with the watch body **420**.

In some embodiments, the watch body **420** includes one or more sensors **421**. The sensors **421** of the watch body **420** can be the same or distinct from the sensors **413** of the wearable band **410**. The sensors **421** of the watch body **420** can be distributed on an inside and/or an outside surface of the watch body **420**. In some embodiments, the sensors **421** are configured to contact a user's skin when the watch body **420** is worn by the user. For example, the sensors **421** can be placed on the bottom side of the watch body **420** and the coupling mechanism **416** can be a cradle with an opening that allows the bottom side of the watch body **420** to directly contact the user's skin. Alternatively, in some embodiments, the watch body **420** does not include sensors that are configured to contact the user's skin (e.g., including sensors internal and/or external to the watch body **420** that are configured to sense data of the watch body **420** and the watch body **420**'s surrounding environment). In some embodiments, the sensors **413** are configured to track a position and/or motion of the watch body **420**.

The watch body **420** and the wearable band **410** can share data using a wired communication method (e.g., a Universal Asynchronous Receiver/Transmitter (UART) or a USB transceiver) and/or a wireless communication method (e.g., near-field communication or Bluetooth). For example, the watch body **420** and the wearable band **410** can share data sensed by the sensors **413** and **421**, as well as application- and device-specific information (e.g., active and/or available applications), output devices (e.g., display or speakers), and/or input devices (e.g., touch screens, microphones, or imaging sensors).

In some embodiments, the watch body **420** can include, without limitation, a front-facing camera **425***a* and/or a rear-facing camera **425***b*, sensors **421** (e.g., a biometric sensor, an IMU sensor, a heart rate sensor, a saturated oxygen sensor, a neuromuscular-signal sensor, an altimeter sensor, a temperature sensor, a bioimpedance sensor, a pedometer sensor, an optical sensor (e.g., FIG. **4**B; imaging sensor **463**), a touch sensor, a sweat sensor). In some embodiments, the watch body **420** can include one or more haptic devices **476** (FIG. **4**B; a vibratory haptic actuator) that is configured to provide haptic feedback (e.g., a cutaneous and/or kinesthetic sensation) to the user. The sensors **421** and/or the haptic device **476** can also be configured to operate in conjunction with multiple applications, including, without limitation, health-monitoring applications, social media applications, game applications, and AR applications (e.g., the applications associated with AR).

As described above, the watch body **420** and the wearable band **410**, when coupled, can form the wrist-wearable device **400**. When coupled, the watch body **420** and wearable band **410** operate as a single device to execute functions (e.g., operations, detections, or communications) described herein. In some embodiments, each device is provided with particular instructions for performing the one or more operations of the wrist-wearable device **400**. For example, in accordance with a determination that the watch body **420** does not include neuromuscular-signal sensors, the wearable band **410** can include alternative instructions for performing associated instructions (e.g., providing sensed neuromuscular-signal data to the watch body **420** via a different electronic device). Operations of the wrist-wearable device **400** can be performed by the watch body **420** alone or in conjunction with the wearable band **410** (e.g., via respective processors and/or hardware components) and vice versa. In some embodiments, operations of the wrist-wearable device **400**, the watch body **420**, and/or the wearable band **410** can be performed in conjunction with one or more processors and/or hardware components of another communicatively coupled device (e.g., FIGS. **6**A-**6**B; the HIPD **600**).

As described below with reference to the block diagram of FIG. **4**B, the wearable band **410** and/or the watch body **420** can each include independent resources required to independently execute functions. For example, the wearable band **410** and/or the watch body **420** can each include a power source (e.g., a battery), a memory, data storage, a processor (e.g., a CPU), communications, a light source, and/or input/output devices.

FIG. **4**B shows block diagrams of a computing system **430** corresponding to the wearable band **410** and a computing system **460** corresponding to the watch body **420**, according to some embodiments. A computing system of the wrist-wearable device **400** includes a combination of components of the wearable band computing system **430** and the watch body computing system **460**, in accordance with some embodiments.

The watch body **420** and/or the wearable band **410** can include one or more components shown in watch body computing system **460**. In some embodiments, a single integrated circuit includes all or a substantial portion of the components of the watch body computing system **460** that are included in a single integrated circuit. Alternatively, in some embodiments, components of the watch body computing system **460** are included in a plurality of integrated circuits that are communicatively coupled. In some embodi-

ments, the watch body computing system **460** is configured to couple (e.g., via a wired or wireless connection) with the wearable band computing system **430**, which allows the computing systems to share components, distribute tasks, and/or perform other operations described herein (individually or as a single device).

The watch body computing system **460** can include one or more processors **479**, a controller **47**, a peripherals interface **461**, a power system **495**, and memory (e.g., a memory **480**), each of which are defined above and described in more detail below.

The power system **495** can include a charger input **496**, a power-management integrated circuit (PMIC) **497**, and a battery **498**, each of which are defined above. In some embodiments, a watch body **420** and a wearable band **410** can have respective charger inputs (e.g., charger inputs **496** and **457**), respective batteries (e.g., batteries **498** and **459**), and can share power with each other (e.g., the watch body **420** can power and/or charge the wearable band **410** and vice versa). Although watch body **420** and/or the wearable band **410** can include respective charger inputs, a single charger input can charge both devices when coupled. The watch body **420** and the wearable band **410** can receive a charge using a variety of techniques. In some embodiments, the watch body **420** and the wearable band **410** can use a wired charging assembly (e.g., power cords) to receive the charge. Alternatively, or in addition, the watch body **420** and/or the wearable band **410** can be configured for wireless charging. For example, a portable charging device can be designed to mate with a portion of watch body **420** and/or wearable band **410** and wirelessly deliver usable power to a battery of watch body **420** and/or wearable band **410**. The watch body **420** and the wearable band **410** can have independent power systems (e.g., power system **495** and **456**) to enable each to operate independently. The watch body **420** and wearable band **410** can also share power (e.g., one can charge the other) via respective PMICs (e.g., PMICs **497** and **458**) that can share power over power and ground conductors and/or over wireless charging antennas.

In some embodiments, the peripherals interface **461** can include one or more sensors **421**, many of which listed below are defined above. The sensors **421** can include one or more coupling sensors **462** for detecting when the watch body **420** is coupled with another electronic device (e.g., a wearable band **410**). The sensors **421** can include imaging sensors **463** (one or more of the cameras **425** and/or separate imaging sensors **463** (e.g., thermal-imaging sensors)). In some embodiments, the sensors **421** include one or more SpO2 sensors **464**. In some embodiments, the sensors **421** include one or more biopotential-signal sensors (e.g., EMG sensors **465**, which may be disposed on a user-facing portion of the watch body **420** and/or the wearable band **410**). In some embodiments, the sensors **421** include one or more capacitive sensors **466**. In some embodiments, the sensors **421** include one or more heart rate sensors **467**. In some embodiments, the sensors **421** include one or more IMUs **468**. In some embodiments, one or more IMUs **468** can be configured to detect movement of a user's hand or other location that the watch body **420** is placed or held.

In some embodiments, the peripherals interface **461** includes an NFC component **469**, a GPS component **470**, a long-term evolution (LTE) component **471**, and/or a Wi-Fi and/or Bluetooth communication component **472**. In some embodiments, the peripherals interface **461** includes one or more buttons **473** (e.g., the peripheral buttons **423** and **427** in FIG. **4**A), which, when selected by a user, cause operations to be performed at the watch body **420**. In some embodiments, the peripherals interface **461** includes one or more indicators, such as a light-emitting diode (LED), to provide a user with visual indicators (e.g., message received, low battery, an active microphone, and/or a camera).

The watch body **420** can include at least one display **405** for displaying visual representations of information or data to the user, including user-interface elements and/or three-dimensional (3D) virtual objects. The display can also include a touch screen for inputting user inputs, such as touch gestures, swipe gestures, and the like. The watch body **420** can include at least one speaker **474** and at least one microphone **475** for providing audio signals to the user and receiving audio input from the user. The user can provide user inputs through the microphone **475** and can also receive audio output from the speaker **474** as part of a haptic event provided by the haptic controller **478**. The watch body **420** can include at least one camera **425**, including a front-facing camera **425***a* and a rear-facing camera **425***b*. The cameras **425** can include ultra-wide-angle cameras, wide-angle cameras, fish-eye cameras, spherical cameras, telephoto cameras, depth-sensing cameras, or other types of cameras.

The watch body computing system **460** can include one or more haptic controllers **478** and associated componentry (e.g., haptic devices **476**) for providing haptic events at the watch body **420** (e.g., a vibrating sensation or audio output in response to an event at the watch body **420**). The haptic controllers **478** can communicate with one or more haptic devices **476**, such as electroacoustic devices, including a speaker of the one or more speakers **474** and/or other audio components and/or electromechanical devices that convert energy into linear motion such as a motor, solenoid, electroactive polymer, piezoelectric actuator, electrostatic actuator, or other tactile output generating component (e.g., a component that converts electrical signals into tactile outputs on the device). The haptic controller **478** can provide haptic events to respective haptic actuators that are capable of being sensed by a user of the watch body **420**. In some embodiments, the one or more haptic controllers **478** can receive input signals from an application of the applications **482**.

In some embodiments, the computer system **430** and/or the computer system **460** can include memory **480**, which can be controlled by a memory controller of the one or more controllers **47** and/or one or more processors **479**. In some embodiments, software components stored in the memory **480** include one or more applications **482** configured to perform operations at the watch body **420**. In some embodiments, the one or more applications **482** include games, word processors, messaging applications, calling applications, web browsers, social media applications, media streaming applications, financial applications, calendars, clocks, etc. In some embodiments, software components stored in the memory **480** include one or more communication interface modules **483** as defined above. In some embodiments, software components stored in the memory **480** include one or more graphics modules **484** for rendering, encoding, and/or decoding audio and/or visual data; and one or more data management modules **485** for collecting, organizing, and/or providing access to the data **487** stored in memory **480**. In some embodiments, one or more of applications **482** and/or one or more modules can work in conjunction with one another to perform various tasks at the watch body **420**.

In some embodiments, software components stored in the memory **480** can include one or more operating systems **481** (e.g., a Linux-based operating system, an Android operating system, etc.). The memory **480** can also include data **487**.

