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(54) **MOTION-BASED BEHAVIOR IDENTIFICATION FOR CONTROLLING THERAPY**

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(73) Assignee: **Medtronic, Inc.**, Minneapolis, MN (US)

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A61B 5/1468	(2006.01)
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A61B 5/11	(2006.01)
A61B 5/0402	(2006.01)

(52) **U.S. Cl.**

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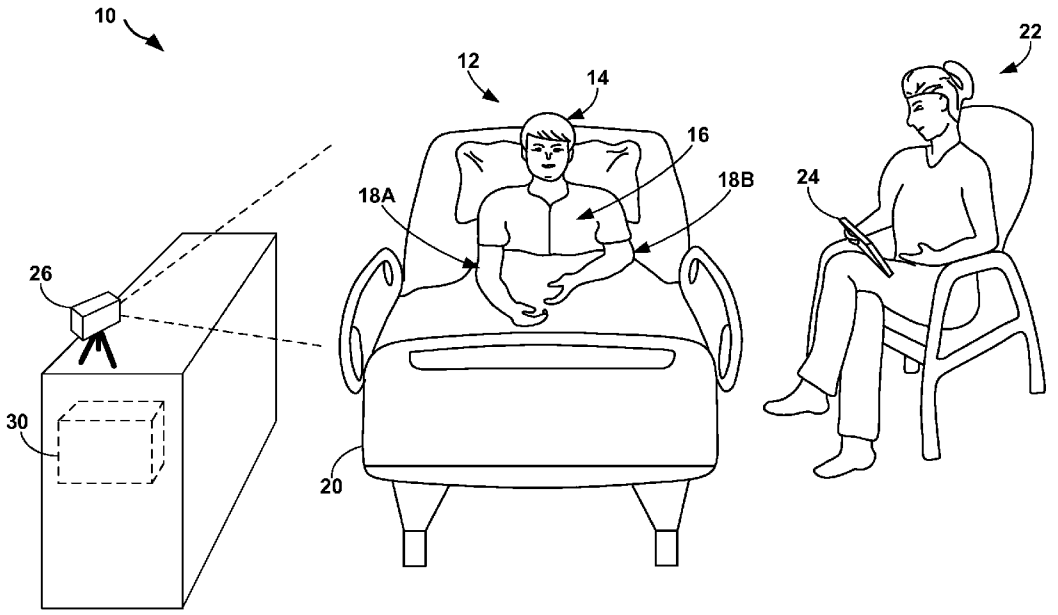
USPC **600/301**; 600/476

(57) **ABSTRACT**

Devices, systems, and techniques for analyzing video information to objectively identify patient behavior are disclosed. A system may analyze obtained video information of patient motion during a period of time to track one or more anatomical regions through a plurality of frames of the video information and calculate one or more movement parameters of the one or more anatomical regions. The system may also compare the one or more movement parameters to respective criteria for each of a plurality of predetermined patient behaviors and identify the patient behaviors that occurred during the period of time. In some examples, a device may control therapy delivery according to the identified patient behaviors and/or sensed parameters previously calibrated based on the identified patient behaviors.