The data **487** can include profile data **488**A, sensor data **489**A, media content data **490**, application data **491**.

It should be appreciated that the watch body computing system **460** is an example of a computing system within the watch body **420**, and that the watch body **420** can have more or fewer components than shown in the watch body computing system **460**, combine two or more components, and/or have a different configuration and/or arrangement of the components. The various components shown in watch body computing system **460** are implemented in hardware, software, firmware, or a combination thereof, including one or more signal processing and/or application-specific integrated circuits.

Turning to the wearable band computing system **430**, one or more components that can be included in the wearable band **410** are shown. The wearable band computing system **430** can include more or fewer components than shown in the watch body computing system **460**, combine two or more components, and/or have a different configuration and/or arrangement of some or all of the components. In some embodiments, all, or a substantial portion of the components of the wearable band computing system **430** are included in a single integrated circuit. Alternatively, in some embodiments, components of the wearable band computing system **430** are included in a plurality of integrated circuits that are communicatively coupled. As described above, in some embodiments, the wearable band computing system **430** is configured to couple (e.g., via a wired or wireless connection) with the watch body computing system **460**, which allows the computing systems to share components, distribute tasks, and/or perform other operations described herein (individually or as a single device).

The wearable band computing system **430**, similar to the watch body computing system **460**, can include one or more processors **449**, one or more controllers **447** (including one or more haptics controller **448**), a peripherals interface **431** that can include one or more sensors **413** and other peripheral devices, power source (e.g., a power system **456**), and memory (e.g., a memory **450**) that includes an operating system (e.g., an operating system **451**), data (e.g., data **454** including profile data **488**B, sensor data **489**B, etc.), and one or more modules (e.g., a communications interface module **452**, a data management module **453**, etc.).

The one or more sensors **413** can be analogous to sensors **421** of the computer system **460** in light of the definitions above. For example, sensors **413** can include one or more coupling sensors **432**, one or more SpO2 sensors **434**, one or more EMG sensors **435**, one or more capacitive sensors **436**, one or more heart rate sensors **437**, and one or more IMU sensors **438**.

The peripherals interface **431** can also include other components analogous to those included in the peripheral interface **461** of the computer system **460**, including an NFC component **439**, a GPS component **440**, an LTE component **441**, a Wi-Fi and/or Bluetooth communication component **442**, and/or one or more haptic devices **476** as described above in reference to peripherals interface **461**. In some embodiments, the peripherals interface **431** includes one or more buttons **443**, a display **433**, a speaker **444**, a microphone **445**, and a camera **455**. In some embodiments, the peripherals interface **431** includes one or more indicators, such as an LED.

It should be appreciated that the wearable band computing system **430** is an example of a computing system within the wearable band **410**, and that the wearable band **410** can have more or fewer components than shown in the wearable band computing system **430**, combine two or more components, and/or have a different configuration and/or arrangement of the components. The various components shown in wearable band computing system **430** can be implemented in one or a combination of hardware, software, and firmware, including one or more signal processing and/or application-specific integrated circuits.

The wrist-wearable device **400** with respect to FIG. **4**A is an example of the wearable band **410** and the watch body **420** coupled, so the wrist-wearable device **400** will be understood to include the components shown and described for the wearable band computing system **430** and the watch body computing system **460**. In some embodiments, wrist-wearable device **400** has a split architecture (e.g., a split mechanical architecture or a split electrical architecture) between the watch body **420** and the wearable band **410**. In other words, all of the components shown in the wearable band computing system **430** and the watch body computing system **460** can be housed or otherwise disposed in a combined wrist-wearable device **400**, or within individual components of the watch body **420**, wearable band **410**, and/or portions thereof (e.g., a coupling mechanism **416** of the wearable band **410**).

The techniques described above can be used with any device for sensing neuromuscular signals, including the arm-wearable devices of FIG. **4**A-**4**B, but could also be used with other types of wearable devices for sensing neuromuscular signals (such as body-wearable or head-wearable devices that might have neuromuscular sensors closer to the brain or spinal column).

In some embodiments, a wrist-wearable device **400** can be used in conjunction with a head-wearable device described below (e.g., AR device **500** and VR device **510**) and/or an HIPD **600**, and the wrist-wearable device **400** can also be configured to be used to allow a user to control aspect of the artificial reality (e.g., by using EMG-based gestures to control user interface objects in the artificial reality and/or by allowing a user to interact with the touchscreen on the wrist-wearable device to also control aspects of the artificial reality). In some embodiments, a wrist-wearable device **400** can also be used in conjunction with a wearable garment, such as smart textile-based garment **700** described below in reference to FIGS. **7**A-**7**C. Having thus described example wrist-wearable device, attention will now be turned to example head-wearable devices, such as AR device **500** and VR device **510**.

Example Head-Wearable Devices

FIGS. **5**A, **5**B-**1**, **5**B-**2**, and **5**C show example head-wearable devices, in accordance with some embodiments. Head-wearable devices can include, but are not limited to, AR devices **500** (e.g., AR or smart eyewear devices, such as smart glasses, smart monocles, smart contacts, etc.), VR devices **510** (e.g., VR headsets or head-mounted displays (HMDs)), or other ocularly coupled devices. The AR devices **500** and the VR devices **510** are instances of the head-wearable devices described in reference to FIGS. **1**A to **1**F herein, such that the head-wearable device should be understood to have the features of the AR devices **500** and/or the VR devices **510** and vice versa. The AR devices **500** and the VR devices **510** can perform various functions and/or operations associated with navigating through user interfaces and selectively opening applications, as well as the functions and/or operations described above with reference to FIGS. **1**A to **1**F (e.g., displaying the user interface **104**, the user interface **120**, and/or any of the constituent user interface elements of these user interfaces.

In some embodiments, an AR system (e.g., FIGS. **3**A-**3**D-**2**; AR systems **300***a*-**300***d*) includes an AR device **500** (as shown in FIG. **5**A) and/or VR device **510** (as shown in FIGS. **5**B-**1**-B-**2**). In some embodiments, the AR device **500** and the VR device **510** can include one or more analogous components (e.g., components for presenting interactive AR environments, such as processors, memory, and/or presentation devices, including one or more displays and/or one or more waveguides), some of which are described in more detail with respect to FIG. **5**C. The head-wearable devices can use display projectors (e.g., display projector assemblies **507**A and **507**B) and/or waveguides for projecting representations of data to a user. Some embodiments of head-wearable devices do not include displays.

FIG. **5**A shows an example visual depiction of the AR device **500** (e.g., which may also be described herein as augmented-reality glasses and/or smart glasses). The AR device **500** can work in conjunction with additional electronic components that are not shown in FIGS. **5**A, such as a wearable accessory device and/or an intermediary processing device, in electronic communication or otherwise configured to be used in conjunction with the AR device **500**. In some embodiments, the wearable accessory device and/or the intermediary processing device may be configured to couple with the AR device **500** via a coupling mechanism in electronic communication with a coupling sensor **524**, where the coupling sensor **524** can detect when an electronic device becomes physically or electronically coupled with the AR device **500**. In some embodiments, the AR device **500** can be configured to couple to a housing (e.g., a portion of frame **504** or temple arms **505**), which may include one or more additional coupling mechanisms configured to couple with additional accessory devices. The components shown in FIG. **5**A can be implemented in hardware, software, firmware, or a combination thereof, including one or more signal-processing components and/or application-specific integrated circuits (ASICs).

The AR device **500** includes mechanical glasses components, including a frame **504** configured to hold one or more lenses (e.g., one or both lenses **506-1** and **506-2**). One of ordinary skill in the art will appreciate that the AR device **500** can include additional mechanical components, such as hinges configured to allow portions of the frame **504** of the AR device **500** to be folded and unfolded, a bridge configured to span the gap between the lenses **506-1** and **506-2** and rest on the user's nose, nose pads configured to rest on the bridge of the nose and provide support for the AR device **500**, earpieces configured to rest on the user's ears and provide additional support for the AR device **500**, temple arms **505** configured to extend from the hinges to the earpieces of the AR device **500**, and the like. One of ordinary skill in the art will further appreciate that some examples of the AR device **500** can include none of the mechanical components described herein. For example, smart contact lenses configured to present AR to users may not include any components of the AR device **500**.

The lenses **506-1** and **506-2** can be individual displays or display devices (e.g., a waveguide for projected representations). The lenses **506-1** and **506-2** may act together or independently to present an image or series of images to a user. In some embodiments, the lenses **506-1** and **506-2** can operate in conjunction with one or more display projector assemblies **507**A and **507**B to present image data to a user. While the AR device **500** includes two displays, embodiments of this disclosure may be implemented in AR devices with a single near-eye display (NED) or more than two NEDs.

The AR device **500** includes electronic components, many of which will be described in more detail below with respect to FIG. **5**C. Some example electronic components are illustrated in FIG. **5**A, including sensors **523-1**, **523-2**, **523-3**, **523-4**, **523-5**, and **523-6**, which can be distributed along a substantial portion of the frame **504** of the AR device **500**. The distinct types of sensors are described below in reference to FIG. **5**C. The AR device **500** also includes a left camera **539**A and a right camera **539**B, which are located on different sides of the frame **504**. And the eyewear device includes one or more processors **548**A and **548**B (e.g., an integral microprocessor, such as an ASIC) that is embedded into a portion of the frame **504**.

FIGS. **5**B-**1** and **5**B-**2** show an example visual depiction of the VR device **510** (e.g., a head-mounted display (HMD) **512**, also referred to herein as an AR headset, a head-wearable device, or a VR headset). The HMD **512** includes a front body **514** and a frame **516** (e.g., a strap or band) shaped to fit around a user's head. In some embodiments, the front body **514** and/or the frame **516** includes one or more electronic elements for facilitating presentation of and/or interactions with an AR and/or VR system (e.g., displays, processors (e.g., processor **548**A-**1**), IMUs, tracking emitters or detectors, or sensors). In some embodiments, the HMD **512** includes output audio transducers (e.g., an audio transducer **518-1**), as shown in FIG. **5**B-**2**. In some embodiments, one or more components, such as the output audio transducer(s) **518** and the frame **516**, can be configured to attach and detach (e.g., are detachably attachable) to the HMD **512** (e.g., a portion or all of the frame **516** and/or the output audio transducer **518**), as shown in FIG. **5**B-**2**. In some embodiments, coupling a detachable component to the HMD **512** causes the detachable component to come into electronic communication with the HMD **512**. The VR device **510** includes electronic components, many of which will be described in more detail below with respect to FIG. **5**C.