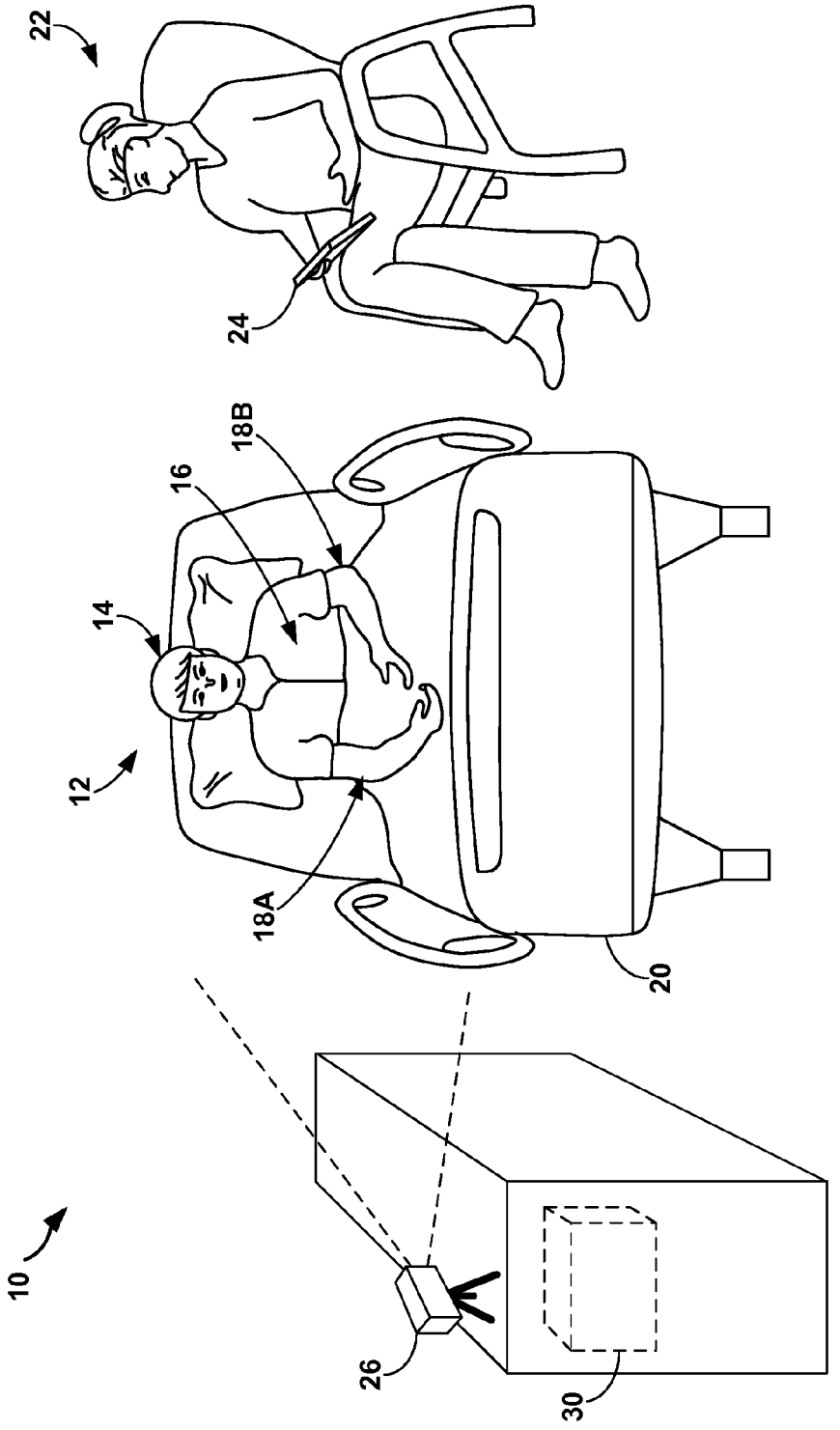


FIG. 1