FIGS. **5**B-**1** and **5**B-**2** also show that the VR device **510** having one or more cameras, such as the left camera **539**A and the right camera **539**B, which can be analogous to the left and right cameras on the frame **504** of the AR device **500**. In some embodiments, the VR device **510** includes one or more additional cameras (e.g., cameras **539**C and **539**D), which can be configured to augment image data obtained by the cameras **539**A and **539**B by providing more information. For example, the camera **539**C can be used to supply color information that is not discerned by cameras **539**A and **539**B. In some embodiments, one or more of the cameras **539**A to **539**D can include an optional IR cut filter configured to remove IR light from being received at the respective camera sensors.

The VR device **510** can include a housing **590** storing one or more components of the VR device **510** and/or additional components of the VR device **510**. The housing **590** can be a modular electronic device configured to couple with the VR device **510** (or an AR device **500**) and supplement and/or extend the capabilities of the VR device **510** (or an AR device **500**). For example, the housing **590** can include additional sensors, cameras, power sources, and processors (e.g., processor **548**A-**2**). to improve and/or increase the functionality of the VR device **510**. Examples of the different components included in the housing **590** are described below in reference to FIG. **5**C.

Alternatively, or in addition, in some embodiments, the head-wearable device, such as the VR device **510** and/or the AR device **500**, includes, or is communicatively coupled to, another external device (e.g., a paired device), such as an

HIPD **6** (discussed below in reference to FIGS. **6**A-**6**B) and/or an optional neckband. The optional neckband can couple to the head-wearable device via one or more connectors (e.g., wired, or wireless connectors). The head-wearable device and the neckband can operate independently without any wired or wireless connection between them. In some embodiments, the components of the head-wearable device and the neckband are located on one or more additional peripheral devices paired with the head-wearable device, the neckband, or some combination thereof. Furthermore, the neckband is intended to represent any suitable type or form of paired device. Thus, the following discussion of neckbands may also apply to various other paired devices, such as smartwatches, smartphones, wrist bands, other wearable devices, hand-held controllers, tablet computers, or laptop computers.

In some situations, pairing external devices, such as an intermediary processing device (e.g., an HIPD device **600**, an optional neckband, and/or a wearable accessory device) with the head-wearable devices (e.g., an AR device **500** and/or a VR device **510**) enables the head-wearable devices to achieve a similar form factor of a pair of glasses while still providing sufficient battery and computational power for expanded capabilities. Some, or all, of the battery power, computational resources, and/or additional features of the head-wearable devices can be provided by a paired device or shared between a paired device and the head-wearable devices, thus reducing the weight, heat profile, and form factor of the head-wearable device overall while allowing the head-wearable device to retain its desired functionality. For example, the intermediary processing device (e.g., the HIPD **600**) can allow components that would otherwise be included in a head-wearable device to be included in the intermediary processing device (and/or a wearable device or accessory device), thereby shifting a weight load from the user's head and neck to one or more other portions of the user's body. In some embodiments, the intermediary processing device has a larger surface area over which to diffuse and disperse heat to the ambient environment. Thus, the intermediary processing device can allow for greater battery and computational capacity than might otherwise have been possible on the head-wearable devices, standing alone. Because weight carried in the intermediary processing device can be less invasive to a user than weight carried in the head-wearable devices, a user may tolerate wearing a lighter eyewear device and carrying or wearing the paired device for greater lengths of time than the user would tolerate wearing a heavier eyewear device standing alone, thereby enabling an AR environment to be incorporated more fully into a user's day-to-day activities.

In some embodiments, the intermediary processing device is communicatively coupled with the head-wearable device and/or to other devices. The other devices may provide certain functions (e.g., tracking, localizing, depth mapping, processing, and/or storage) to the head-wearable device. In some embodiments, the intermediary processing device includes a controller and a power source. In some embodiments, sensors of the intermediary processing device are configured to sense additional data that can be shared with the head-wearable devices in an electronic format (analog or digital).

The controller of the intermediary processing device processes information generated by the sensors on the intermediary processing device and/or the head-wearable devices. The intermediary processing device, such as an HIPD **600**, can process information generated by one or more of its sensors and/or information provided by other communicatively coupled devices. For example, a head-wearable device can include an IMU, and the intermediary processing device (a neckband and/or an HIPD **600**) can compute all inertial and spatial calculations from the IMUs located on the head-wearable device. Additional examples of processing performed by a communicatively coupled device, such as the HIPD **600**, are provided below in reference to FIGS. **6**A and **6**B.

AR systems may include a variety of types of visual feedback mechanisms. For example, display devices in the AR devices **500** and/or the VR devices **510** may include one or more liquid-crystal displays (LCDs), light emitting diode (LED) displays, organic LED (OLED) displays, and/or any other suitable type of display screen. AR systems may include a single display screen for both eyes or may provide a display screen for each eye, which may allow for additional flexibility for varifocal adjustments or for correcting a refractive error associated with the user's vision. Some AR systems also include optical subsystems having one or more lenses (e.g., conventional concave or convex lenses, Fresnel lenses, or adjustable liquid lenses) through which a user may view a display screen. In addition to or instead of using display screens, some AR systems include one or more projection systems. For example, display devices in the AR device **500** and/or the VR device **510** may include micro-LED projectors that project light (e.g., using a waveguide) into display devices, such as clear combiner lenses that allow ambient light to pass through. The display devices may refract the projected light toward a user's pupil and may enable a user to simultaneously view both AR content and the real world. AR systems may also be configured with any other suitable type or form of image projection system. As noted, some AR systems may, instead of blending an artificial reality with actual reality, substantially replace one or more of a user's sensory perceptions of the real world with a virtual experience.

While the example head-wearable devices are respectively described herein as the AR device **500** and the VR device **510**, either or both of the example head-wearable devices described herein can be configured to present fully immersive VR scenes presented in substantially all of a user's field of view, additionally or alternatively to, subtler augmented-reality scenes that are presented within a portion, less than all, of the user's field of view.

In some embodiments, the AR device **500** and/or the VR device **510** can include haptic feedback systems. The haptic feedback systems may provide several distinct types of cutaneous feedback, including vibration, force, traction, shear, texture, and/or temperature. The haptic feedback systems may also provide various types of kinesthetic feedback, such as motion and compliance. The haptic feedback can be implemented using motors, piezoelectric actuators, fluidic systems, and/or a variety of other types of feedback mechanisms. The haptic feedback systems may be implemented independently of other AR devices, within other AR devices, and/or in conjunction with other AR devices (e.g., wrist-wearable devices that may be incorporated into headwear, gloves, body suits, handheld controllers, environmental devices (e.g., chairs or floormats), and/or any other type of device or system, such as a wrist-wearable device **400**, an HIPD **600**, smart textile-based garment **700**), and/or other devices described herein.

FIG. **5**C illustrates a computing system **520** and an optional housing **590**, each of which shows components that can be included in a head-wearable device (e.g., the AR device **500** and/or the VR device **510**). In some embodiments, more or fewer components can be included in the

optional housing **590** depending on practical restraints of the respective head-wearable device being described. Additionally, or alternatively, the optional housing **590** can include additional components to expand and/or augment the functionality of a head-wearable device.

In some embodiments, the computing system **520** and/or the optional housing **590** can include one or more peripheral interfaces **522**A and **522**B, one or more power systems **542**A and **542**B (including charger input **543**, PMIC **544**, and battery **545**), one or more controllers **546**A and **546**B (including one or more haptic controllers **547**), one or more processors **548**A and **548**B (as defined above, including any of the examples provided), and memory **550**A and **550**B, which can all be in electronic communication with each other. For example, the one or more processors **548**A and/or **548**B can be configured to execute instructions stored in the memory **550**A and/or **550**B, which can cause a controller of the one or more controllers **546**A and/or **546**B to cause operations to be performed at one or more peripheral devices of the peripheral interfaces **522**A and/or **522**B. In some embodiments, each operation described can occur based on electrical power provided by the power system **542**A and/or **542**B.

In some embodiments, the peripherals interface **522**A can include one or more devices configured to be part of the computing system **520**, many of which have been defined above and/or described with respect to wrist-wearable devices shown in FIGS. **4**A and **4**B. For example, the peripherals interface can include one or more sensors **523**A. Some example sensors include one or more coupling sensors **524**, one or more acoustic sensors **525**, one or more imaging sensors **526**, one or more EMG sensors **527**, one or more capacitive sensors **528**, and/or one or more IMUs **529**. In some embodiments, the sensors **523**A further include depth sensors **567**, light sensors **568**, and/or any other types of sensors defined above or described with respect to any other embodiments discussed herein.

In some embodiments, the peripherals interface can include one or more additional peripheral devices, including one or more NFC devices **530**, one or more GPS devices **531**, one or more LTE devices **532**, one or more Wi-Fi and/or Bluetooth devices **533**, one or more buttons **534** (e.g., including buttons that are slidable or otherwise adjustable), one or more displays **535**A, one or more speakers **536**A, one or more microphones **537**A, one or more cameras **538**A (e.g., including the first camera **539-1** through nth camera **539-*n***, which are analogous to the left camera **539**A and/or the right camera **539**B), one or more haptic devices **540**, and/or any other types of peripheral devices defined above or described with respect to any other embodiments discussed herein.

The head-wearable devices can include a variety of types of visual feedback mechanisms (e.g., presentation devices). For example, display devices in the AR device **500** and/or the VR device **510** can include one or more liquid-crystal displays (LCDs), light emitting diode (LED) displays, organic LED (OLED) displays, micro-LEDs, and/or any other suitable types of display screens. The head-wearable devices can include a single display screen (e.g., configured to be seen by both eyes) and/or can provide separate display screens for each eye, which can allow for additional flexibility for varifocal adjustments and/or for correcting a refractive error associated with the user's vision. Some embodiments of the head-wearable devices also include optical subsystems having one or more lenses (e.g., conventional concave or convex lenses, Fresnel lenses, or adjustable liquid lenses) through which a user can view a display screen. For example, respective displays **535**A can be coupled to each of the lenses **506-1** and **506-2** of the AR device **500**. The displays **535**A coupled to each of the lenses **506-1** and **506-2** can act together or independently to present an image or series of images to a user. In some embodiments, the AR device **500** and/or the VR device **510** includes a single display **535**A (e.g., a near-eye display) or more than two displays **535**A.