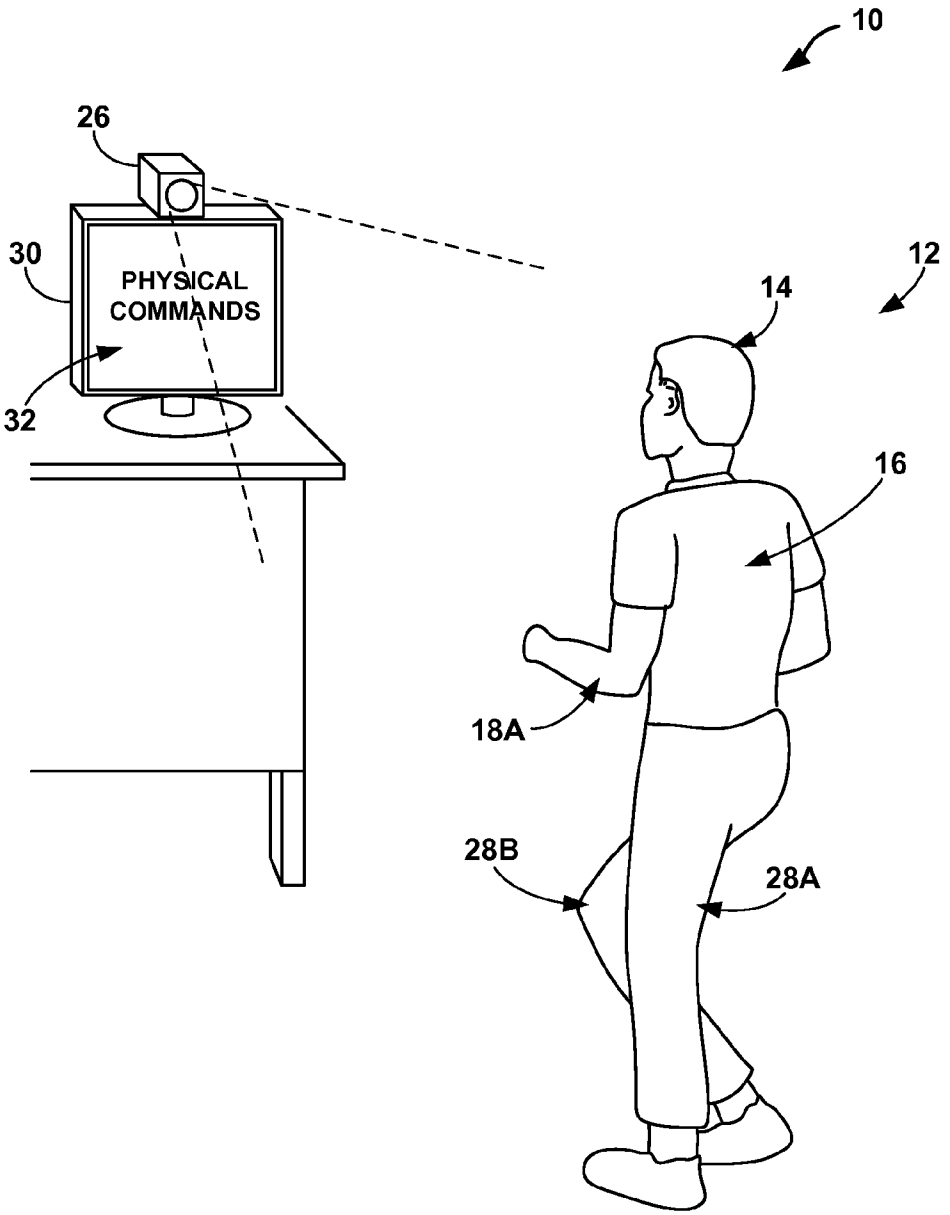
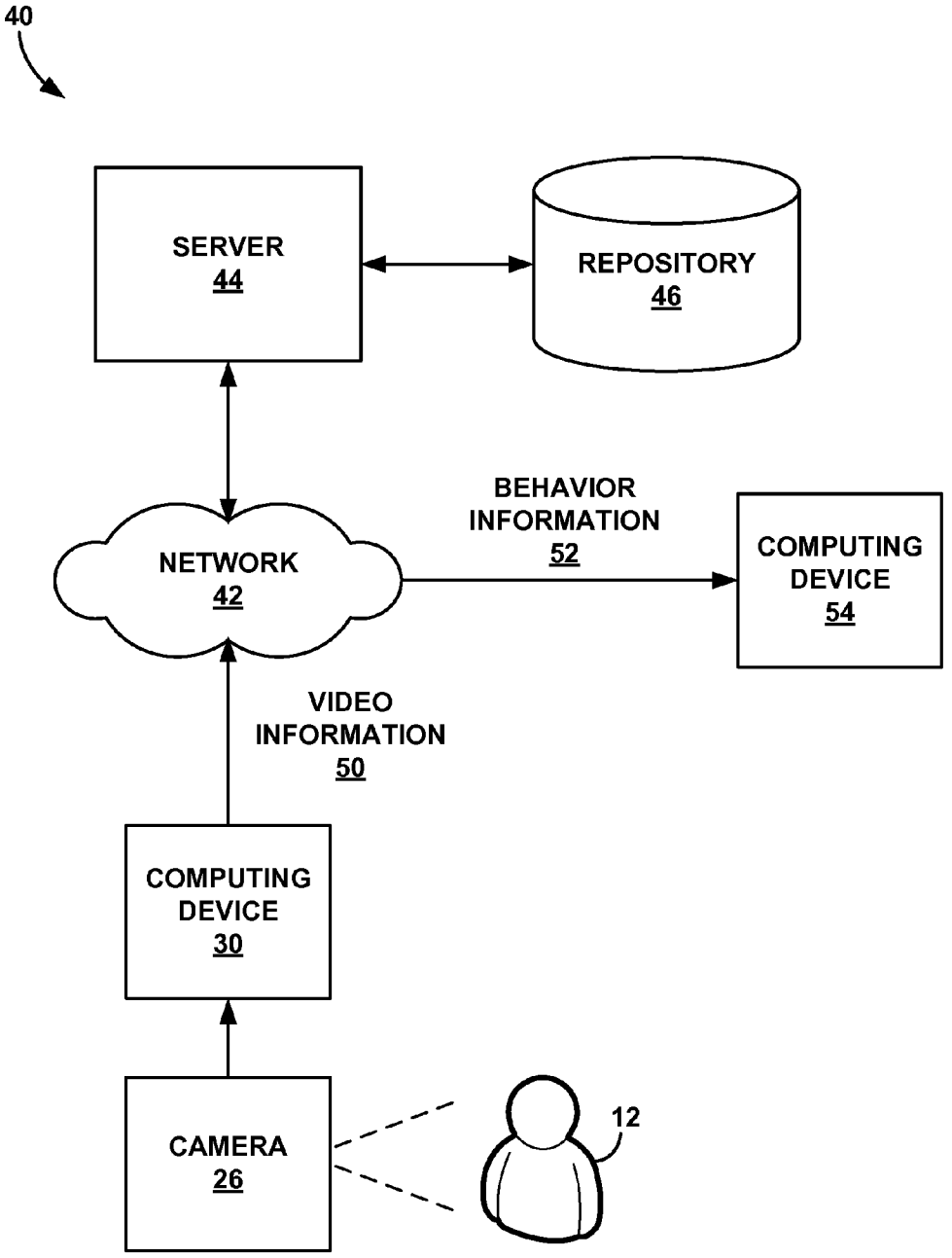