In some embodiments, a first set of one or more displays **535**A can be used to present an augmented-reality environment, and a second set of one or more display devices **535**A can be used to present a VR environment. In some embodiments, one or more waveguides are used in conjunction with presenting AR content to the user of the AR device **500** and/or the VR device **510** (e.g., as a means of delivering light from a display projector assembly and/or one or more displays **535**A to the user's eyes). In some embodiments, one or more waveguides are fully or partially integrated into the AR device **500** and/or the VR device **510**. Additionally, or alternatively, to display screens, some AR systems include one or more projection systems. For example, display devices in the AR device **500** and/or the VR device **510** can include micro-LED projectors that project light (e.g., using a waveguide) into display devices, such as clear combiner lenses that allow ambient light to pass through. The display devices can refract the projected light toward a user's pupil and can enable a user to simultaneously view both AR content and the real world. The head-wearable devices can also be configured with any other suitable type or form of image projection system. In some embodiments, one or more waveguides are provided, additionally or alternatively, to the one or more display(s) **535**A.

In some embodiments of the head-wearable devices, ambient light and/or a real-world live view (e.g., a live feed of the surrounding environment that a user would normally sec) can be passed through a display element of a respective head-wearable device presenting aspects of the AR system. In some embodiments, ambient light and/or the real-world live view can be passed through a portion, less than all, of an AR environment presented within a user's field of view (e.g., a portion of the AR environment co-located with a physical object in the user's real-world environment that is within a designated boundary (e.g., a guardian boundary) configured to be used by the user while they are interacting with the AR environment). For example, a visual user interface element (e.g., a notification user interface element) can be presented at the head-wearable devices, and an amount of ambient light and/or the real-world live view (e.g., 15%-50% of the ambient light and/or the real-world live view) can be passed through the user interface element, such that the user can distinguish at least a portion of the physical environment over which the user interface element is being displayed.

The head-wearable devices can include one or more external displays **535**A for presenting information to users. For example, an external display **535**A can be used to show a current battery level, network activity (e.g., connected, disconnected), current activity (e.g., playing a game, in a call, in a meeting, or watching a movie), and/or other relevant information. In some embodiments, the external displays **535**A can be used to communicate with others. For example, a user of the head-wearable device can cause the external displays **535**A to present a "do not disturb" notification. The external displays **535**A can also be used by the user to share any information captured by the one or more components of the peripherals interface **522**A and/or gen-

erated by the head-wearable device (e.g., during operation and/or performance of one or more applications).

The memory **550**A can include instructions and/or data executable by one or more processors **548**A (and/or processors **548**B of the housing **590**) and/or a memory controller of the one or more controllers **546**A (and/or controller **546**B of the housing **590**). The memory **550**A can include one or more operating systems **551**, one or more applications **552**, one or more communication interface modules **553**A, one or more graphics modules **554**A, one or more AR processing modules **555**A, and/or any other types of modules or components defined above or described with respect to any other embodiments discussed herein.

The data **560** stored in memory **550**A can be used in conjunction with one or more of the applications and/or programs discussed above. The data **560** can include profile data **561**, sensor data **562**, media content data **563**, AR application data **564**, and/or any other types of data defined above or described with respect to any other embodiments discussed herein.

In some embodiments, the controller **546**A of the head-wearable devices processes information generated by the sensors **523**A on the head-wearable devices and/or another component of the head-wearable devices and/or communicatively coupled with the head-wearable devices (e.g., components of the housing **590**, such as components of peripherals interface **522**B). For example, the controller **546**A can process information from the acoustic sensors **525** and/or image sensors **526**. For each detected sound, the controller **546**A can perform a direction of arrival (DOA) estimation to estimate a direction from which the detected sound arrived at a head-wearable device. As one or more of the acoustic sensors **525** detect sounds, the controller **546**A can populate an audio data set with the information (e.g., represented by sensor data **562**).

In some embodiments, a physical electronic connector can convey information between the head-wearable devices and another electronic device, and/or between one or more processors **548**A of the head-wearable devices and the controller **546**A. The information can be in the form of optical data, electrical data, wireless data, or any other transmittable data form. Moving the processing of information generated by the head-wearable devices to an intermediary processing device can reduce weight and heat in the eyewear device, making it more comfortable and safer for a user. In some embodiments, an optional accessory device (e.g., an electronic neckband or an HIPD **600**) is coupled to the head-wearable devices via one or more connectors. The connectors can be wired or wireless connectors and can include electrical and/or non-electrical (e.g., structural) components. In some embodiments, the head-wearable devices and the accessory device can operate independently without any wired or wireless connection between them.

The head-wearable devices can include various types of computer vision components and subsystems. For example, the AR device **500** and/or the VR device **510** can include one or more optical sensors such as two-dimensional (2D) or three-dimensional (3D) cameras, time-of-flight depth sensors, single-beam or sweeping laser rangefinders, 3D LiDAR sensors, and/or any other suitable type or form of optical sensor. A head-wearable device can process data from one or more of these sensors to identify a location of a user and/or aspects of the user's real-world physical surroundings, including the locations of real-world objects within the real-world physical surroundings. In some embodiments, the methods described herein are used to map the real world, to provide a user with context about real-world surroundings, and/or to generate interactable virtual objects (which can be replicas or digital twins of real-world objects that can be interacted with an AR environment), among a variety of other functions. For example, FIGS. **5**B-**1** and **5**B-**2** show the VR device **510** having cameras **539**A-**539**D, which can be used to provide depth information for creating a voxel field and a 2D mesh to provide object information to the user to avoid collisions.

The optional housing **590** can include analogous components to those describe above with respect to the computing system **520**. For example, the optional housing **590** can include a respective peripherals interface **522**B, including more or fewer components to those described above with respect to the peripherals interface **522**A. As described above, the components of the optional housing **590** can be used to augment and/or expand on the functionality of the head-wearable devices. For example, the optional housing **590** can include respective sensors **523**B, speakers **536**B, displays **535**B, microphones **537**B, cameras **538**B, and/or other components to capture and/or present data. Similarly, the optional housing **590** can include one or more processors **548**B, controllers **546**B, and/or memory **550**B (including respective communication interface modules **553**B, one or more graphics modules **554**B, one or more AR processing modules **555**B) that can be used individually and/or in conjunction with the components of the computing system **520**.

The techniques described above in FIGS. **5**A-**5**C can be used with different head-wearable devices. In some embodiments, the head-wearable devices (e.g., the AR device **500** and/or the VR device **510**) can be used in conjunction with one or more wearable devices such as a wrist-wearable device **400** (or components thereof) and/or a smart textile-based garment **700** (FIGS. **7**A-**7**C), as well as an HIPD **600**. Having thus described example the head-wearable devices, attention will now be turned to example handheld intermediary processing devices, such as HIPD **600**.

Example Handheld Intermediary Processing Devices

FIGS. **6**A and **6**B illustrate an example handheld intermediary processing device (HIPD) **600**, in accordance with some embodiments. The HIPD **600** can perform various functions and/or operations associated with navigating through user interfaces and selectively opening applications, as well as the functions and/or operations described above with reference to FIGS. **1**A to **1**F. For example, in accordance with some embodiments, data obtained by the HIPD **600** can be used (e.g., in combination with data obtained by the wrist-wearable device **400**) to identify one or more target inputs corresponding to a respective sequence of handwriting motions that the user **302** is performing, and/or to identify devolved sequences of handwriting motions and/or refined devolved sequences of handwriting motions corresponding to such sequences.

FIG. **6**A shows a top view **605** and a side view **625** of the HIPD **600**. The HIPD **600** is configured to communicatively couple with one or more wearable devices (or other electronic devices) associated with a user. For example, the HIPD **600** is configured to communicatively couple with the wrist-wearable device **400** (or components thereof, such as the watch body **420** and the wearable band **410**), AR device **500**, and/or VR device **510**. The HIPD **600** can be configured to be held by a user (e.g., as a handheld controller), carried on the user's person (e.g., in their pocket or in their bag), placed in proximity of the user (e.g., placed on their

desk while seated at their desk or on a charging dock), and/or placed at or within a predetermined distance from a wearable device or other electronic device (e.g., where, in some embodiments, the predetermined distance is the maximum distance (e.g., 10 meters) at which the HIPD **600** can successfully be communicatively coupled with an electronic device, such as a wearable device).

The HIPD **600** can perform various functions independently and/or in conjunction with one or more wearable devices (e.g., wrist-wearable device **400**, AR device **500**, and/or VR device **510**). The HIPD **600** is configured to increase and/or improve the functionality of communicatively coupled devices, such as the wearable devices. The HIPD **600** is configured to perform one or more functions or operations associated with interacting with user interfaces and applications of communicatively coupled devices, interacting with an AR environment, interacting with a VR environment, and/or operating as a human-machine interface controller. Additionally, as will be described in more detail below, functionality and/or operations of the HIPD **600** can include, without limitation, task offloading and/or handoffs, thermals offloading and/or handoffs, 6 degrees of freedom (6DoF) raycasting and/or gaming (e.g., using imaging devices or cameras **614**A and **614**B, which can be used for simultaneous localization and mapping (SLAM), and/or with other image processing techniques), portable charging; messaging, image capturing via one or more imaging devices or cameras (e.g., cameras **622**A and **622**B), sensing user input (e.g., sensing a touch on a multi-touch input surface **602**), wireless communications and/or interlining (e.g., cellular, near field, Wi-Fi, or personal area network), location determination, financial transactions, providing haptic feedback, alarms, notifications, biometric authentication, health monitoring, sleep monitoring. The above-example functions can be executed independently in the HIPD **600** and/or in communication between the HIPD **600** and another wearable device described herein. In some embodiments, functions can be executed on the HIPD **600** in conjunction with an AR environment. As the skilled artisan will appreciate upon reading the descriptions provided herein, the novel HIPD **600** described herein can be used with any type of suitable AR environment.