FIG. 2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SERVER
44
REPOSITORY
46
NETWORK
42
BEHAVIOR
INFORMATION
52
COMPUTING
DEVICE
54
VIDEO
INFORMATION
50
COMPUTING
DEVICE
30
CAMERA
26
12

FIG. 3

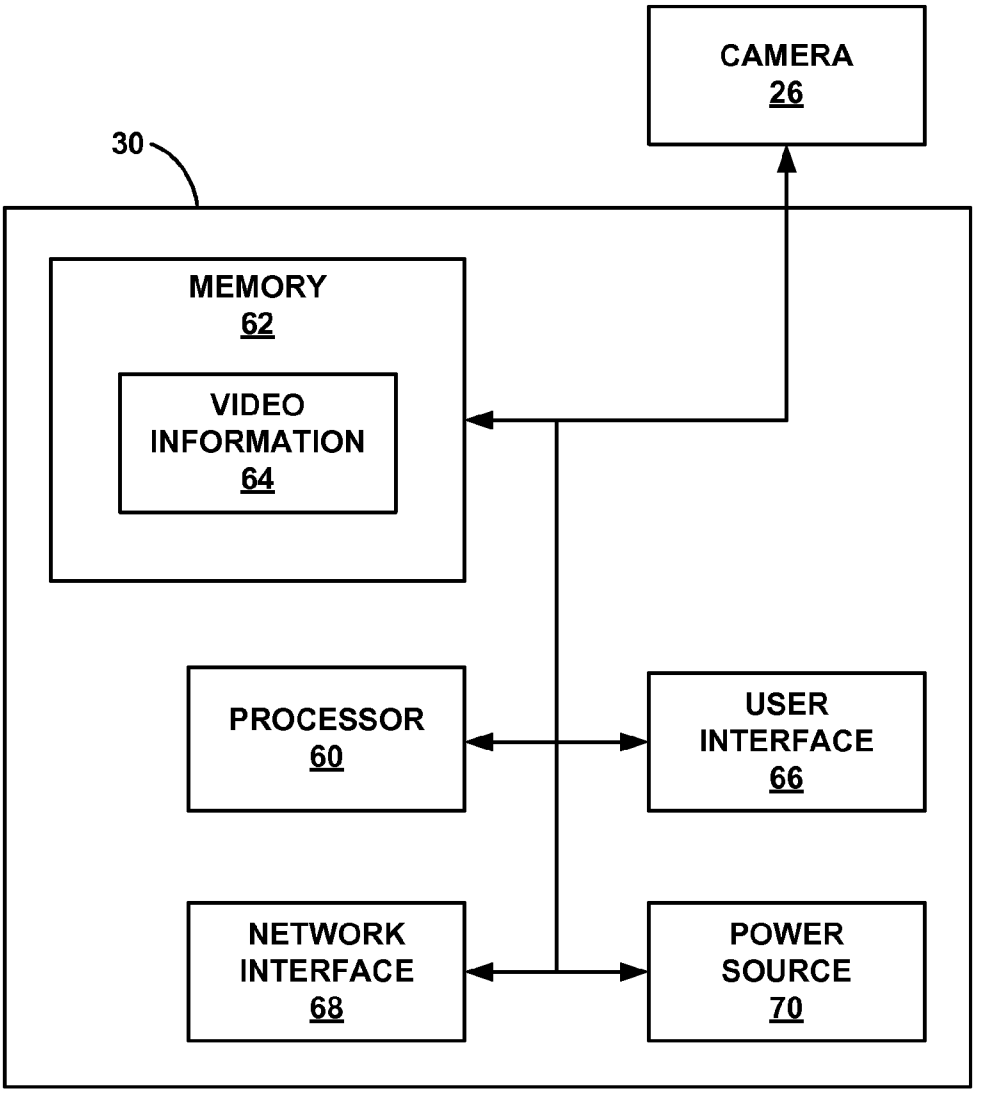

CAMERA
26
30
MEMORY
62
VIDEO
INFORMATION
64
PROCESSOR
60
USER
INTERFACE
66
NETWORK
INTERFACE
68
POWER
SOURCE
70

FIG. 4

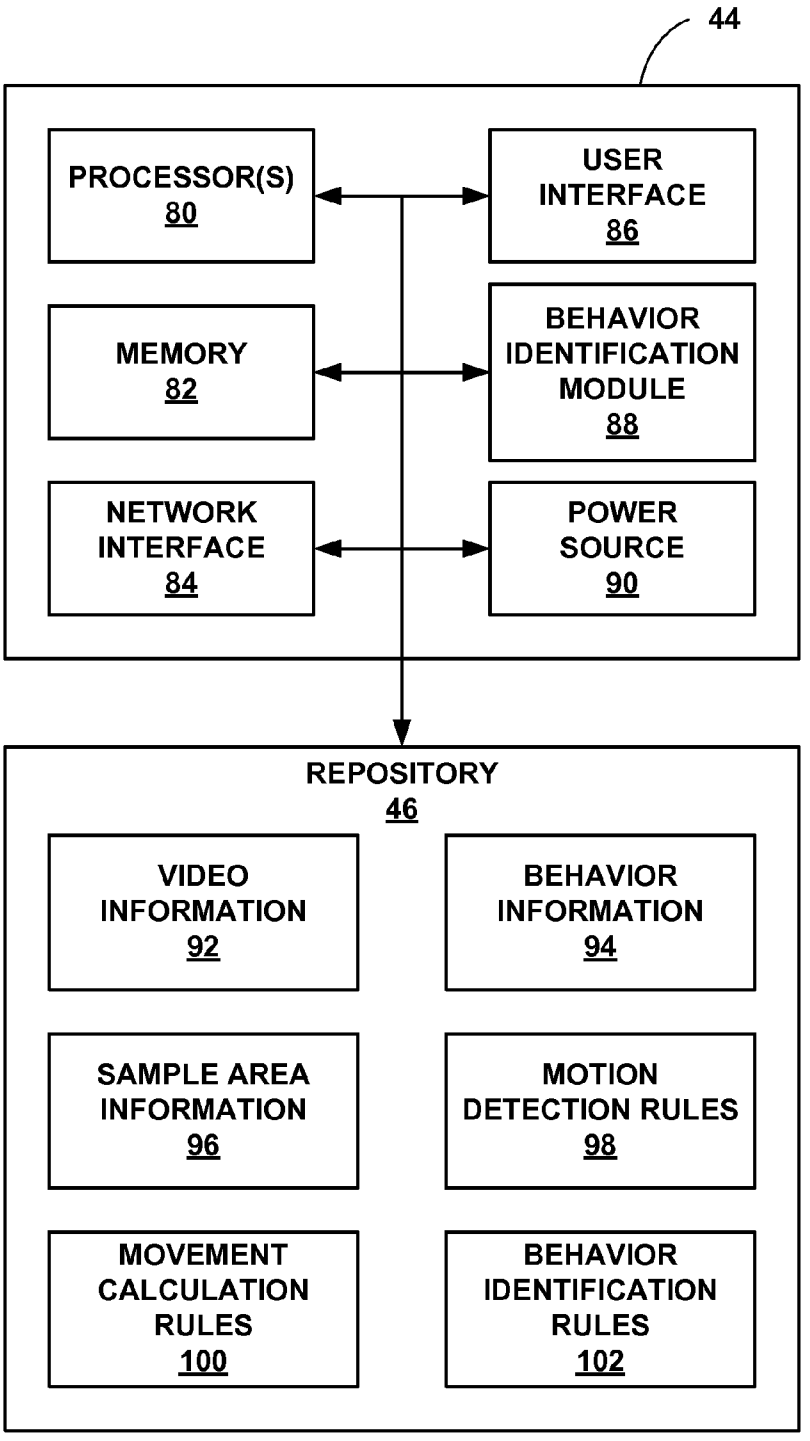

44
PROCESSOR(S)
80
USER
INTERFACE
86
MEMORY
82
BEHAVIOR
IDENTIFICATION
MODULE
88
NETWORK
INTERFACE
84
POWER
SOURCE
90
REPOSITORY
46
VIDEO
INFORMATION
92
BEHAVIOR
INFORMATION
94
SAMPLE AREA
INFORMATION
96
MOTION
DETECTION RULES
98
MOVEMENT
CALCULATION
RULES
100
BEHAVIOR
IDENTIFICATION
RULES
102