While the HIPD **600** is communicatively coupled with a wearable device and/or other electronic device, the HIPD **600** is configured to perform one or more operations initiated at the wearable device and/or the other electronic device. In particular, one or more operations of the wearable device and/or the other electronic device can be offloaded to the HIPD **600** to be performed. The HIPD **600** performs one or more operations of the wearable device and/or the other electronic device and provides data corresponding to the completed operations to the wearable device and/or the other electronic device. For example, a user can initiate a video stream using the AR device **500** and back-end tasks associated with performing the video stream (e.g., video rendering) can be offloaded to the HIPD **600**, which the HIPD **600** performs and provides corresponding data to the AR device **500** to perform remaining front-end tasks associated with the video stream (e.g., presenting the rendered video data via a display of the AR device **500**). In this way, the HIPD **600**, which has more computational resources and greater thermal headroom than a wearable device can perform computationally intensive tasks for the wearable device, improving performance of an operation performed by the wearable device.

The HIPD **600** includes a multi-touch input surface **602** on a first side (e.g., a front surface) that is configured to detect one or more user inputs. In particular, the multi-touch input surface **602** can detect single-tap inputs, multi-tap inputs, swipe gestures and/or inputs, force-based and/or pressure-based touch inputs, held taps, and the like. The multi-touch input surface **602** is configured to detect capacitive touch inputs and/or force (and/or pressure) touch inputs. The multi-touch input surface **602** includes a first touch-input surface **604** defined by a surface depression, and a second touch-input surface **606** defined by a substantially planar portion. The first touch-input surface **604** can be disposed adjacent to the second touch-input surface **606**. In some embodiments, the first touch-input surface **604** and the second touch-input surface **606** can be different dimensions, shapes, and/or cover different portions of the multi-touch input surface **602**. For example, the first touch-input surface **604** can be substantially circular and the second touch-input surface **606** is substantially rectangular. In some embodiments, the surface depression of the multi-touch input surface **602** is configured to guide user handling of the HIPD **600**. In particular, the surface depression is configured such that the user holds the HIPD **600** upright when held in a single hand (e.g., such that the using imaging devices or cameras **614**A and **614**B are pointed toward a ceiling or the sky). Additionally, the surface depression is configured such that the user's thumb rests within the first touch-input surface **604**.

In some embodiments, the different touch-input surfaces include a plurality of touch-input zones. For example, the second touch-input surface **606** includes at least a first touch-input zone **608** within a second touch-input zone **606** and a third touch-input zone **610** within the first touch-input zone **608**. In some embodiments, one or more of the touch-input zones are optional and/or user defined (e.g., a user can specific a touch-input zone based on their preferences). In some embodiments, each touch-input surface and/or touch-input zone is associated with a predetermined set of commands. For example, a user input detected within the first touch-input zone **608** causes the HIPD **600** to perform a first command and a user input detected within the second touch-input zone **606** causes the HIPD **600** to perform a second command, distinct from the first. In some embodiments, different touch-input surfaces and/or touch-input zones are configured to detect one or more types of user inputs. The different touch-input surfaces and/or touch-input zones can be configured to detect the same or distinct types of user inputs. For example, the first touch-input zone **608** can be configured to detect force touch inputs (e.g., a magnitude at which the user presses down) and capacitive touch inputs, and the second touch-input zone **606** can be configured to detect capacitive touch inputs.

The HIPD **600** includes one or more sensors **651** for sensing data used in the performance of one or more operations and/or functions. For example, the HIPD **600** can include an IMU that is used in conjunction with cameras **614** for 3-dimensional object manipulation (e.g., enlarging, moving, destroying, etc. an object) in an AR or VR environment. Non-limiting examples of the sensors **651** included in the HIPD **600** include a light sensor, a magnetometer, a depth sensor, a pressure sensor, and a force sensor. Additional examples of the sensors **651** are provided below in reference to FIG. **6**B.

The HIPD **600** can include one or more light indicators **612** to provide one or more notifications to the user. In some embodiments, the light indicators are LEDs or other types of illumination devices. The light indicators **612** can operate as a privacy light to notify the user and/or others near the user that an imaging device and/or microphone are active. In

some embodiments, a light indicator is positioned adjacent to one or more touch-input surfaces. For example, a light indicator can be positioned around the first touch-input surface **604**. The light indicators can be illuminated in distinct colors and/or patterns to provide the user with one or more notifications and/or information about the device. For example, a light indicator positioned around the first touch-input surface **604** can flash when the user receives a notification (e.g., a message), change red when the HIPD **600** is out of power, operate as a progress bar (e.g., a light ring that is closed when a task is completed (e.g., 0% to 100%)), operates as a volume indicator, etc.).

In some embodiments, the HIPD **600** includes one or more additional sensors on another surface. For example, as shown FIG. **6**A, HIPD **600** includes a set of one or more sensors (e.g., sensor set **620**) on an edge of the HIPD **600**. The sensor set **620**, when positioned on an edge of the of the HIPD **600**, can be pe positioned at a predetermined tilt angle (e.g., 26 degrees), which allows the sensor set **620** to be angled toward the user when placed on a desk or other flat surface. Alternatively, in some embodiments, the sensor set **620** is positioned on a surface opposite the multi-touch input surface **602** (e.g., a back surface). The one or more sensors of the sensor set **620** are discussed in detail below.

The side view **625** of the of the HIPD **600** shows the sensor set **620** and camera **614**B. The sensor set **620** includes one or more cameras **622**A and **622**B, a depth projector **624**, an ambient light sensor **628**, and a depth receiver **630**. In some embodiments, the sensor set **620** includes a light indicator **626**. The light indicator **626** can operate as a privacy indicator to let the user and/or those around them know that a camera and/or microphone is active. The sensor set **620** is configured to capture a user's facial expression such that the user can puppet a custom avatar (e.g., showing emotions, such as smiles, laughter, etc., on the avatar or a digital representation of the user). The sensor set **620** can be configured as a side stereo RGB system, a rear indirect Time-of-Flight (iToF) system, or a rear stereo RGB system. As the skilled artisan will appreciate upon reading the descriptions provided herein, the novel HIPD **600** described herein can use different sensor set **620** configurations and/or sensor set **620** placement.

In some embodiments, the HIPD **600** includes one or more haptic devices **671** (FIG. **6**B; e.g., a vibratory haptic actuator) that are configured to provide haptic feedback (e.g., kinesthetic sensation). The sensors **651**, and/or the haptic devices **671** can be configured to operate in conjunction with multiple applications and/or communicatively coupled devices including, without limitation, a wearable devices, health monitoring applications, social media applications, game applications, and artificial reality applications (e.g., the applications associated with artificial reality).

The HIPD **600** is configured to operate without a display. However, in optional embodiments, the HIPD **600** can include a display **668** (FIG. **6**B). The HIPD **600** can also income one or more optional peripheral buttons **667** (FIG. **6**B). For example, the peripheral buttons **667** can be used to turn on or turn off the HIPD **600**. Further, the HIPD **600** housing can be formed of polymers and/or elastomer elastomers. The HIPD **600** can be configured to have a non-slip surface to allow the HIPD **600** to be placed on a surface without requiring a user to watch over the HIPD **600**. In other words, the HIPD **600** is designed such that it would not easily slide off a surfaces. In some embodiments, the HIPD **600** include one or magnets to couple the HIPD **600** to another surface. This allows the user to mount the HIPD **600** to different surfaces and provide the user with greater flexibility in use of the HIPD **600**.

As described above, the HIPD **600** can distribute and/or provide instructions for performing the one or more tasks at the HIPD **600** and/or a communicatively coupled device. For example, the HIPD **600** can identify one or more back-end tasks to be performed by the HIPD **600** and one or more front-end tasks to be performed by a communicatively coupled device. While the HIPD **600** is configured to offload and/or handoff tasks of a communicatively coupled device, the HIPD **600** can perform both back-end and front-end tasks (e.g., via one or more processors, such as CPU **67**; FIG. **6**B). The HIPD **600** can, without limitation, can be used to perform augmenting calling (e.g., receiving and/or sending 3D or 2.5D live volumetric calls, live digital human representation calls, and/or avatar calls), discreet messaging, 6DoF portrait/landscape gaming, AR/VR object manipulation, AR/VR content display (e.g., presenting content via a virtual display), and/or other AR/VR interactions. The HIPD **600** can perform the above operations alone or in conjunction with a wearable device (or other communicatively coupled electronic device).

FIG. **6**B shows block diagrams of an HIPD computing system **640** of the HIPD **600**, in accordance with some embodiments. The HIPD **600**, described in detail above, can include one or more components shown in HIPD computing system **640**. The HIPD **600** will be understood to include the components shown and described below for the HIPD computing system **640**. In some embodiments, all, or a substantial portion of the components of the HIPD computing system **640** are included in a single integrated circuit. Alternatively, in some embodiments, components of the HIPD computing system **640** are included in a plurality of integrated circuits that are communicatively coupled.

The HIPD computing system **640** can include a processor (e.g., a CPU **67**, a GPU, and/or a CPU with integrated graphics), a controller **675**, a peripherals interface **650** that includes one or more sensors **651** and other peripheral devices, a power source (e.g., a power system **695**), and memory (e.g., a memory **678**) that includes an operating system (e.g., an operating system **679**), data (e.g., data **688**), one or more applications (e.g., applications **680**), and one or more modules (e.g., a communications interface module **681**, a graphics module **682**, a task and processing management module **683**, an interoperability module **684**, an AR processing module **685**, a data management module **686**, etc.). The HIPD computing system **640** further includes a power system **695** that includes a charger input and output **696**, a PMIC **697**, and a battery **698**, all of which are defined above.

In some embodiments, the peripherals interface **650** can include one or more sensors **651**. The sensors **651** can include analogous sensors to those described above in reference to FIG. **4**B. For example, the sensors **651** can include imaging sensors **654**, (optional) EMG sensors **656**, IMUs **658**, and capacitive sensors **660**. In some embodiments, the sensors **651** can include one or more pressure sensor **652** for sensing pressure data, an altimeter **653** for sensing an altitude of the HIPD **600**, a magnetometer **655** for sensing a magnetic field, a depth sensor **657** (or a time-of flight sensor) for determining a difference between the camera and the subject of an image, a position sensor **659** (e.g., a flexible position sensor) for sensing a relative displacement or position change of a portion of the HIPD **600**, a force sensor **661** for sensing a force applied to a portion of the HIPD **600**, and a light sensor **662** (e.g., an ambient light

sensor) for detecting an amount of lighting. The sensors **651** can include one or more sensors not shown in FIG. **6**B.

Analogous to the peripherals described above in reference to FIGS. **4**B, the peripherals interface **650** can also include an NFC component **663**, a GPS component **664**, an LTE component **665**, a Wi-Fi and/or Bluetooth communication component **666**, a speaker **669**, a haptic device **671**, and a microphone **673**. As described above in reference to FIG. **6**A, the HIPD **600** can optionally include a display **668** and/or one or more buttons **667**. The peripherals interface **650** can further include one or more cameras **670**, touch surfaces **672**, and/or one or more light emitters **674**. The multi-touch input surface **602** described above in reference to FIG. **6**A is an example of touch surface **672**. The light emitters **674** can be one or more LEDs, lasers, etc. and can be used to project or present information to a user. For example, the light emitters **674** can include light indicators **612** and **626** described above in reference to FIG. **6**A. The cameras **670** (e.g., cameras **614**A, **614**B, and **622** described above in FIG. **6**A) can include one or more wide angle cameras, fish-eye cameras, spherical cameras, compound eye cameras (e.g., stereo and multi cameras), depth cameras, RGB cameras, ToF cameras, RGB-D cameras (depth and ToF cameras), and/or other available cameras. Cameras **670** can be used for SLAM; 6 DoF ray casting, gaming, object manipulation, and/or other rendering; facial recognition and facial expression recognition, etc.

Similar to the watch body computing system **460** and the watch band computing system **430** described above in reference to FIG. **4**B, the HIPD computing system **640** can include one or more haptic controllers **676** and associated componentry (e.g., haptic devices **671**) for providing haptic events at the HIPD **600**.

Memory **678** can include high-speed random-access memory and/or non-volatile memory, such as one or more magnetic disk storage devices, flash memory devices, or other non-volatile solid-state memory devices. Access to the memory **678** by other components of the HIPD **600**, such as the one or more processors and the peripherals interface **650**, can be controlled by a memory controller of the controllers **675**.

In some embodiments, software components stored in the memory **678** include one or more operating systems **679**, one or more applications **680**, one or more communication interface modules **681**, one or more graphics modules **682**, one or more data management modules **685**, which are analogous to the software components described above in reference to FIG. **4**B.

In some embodiments, software components stored in the memory **678** include a task and processing management module **683** for identifying one or more front-end and back-end tasks associated with an operation performed by the user, performing one or more front-end and/or back-end tasks, and/or providing instructions to one or more communicatively coupled devices that cause performance of the one or more front-end and/or back-end tasks. In some embodiments, the task and processing management module **683** uses data **688** (e.g., device data **690**) to distribute the one or more front-end and/or back-end tasks based on communicatively coupled devices' computing resources, available power, thermal headroom, ongoing operations, and/or other factors. For example, the task and processing management module **683** can cause the performance of one or more back-end tasks (of an operation performed at communicatively coupled AR device **500**) at the HIPD **600** in accordance with a determination that the operation is utilizing a predetermined amount (e.g., at least 70%) of computing resources available at the AR device **500**.

In some embodiments, software components stored in the memory **678** include an interoperability module **684** for exchanging and utilizing information received and/or provided to distinct communicatively coupled devices. The interoperability module **684** allows for different systems, devices, and/or applications to connect and communicate in a coordinated way without user input. In some embodiments, software components stored in the memory **678** include an AR module **685** that is configured to process signals based at least on sensor data for use in an AR and/or VR environment. For example, the AR processing module **685** can be used for 3D object manipulation, gesture recognition, facial and facial expression, recognition, etc.

The memory **678** can also include data **687**, including structured data. In some embodiments, the data **687** can include profile data **688**, device data **689** (including device data of one or more devices communicatively coupled with the HIPD **600**, such as device type, hardware, software, configurations, etc.), sensor data **691**, media content data **692**, application data **693**.

It should be appreciated that the HIPD computing system **640** is an example of a computing system within the HIPD **600**, and that the HIPD **600** can have more or fewer components than shown in the HIPD computing system **640**, combine two or more components, and/or have a different configuration and/or arrangement of the components. The various components shown in HIPD computing system **640** are implemented in hardware, software, firmware, or a combination thereof, including one or more signal processing and/or application-specific integrated circuits.

The techniques described above in FIG. **6**A-**6**B can be used with any device used as a human-machine interface controller. In some embodiments, an HIPD **600** can be used in conjunction with one or more wearable device such as a head-wearable device (e.g., AR device **500** and VR device **510**) and/or a wrist-wearable device **400** (or components thereof). In some embodiments, an HIPD **600** can also be used in conjunction with a wearable garment, such as smart textile-based garment **700** (FIGS. **7**A-**7**C). Having thus described example HIPD **600**, attention will now be turned to example feedback devices, such as smart textile-based garment **700**.

Example Smart Textile-Based Garments

FIGS. **7**A and **7**B illustrate an example smart textile-based garment, in accordance with some embodiments. The smart textile-based garment **700** (e.g., wearable gloves, a shirt, a headband, a wristbands, socks, etc.) is configured to communicatively couple with one or more electronic devices, such as a wrist-wearable device **400**, a head-wearable device, an HIPD **600**, a laptop, tablet, and/or other computing devices. The smart textile-based garment **700** can perform various functions and/or operations associated with navigating through user interfaces and selectively opening applications, as well as the functions and/or operations described above with reference to FIGS. **1**A to **1**F. That is, in some embodiments, the smart textile-based garment **700** may be used instead of or in addition to the wrist-wearable device **400** for detecting sequences of handwriting motions, and/or providing feedback to the user **302** about sequences of handwriting motions that have been performed.

The smart textile-based garment **700** can be part of an AR system, such as AR system **300***d* described above in reference to FIGS. **3**D-**1** and **3**D-**2**. The smart textile-based

garment **700** is also configured to provide feedback (e.g., tactile or other haptic feedback) to a user based on the user's interactions with a computing system (e.g., navigation of a user interface, operation of an application (e.g., game vibrations, media responsive haptics), device notifications, etc.)), and/or the user's interactions within an AR environment. In some embodiments, the smart textile-based garment **700** receives instructions from a communicatively coupled device (e.g., the wrist-wearable device **400**, a head-wearable device, and HIPD **600**, etc.) for causing the performance of a feedback response. Alternatively, or in addition, in some embodiments, the smart textile-based garment **700** determines one or more feedback responses to provide a user. The smart textile-based garment **700** can determine the one or more feedback responses based on sensor data captured by one or more of its sensors (e.g., sensors **751**; FIG. **7**C) or communicatively coupled sensors (e.g., sensors of a wrist-wearable device **400**, a head-wearable device, an HIPD **600**, and/or another computing device that is part of the relevant computing system).

Non-limiting examples of the feedback determined by the smart textile-based garment **700** and/or a communicatively coupled device include visual feedback, audio feedback, haptic (e.g., tactile, kinesthetic, etc.) feedback, thermal or temperature feedback, and/or other sensory perceptible feedback. The smart textile-based garment **700** can include respective feedback devices (e.g., a haptic device or assembly **762** or other feedback devices or assemblies) to provide the feedback responses to the user. Similarly, the smart textile-based garment **700** can communicatively couple with another device (and/or the other device's feedback devices) to coordinate the feedback provided to the user. For example, a VR device **510** can present an AR environment to a user and as the user interacts with objects within the AR environment, such as a virtual cup, the smart textile-based garment **700** provides respective response to the user. In particular, the smart textile-based garment **700** can provide haptic feedback to prevent (or, at a minimum, hinder/resist movement of) one or more of the user's fingers from bending past a certain point to simulate the sensation of touching a solid cup and/or thermal feedback to simulate the sensation of a cold or warm beverage.

Additionally or alternatively, in some embodiments, the smart textile-based garment **700** is configured to operate as a controller configured to perform one or more functions or operations associated with interacting with user interfaces and applications of communicatively coupled devices, interacting with an AR environment, interacting with VR environment, and/or operating as a human-machine interface controller, as well as functions and/or operations described above with reference to FIGS. **1**A to **2**.

FIG. **7**A shows one or more haptic assemblies **762** (e.g., first through fourth haptic assemblies **762-1** through **762-4**) on a portion of the smart textile-based garment **700** adjacent to a palmar side of the user's hand and FIG. **7**B shows additional haptic assemblies (e.g., a fifth haptic assembly **762-5**) on a portion of the smart textile-based garment **700** adjacent to a dorsal side of the user's hand. In some embodiments, the haptic assemblies **762** include a mechanism that, at a minimum, provide resistance when a respective haptic assembly **762** is transitioned from a first state (e.g., a first pressurized state (e.g., at atmospheric pressure or deflated)) to a second state (e.g., a second pressurized state (e.g., inflated to a threshold pressure)). In other words, the haptic assemblies **762** described can transition between a first pressurized state and a second pressurized state to provide haptic feedback to the user. Structures of haptic assemblies **762** can be integrated into various devices configured to be in contact or proximity to a user's skin, including, but not limited to devices such as glove worn devices, body worn clothing device, headset devices. Each of the haptic assemblies **762** can be included in or physically coupled to a garment component **704** of the smart textile-based garment **700**. For example, each of the haptic assemblies **762-1**, **762-2**, **762-3**, . . . **762**-N that are physically coupled to the garment component **704** are configured to contact respective phalanges of a user's thumb and fingers.