FIG. 5

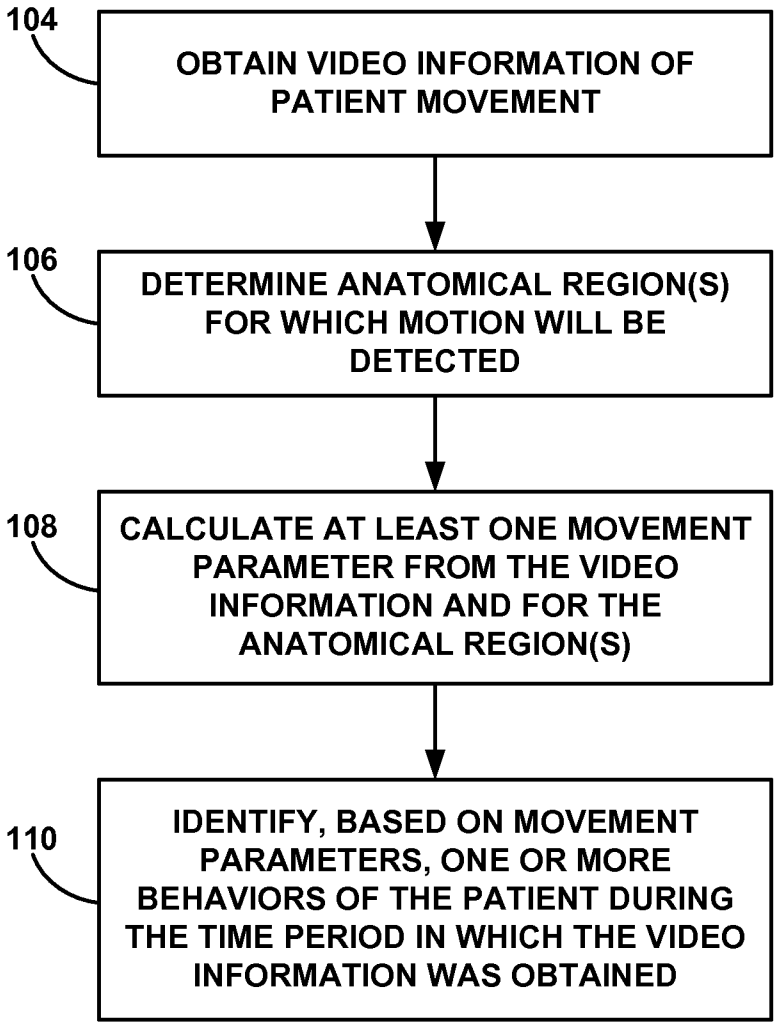

104
OBTAIN VIDEO INFORMATION OF PATIENT MOVEMENT
106
DETERMINE ANATOMICAL REGION(S) FOR WHICH MOTION WILL BE DETECTED
108
CALCULATE AT LEAST ONE MOVEMENT PARAMETER FROM THE VIDEO INFORMATION AND FOR THE ANATOMICAL REGION(S)
110
IDENTIFY, BASED ON MOVEMENT PARAMETERS, ONE OR MORE BEHAVIORS OF THE PATIENT DURING THE TIME PERIOD IN WHICH THE VIDEO INFORMATION WAS OBTAINED

FIG. 6

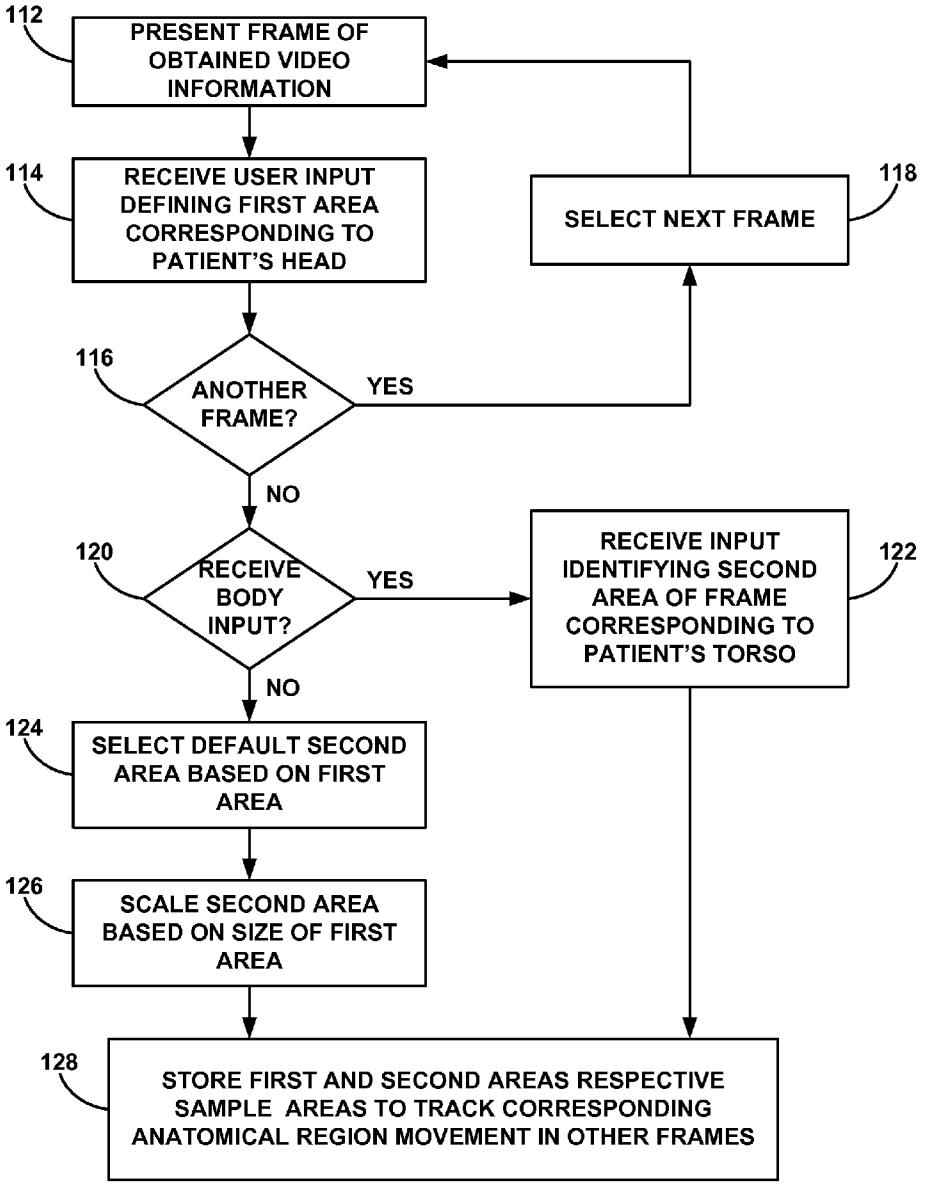

112
PRESENT FRAME OF OBTAINED VIDEO INFORMATION
114
RECEIVE USER INPUT DEFINING FIRST AREA CORRESPONDING TO PATIENT'S HEAD
116
ANOTHER FRAME?
YES
NO
118
SELECT NEXT FRAME
120
RECEIVE BODY INPUT?
YES
NO
122
RECEIVE INPUT IDENTIFYING SECOND AREA OF FRAME CORRESPONDING TO PATIENT'S TORSO
124
SELECT DEFAULT SECOND AREA BASED ON FIRST AREA
126
SCALE SECOND AREA BASED ON SIZE OF FIRST AREA
128
STORE FIRST AND SECOND AREAS RESPECTIVE SAMPLE AREAS TO TRACK CORRESPONDING ANATOMICAL REGION MOVEMENT IN OTHER FRAMES

FIG. 7

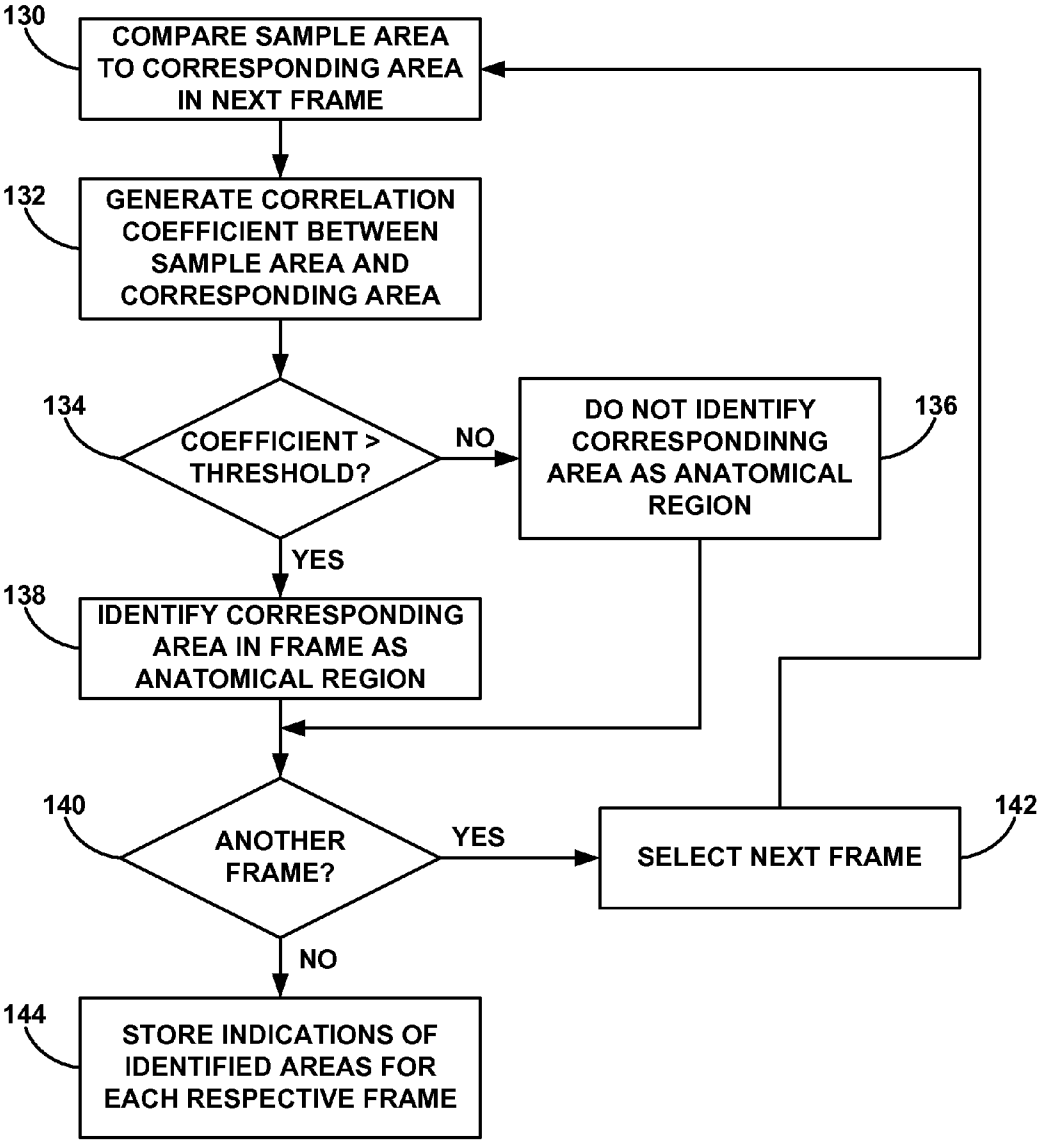

130
COMPARE SAMPLE AREA TO CORRESPONDING AREA IN NEXT FRAME
132
GENERATE CORRELATION COEFFICIENT BETWEEN SAMPLE AREA AND CORRESPONDING AREA
134
COEFFICIENT > THRESHOLD?
NO
DO NOT IDENTIFY CORRESPONDINNG AREA AS ANATOMICAL REGION
136
YES
138
IDENTIFY CORRESPONDING AREA IN FRAME AS ANATOMICAL REGION
140
ANOTHER FRAME?
YES
SELECT NEXT FRAME
142
NO
144
STORE INDICATIONS OF IDENTIFIED AREAS FOR EACH RESPECTIVE FRAME