Due to the ever-changing nature of artificial-reality, the haptic assemblies **762** may be required to transition between the multiple states hundreds, or perhaps thousands of times, during a single use. Thus, the haptic assemblies **762** described herein are durable and designed to quickly transition from state to state. To provide some context, in a first pressurized state, the haptic assemblies **762** do not impede free movement of a portion of the wearer's body. For example, one or more haptic assemblies **762** incorporated into a glove are made from flexible materials that do not impede free movement of the wearer's hand and fingers (e.g., an electrostatic-zipping actuator). The haptic assemblies **762** are configured to conform to a shape of the portion of the wearer's body when in the first pressurized state. However, once in a second pressurized state, the haptic assemblies **762** can be configured to restrict and/or impede free movement of the portion of the wearer's body (e.g., appendages of the user's hand). For example, the respective haptic assembly **762** (or multiple respective haptic assemblies) can restrict movement of a wearer's finger (e.g., prevent the finger from curling or extending) when the haptic assembly **762** is in the second pressurized state. Moreover, once in the second pressurized state, the haptic assemblies **762** may take different shapes, with some haptic assemblies **762** configured to take a planar, rigid shape (e.g., flat, and rigid), while some other haptic assemblies **762** are configured to curve or bend, at least partially.

The smart textile-based garment **700** can be one of a plurality of devices in an AR system (e.g., AR systems of FIGS. **3**A-**3**D-**2**). For example, a user can wear a pair of gloves (e.g., a first type of smart textile-based garment **700**), wear a haptics component of a wrist-wearable device **400** (FIGS. **4**A-**4**B), wear a headband (e.g., a second type of smart textile-based garment **700**), hold an HIPD **600**, etc. As explained above, the haptic assemblies **762** are configured to provide haptic simulations to a wearer of the smart textile-based garments **700**. The garment component **704** of each smart textile-based garment **700** can be one of various articles of clothing (e.g., gloves, socks, shirts, pants, etc.). Thus, a user may wear multiple smart textile-based garments **700** that are each configured to provide haptic stimulations to respective parts of the body where the smart textile-based garments **700** are being worn. Although the smart textile-based garment **700** are described as an individual device, in some embodiments, the smart textile-based garment **700** can be combined with other wearable devices described herein. For example, the smart textile-based garment **700** can form part of a VR device **510** (e.g., a headband portion).

FIG. **7**C shows block diagrams of a computing system **740** of the haptic assemblies **762**, in accordance with some embodiments. The computing system **740** can include one or more peripheral interfaces **750**, one or more power systems **795** (including charger input **796**, PMIC **797**, and battery **798**), one or more controllers **775** (including one or more haptic controllers **776**), one or more processors **777** (as defined above, including any of the examples provided), and memory **778**, which can all be in electronic communication

with each other. For example, the one or more processors **77** can be configured to execute instructions stored in the memory **778**, which can cause a controller of the one or more controllers **775** to cause operations to be performed at one or more peripheral devices of the peripherals interface **750**. In some embodiments, each operation described can occur based on electrical power provided by the power system **795**.

In some embodiments, the peripherals interface **750** can include one or more devices configured to be part of the computing system **740**, many of which have been defined above and/or described with respect to wrist-wearable devices shown in FIGS. **4**A-**6**B. For example, the peripherals interface **750** can include one or more sensors **751**, such as one or more pressure sensors **752**, one or more EMG sensors **756**, one or more IMUs **758**, one or more position sensors **759**, one or more capacitive sensors **760**, one or more force sensors **761**; and/or any other types of sensors defined above or described with respect to any other embodiments discussed herein. In some embodiments, the peripherals interface can include one or more additional peripheral devices, including one or more Wi-Fi and/or Bluetooth devices **768**, an LTE component **769**, a GPS component **770**, a microphone **771**, one or more haptic assemblies **762**, one or more support structures **763** (which can include one or more bladders **764**, one or more manifolds **765**, one or more pressure-changing devices **767**, one or more displays **772**, one or more buttons **773**, one or more speakers **774**, and/or any other types of peripheral devices defined above or described with respect to any other embodiments discussed herein. In some embodiments, computing system **740** includes more or fewer components than those shown in FIG. **7**C.

In some embodiments, each haptic assembly **762** includes a support structure **763** and at least one bladder **764**. The bladder **764** (e.g., a membrane) is a sealed, inflatable pocket made from a durable and puncture-resistant material, such as thermoplastic polyurethane (TPU), a flexible polymer, or the like. The bladder **764** contains a medium (e.g., a fluid such as air, inert gas, or even a liquid) that can be added to or removed from the bladder **764** to change pressure (e.g., fluid pressure) inside the bladder **764**. The support structure **763** is made from a material that is stronger and stiffer than the material of the bladder **764**. A respective support structure **763** coupled to a respective bladder **764** is configured to reinforce the respective bladder **764** as the respective bladder changes shape and size due to changes in pressure (e.g., fluid pressure) inside the bladder. The above example haptic assembly **762** is non-limiting. The haptic assembly **762** can include eccentric rotating mass (ERM), linear resonant actuators (LRA), voice coil motor (VCM), piezo haptic actuator, thermoelectric devices, solenoid actuators, ultrasonic transducers, thermo-resistive heaters, Peltier devices, and/or other devices configured to generate a perceptible response.

The smart textile-based garment **700** also includes a haptic controller **776** and a pressure-changing device **767**. Alternatively, in some embodiments, the computing system **740** is communicatively coupled with a haptic controller **776** and/or pressure-changing device **767** (e.g., in electronic communication with one or more processors **77** of the computing system **740**). The haptic controller **776** is configured to control operation of the pressure-changing device **767**, and in turn operation of the smart textile-based garments **700**. For example, the haptic controller **776** sends one or more signals to the pressure-changing device **767** to activate the pressure-changing device **767** (e.g., turn it on and off). The one or more signals can specify a desired pressure (e.g., pounds per square inch) to be output by the pressure-changing device **767**. Generation of the one or more signals, and in turn the pressure output by the pressure-changing device **767**, can be based on information collected by sensors **751** of the smart textile-based garment **700** and/or other communicatively coupled device. For example, the haptic controller **776** can provide one or more signals, based on collected sensor data, to cause the pressure-changing device **767** to increase the pressure (e.g., fluid pressure) inside a first haptic assembly **762** at a first time, and provide one or more additional signals, based on additional sensor data, to the pressure-changing device **767**, to cause the pressure-changing device **767** to further increase the pressure inside a second haptic assembly **762** at a second time after the first time. Further, the haptic controller **776** can provide one or more signals to cause the pressure-changing device **767** to inflate one or more bladders **764** in a first portion of a smart textile-based garment **700** (e.g., a first finger), while one or more bladders **764** in a second portion of the smart textile-based garment **700** (e.g., a second finger) remain unchanged. Additionally, the haptic controller **776** can provide one or more signals to cause the pressure-changing device **767** to inflate one or more bladders **764** in a first smart textile-based garment **700** to a first pressure and inflate one or more other bladders **764** in the first smart textile-based garment **700** to a second pressure different from the first pressure. Depending on the number of smart textile-based garments **700** serviced by the pressure-changing device **767**, and the number of bladders therein, many different inflation configurations can be achieved through the one or more signals, and the examples above are not meant to be limiting.

The smart textile-based garment **700** may include an optional manifold **765** between the pressure-changing device **767**, the haptic assemblies **762**, and/or other portions of the smart textile-based garment **700**. The manifold **765** may include one or more valves (not shown) that pneumatically couple each of the haptic assemblies **762** with the pressure-changing device **767** via tubing. In some embodiments, the manifold **765** is in communication with the controller **775**, and the controller **775** controls the one or more valves of the manifold **765** (e.g., the controller generates one or more control signals). The manifold **765** is configured to switchably couple the pressure-changing device **767** with one or more haptic assemblies **762** of the smart textile-based garment **700**. In some embodiments, one or more smart textile-based garments **700** or other haptic devices can be coupled in a network of haptic devices, and the manifold **765** can distribute the fluid between the coupled smart textile-based garments **700**.

In some embodiments, instead of using the manifold **765** to pneumatically couple the pressure-changing device **767** with the haptic assemblies **762**, the smart textile-based garment **700** may include multiple pressure-changing devices **767**, where each pressure-changing device **767** is pneumatically coupled directly with a single (or multiple) haptic assembly **762**. In some embodiments, the pressure-changing device **767** and the optional manifold **765** can be configured as part of one or more of the smart textile-based garments **700** (not illustrated) while, in other embodiments, the pressure-changing device **767** and the optional manifold **765** can be configured as external to the smart textile-based garments **700**. In some embodiments, a single pressure-changing device **767** can be shared by multiple smart textile-based garments **700** or other haptic devices. In some embodiments, the pressure-changing device **767** is a pneu-

matic device, hydraulic device, a pneudraulic device, or some other device capable of adding and removing a medium (e.g., fluid, liquid, or gas) from the one or more haptic assemblies **762**.

The memory **778** includes instructions and data, some, or all of which may be stored as non-transitory computer-readable storage media within the memory **778**. For example, the memory **778** can include one or more operating systems **779**, one or more communication interface applications **781**, one or more interoperability modules **784**, one or more AR processing applications **785**, one or more data-management modules **786**, and/or any other types of data defined above or described with respect to FIGS. **4**A-**6**B.

The memory **778** also includes data **788**, which can be used in conjunction with one or more of the applications discussed above. The data **788** can include device data **790**, sensor data **791**, and/or any other types of data defined above or described with respect to FIGS. **4**A-**6**B.

The different components of the computing system **740** (and the smart textile-based garment **700**) shown in FIGS. **7**A-**7**C can be coupled via a wired connection (e.g., via busing). Alternatively, one or more of the devices shown in FIGS. **7**A-**7**C may be wirelessly connected (e.g., via short-range communication signals).

Any data collection performed by the devices described herein and/or any devices configured to perform or cause the performance of the different embodiments described above in reference to any of the Figures, hereinafter the "devices," is done with user consent and in a manner that is consistent with all applicable privacy laws. Users are given options to allow the devices to collect data, as well as the option to limit or deny collection of data by the devices. A user is able to opt in or opt out of any data collection at any time. Further, users are given the option to request the removal of any collected data.

It will be understood that, although the terms "first," "second," etc., may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the claims. As used in the description of the embodiments and the appended claims, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

As used herein, the term "if" can be construed to mean "when" or "upon" or "in response to determining" or "in accordance with a determination" or "in response to detecting," that a stated condition precedent is true, depending on the context. Similarly, the phrase "if it is determined [that a stated condition precedent is true]" or "if [a stated condition precedent is true]" or "when [a stated condition precedent is true]" can be construed to mean "upon determining" or "in response to determining" or "in accordance with a determination" or "upon detecting" or "in response to detecting" that the stated condition precedent is true, depending on the context.