FIG. 8

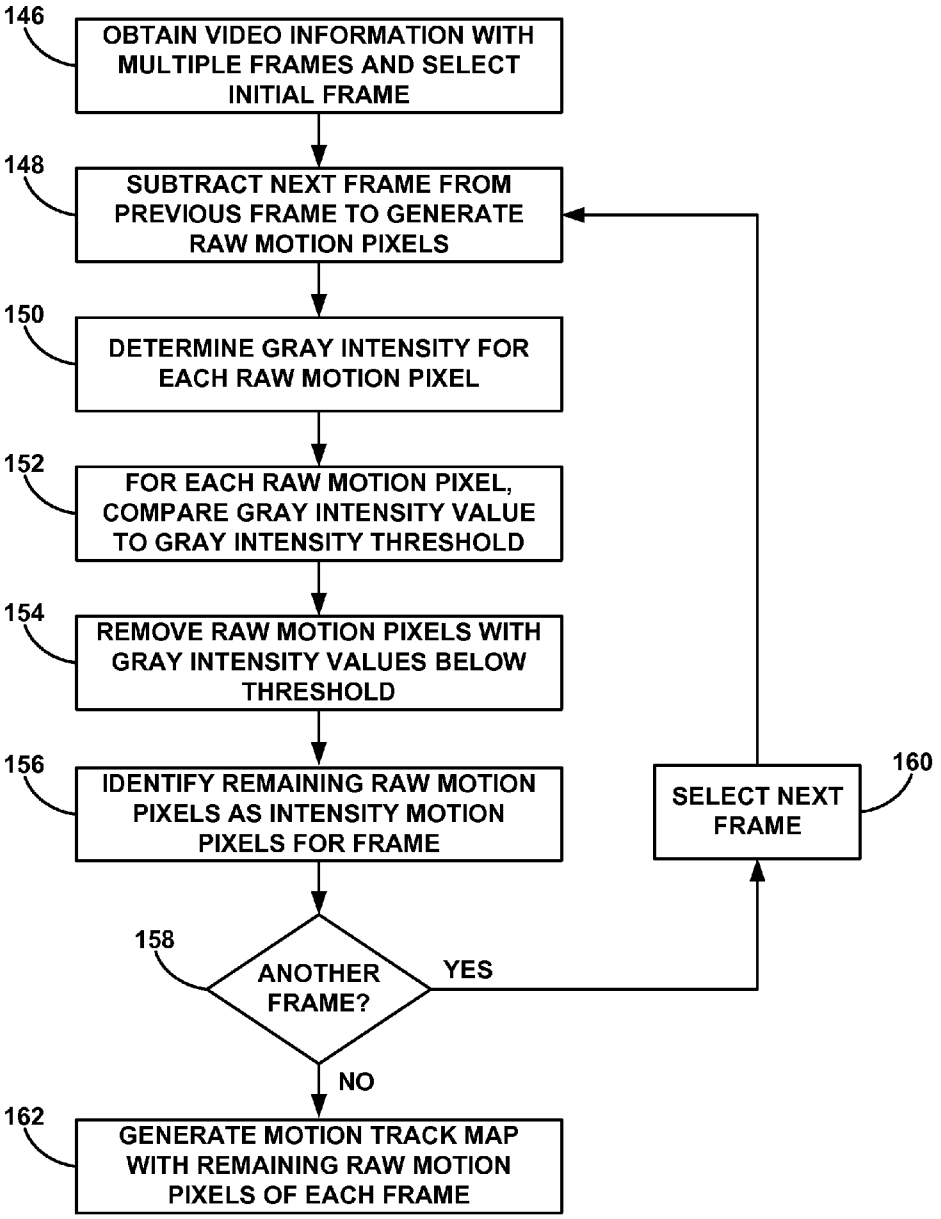

146
OBTAIN VIDEO INFORMATION WITH MULTIPLE FRAMES AND SELECT INITIAL FRAME
148
SUBTRACT NEXT FRAME FROM PREVIOUS FRAME TO GENERATE RAW MOTION PIXELS
150
DETERMINE GRAY INTENSITY FOR EACH RAW MOTION PIXEL
152
FOR EACH RAW MOTION PIXEL, COMPARE GRAY INTENSITY VALUE TO GRAY INTENSITY THRESHOLD
154
REMOVE RAW MOTION PIXELS WITH GRAY INTENSITY VALUES BELOW THRESHOLD
156
IDENTIFY REMAINING RAW MOTION PIXELS AS INTENSITY MOTION PIXELS FOR FRAME
158
ANOTHER FRAME?
YES
NO
160
SELECT NEXT FRAME
162
GENERATE MOTION TRACK MAP WITH REMAINING RAW MOTION PIXELS OF EACH FRAME