The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the claims to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain principles of operation and practical applications, to thereby enable others skilled in the art.

What is claimed is:

1. A non-transitory computer-readable storage medium comprising instructions for:

obtaining, via one or more sensors of a wearable electronic device in operable communication with a computing system, data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs while wearing the wearable electronic device of the computing system, wherein:

the one or more sensors include a biopotential-signal-sensing component, and the biopotential-signal-sensing component is configured to detect data used to determine respective handwriting motions performed by the user;

identifying, based on at least (i) the data corresponding to the user attempting to perform the sequence of handwriting motions and (ii) the one or more target inputs associated with the sequence of handwriting motions:

a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs, wherein:

the devolved sequence of handwriting motions is a different sequence as compared to the sequence of handwriting motions, and includes fewer handwriting motions as compared to the sequence of handwriting motions; and

causing presentation, via the computing system, of a representation of the devolved sequence of handwriting motions.

2. The non-transitory computer-readable storage medium of claim **1**, further comprising instructions for:

obtaining, via the one or more sensors of the wearable electronic device, other data corresponding to the user attempting to perform the devolved sequence of handwriting motions associated with the respective target input of the one or more target inputs;

identifying, based on at least (i) the other data corresponding to the user attempting to perform the devolved sequence of handwriting motions and (ii) the respective target input of the one or more target inputs:

a refined devolved sequence of handwriting motions to suggest to the user for inputting the respective target input, wherein the refined devolved sequence of handwriting motions is a different sequence as compared to the devolved sequence of handwriting motions identified based on the sequence of handwriting motions; and

causing presentation, via the computing system, of a representation of the refined devolved sequence of handwriting motions.

3. The non-transitory computer-readable storage medium of claim **2**, wherein:

the devolved sequence of handwriting motions is selected from a predefined set of devolved sequences corresponding to particular target inputs; and

the refined devolved sequence is identified via a self-supervised model that is co-adapted based on sequences of handwriting motions performed by the user.

4. The non-transitory computer-readable storage medium of claim **1**, further comprising instructions for:

identifying another devolved sequence of handwriting motions to suggest to the user for inputting a different respective target input of the one or more target inputs, wherein:

the devolved sequence of handwriting motions and the other devolved sequence of handwriting motions individually, and collectively, include fewer handwriting motions as compared to the sequence of handwriting motions.

5. The non-transitory computer-readable storage medium of claim **1**, further comprising instructions for:

in accordance with determining that removing one or more handwriting motions of the sequence of handwriting motions would reduce an accuracy of detecting target inputs by less than a threshold error rate:

identifying the devolved sequence of handwriting motions includes determining the devolved sequence of handwriting motions by removing the one or more handwriting motions from the sequence of handwriting motions that was performed by the user.

6. The non-transitory computer-readable storage medium of claim **1**, further comprising instructions for:

based on the data corresponding to the sequence of handwriting motions from the one or more sensors of the wearable electronic device:

identifying a plurality of devolved sequences of handwriting motions to suggest to the user for inputting the respective target input, including the devolved sequence of handwriting motions; and

causing presentation, via the computing system, of a plurality of representations, each respective representation corresponding to one of the plurality of devolved sequences of handwriting motions.

7. The non-transitory computer-readable storage medium of claim **1**, further comprising instructions for:

based on the data corresponding to the sequence of handwriting motions, applying a co-adaptation to an input detection model used to identify the devolved sequence of handwriting motions, wherein the co-adaptation is based on user-specific aspects of performance of one or more respective handwriting motions of the sequence of handwriting motions; and

using the co-adaptation to the input detection model to detect a different sequence of handwriting motions corresponding to one or more different target inputs.

8. A method, comprising:

obtaining, via one or more sensors of a wearable electronic device in operable communication with a computing system, data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs while wearing the wearable electronic device of the computing system, wherein:

the one or more sensors include a biopotential-signal-sensing component, and the biopotential-signal-sensing component is configured to detect data used to determine respective handwriting motions performed by the user;

identifying, based on at least (i) the data corresponding to the user attempting to perform the sequence of handwriting motions and (ii) the one or more target inputs associated with the sequence of handwriting motions:

a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs, wherein:

the devolved sequence of handwriting motions is a different sequence as compared to the sequence of handwriting motions, and includes fewer handwriting motions as compared to the sequence of handwriting motions; and

causing presentation, via the computing system, of a representation of the devolved sequence of handwriting motions.

9. The method of claim **8**, further comprising:

obtaining, via the one or more sensors of the wearable electronic device, other data corresponding to the user attempting to perform the devolved sequence of handwriting motions associated with the respective target input of the one or more target inputs;

identifying, based on at least (i) the other data corresponding to the user attempting to perform the devolved sequence of handwriting motions and (ii) the respective target input of the one or more target inputs:

a refined devolved sequence of handwriting motions to suggest to the user for inputting the respective target input, wherein the refined devolved sequence of handwriting motions is a different sequence as compared to the devolved sequence of handwriting motions identified based on the sequence of handwriting motions; and

causing presentation, via the computing system, of a representation of the refined devolved sequence of handwriting motions.

10. The method of claim **9**, wherein:

the devolved sequence of handwriting motions is selected from a predefined set of devolved sequences corresponding to particular target inputs; and

the refined devolved sequence is identified via a self-supervised model that is co-adapted based on sequences of handwriting motions performed by the user.

11. The method of claim **8**, further comprising:

identifying another devolved sequence of handwriting motions to suggest to the user for inputting a different respective target input of the one or more target inputs, wherein:

the devolved sequence of handwriting motions and the other devolved sequence of handwriting motions individually, and collectively, include fewer handwriting motions as compared to the sequence of handwriting motions.

12. The method of claim **8**, further comprising:

in accordance with determining that removing one or more handwriting motions of the sequence of handwriting motions would reduce an accuracy of detecting target inputs by less than a threshold error rate:

identifying the devolved sequence of handwriting motions includes determining the devolved sequence of handwriting motions by removing the one or more handwriting motions from the sequence of handwriting motions that was performed by the user.

13. The method of claim **8**, further comprising:

based on the data corresponding to the sequence of handwriting motions from the one or more sensors of the wearable electronic device:

identifying a plurality of devolved sequences of handwriting motions to suggest to the user for inputting the respective target input, including the devolved sequence of handwriting motions; and

causing presentation, via the computing system, of a plurality of representations, each respective representation corresponding to one of the plurality of devolved sequences of handwriting motions.

14. The method of claim **8**, further comprising:

based on the data corresponding to the sequence of handwriting motions, applying a co-adaptation to an input detection model used to identify the devolved sequence of handwriting motions, wherein the co-adaptation is based on user-specific aspects of performance of one or more respective handwriting motions of the sequence of handwriting motions; and

using the co-adaptation to the input detection model to detect a different sequence of handwriting motions corresponding to one or more different target inputs.

15. A computing system, comprising:

a wearable electronic device comprising:

one or more sensors in operable communication with the computing system; and

one or more processors configured to:

obtain, via the one or more sensors of the wearable electronic device of the computing system, data corresponding to a user attempting to perform a sequence of handwriting motions associated with one or more target inputs while wearing the wearable electronic device of the computing system, wherein:

the one or more sensors include a biopotential-signal-sensing component, and the biopotential-signal-sensing component is configured to detect data used to determine respective handwriting motions performed by the user;

identify, based on at least (i) the data corresponding to the user attempting to perform the sequence of handwriting motions and (ii) the one or more target inputs associated with the sequence of handwriting motions:

a devolved sequence of handwriting motions to suggest to the user for inputting a respective target input of the one or more target inputs, wherein:

the devolved sequence of handwriting motions is a different sequence as compared to the sequence of handwriting motions, and includes fewer handwriting motions as compared to the sequence of handwriting motions; and

cause presentation, via the computing system, of a representation of the devolved sequence of handwriting motions.

16. The computing system of claim **15**, wherein the one or more processors are further configured to:

obtain, via the one or more sensors of the wearable electronic device, other data corresponding to the user attempting to perform the devolved sequence of handwriting motions associated with the respective target input of the one or more target inputs;

identify, based on at least (i) the other data corresponding to the user attempting to perform the devolved sequence of handwriting motions and (ii) the respective target input of the one or more target inputs:

a refined devolved sequence of handwriting motions to suggest to the user for inputting the respective target input, wherein the refined devolved sequence of handwriting motions is a different sequence as compared to the devolved sequence of handwriting motions identified based on the sequence of handwriting motions; and

cause presentation, via the computing system, of a representation of the refined devolved sequence of handwriting motions.

17. The computing system of claim **16**, wherein:

the devolved sequence of handwriting motions is selected from a predefined set of devolved sequences corresponding to particular target inputs; and

the refined devolved sequence is identified via a self-supervised model that is co-adapted based on sequences of handwriting motions performed by the user.

18. The computing system of claim **15**, wherein the one or more processors are further configured to:

identify another devolved sequence of handwriting motions to suggest to the user for inputting a different respective target input of the one or more target inputs, wherein:

the devolved sequence of handwriting motions and the other devolved sequence of handwriting motions individually, and collectively, include fewer handwriting motions as compared to the sequence of handwriting motions.

19. The computing system of claim **15**, wherein the one or more processors are further configured to:

in accordance with determining that removing one or more handwriting motions of the sequence of handwriting motions would reduce an accuracy of detecting target inputs by less than a threshold error rate:

identify the devolved sequence of handwriting motions includes determining the devolved sequence of handwriting motions by removing the one or more handwriting motions from the sequence of handwriting motions that was performed by the user.

20. The computing system of claim **15**, wherein the one or more processors are further configured to:

based on the data corresponding to the sequence of handwriting motions from the one or more sensors of the wearable electronic device:

identify a plurality of devolved sequences of handwriting motions to suggest to the user for inputting the respective target input, including the devolved sequence of handwriting motions; and

cause presentation, via the computing system, of a plurality of representations, each respective representation corresponding to one of the plurality of devolved sequences of handwriting motions.

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