FIG. 9

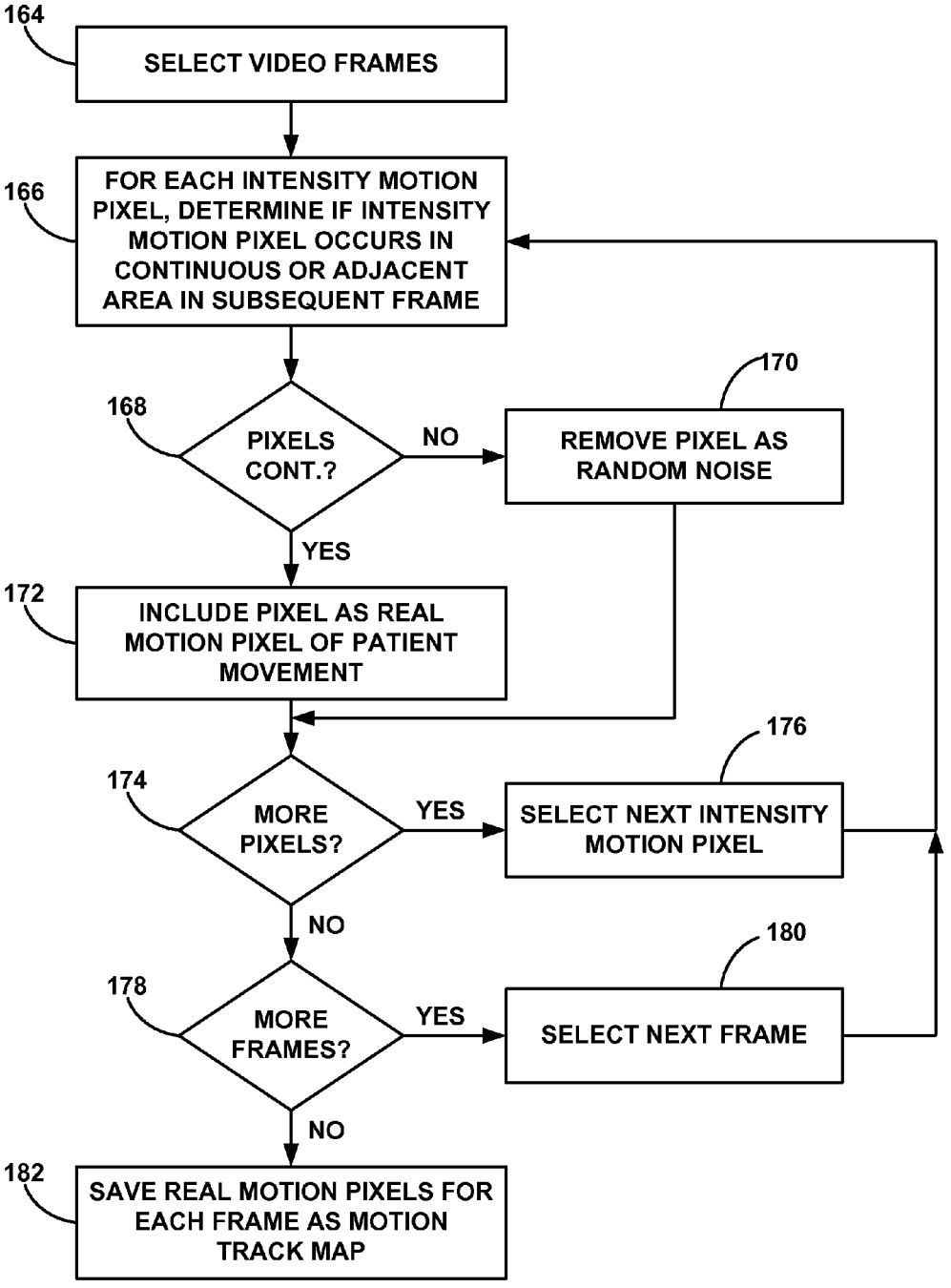

164
SELECT VIDEO FRAMES
166
FOR EACH INTENSITY MOTION PIXEL, DETERMINE IF INTENSITY MOTION PIXEL OCCURS IN CONTINUOUS OR ADJACENT AREA IN SUBSEQUENT FRAME
168
PIXELS CONT.?
NO
170
REMOVE PIXEL AS RANDOM NOISE
YES
172
INCLUDE PIXEL AS REAL MOTION PIXEL OF PATIENT MOVEMENT
174
MORE PIXELS?
YES
176
SELECT NEXT INTENSITY MOTION PIXEL
NO
178
MORE FRAMES?
YES
180
SELECT NEXT FRAME
NO
182
SAVE REAL MOTION PIXELS FOR EACH FRAME AS MOTION TRACK MAP

FIG. 10

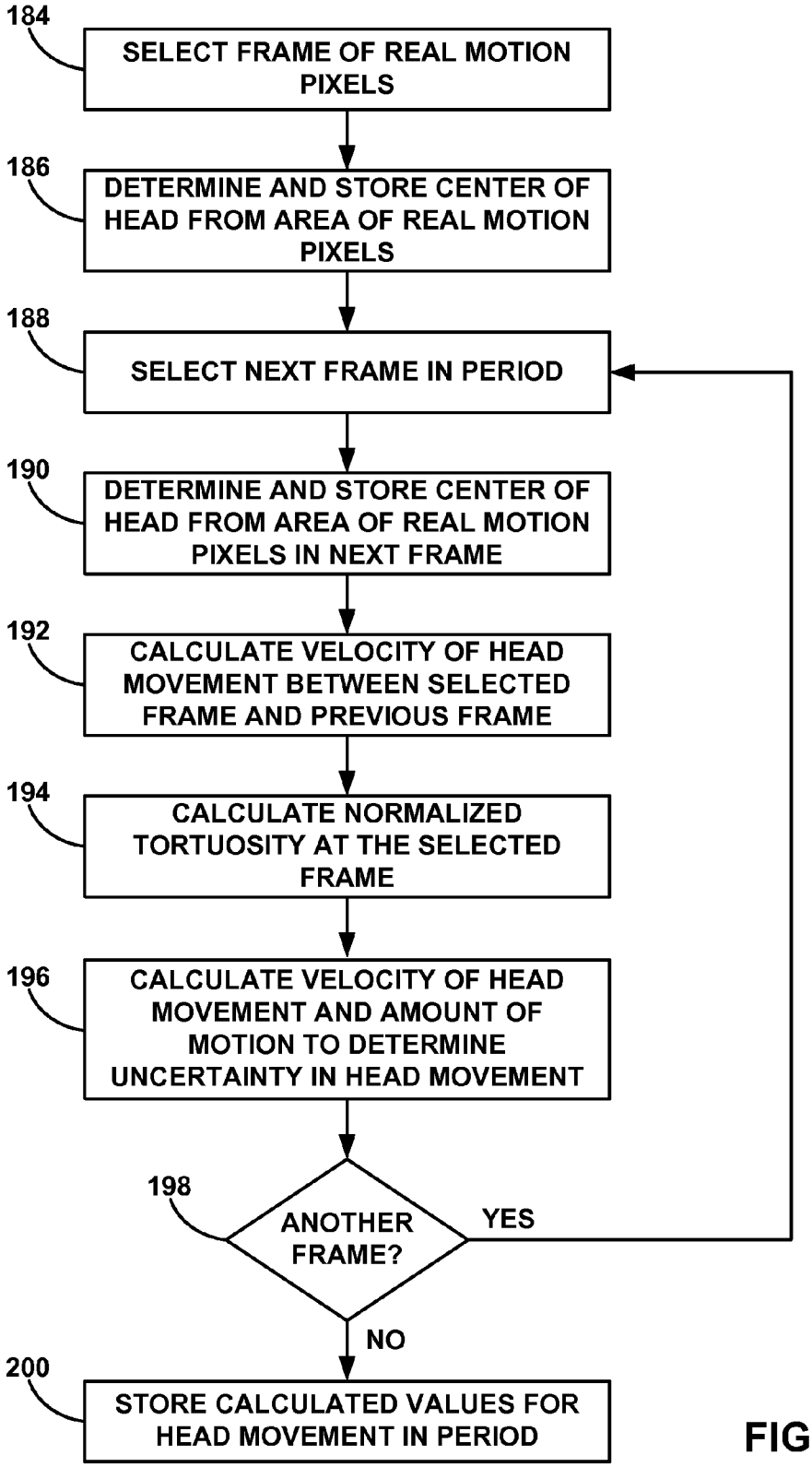

184
SELECT FRAME OF REAL MOTION PIXELS
186
DETERMINE AND STORE CENTER OF HEAD FROM AREA OF REAL MOTION PIXELS
188
SELECT NEXT FRAME IN PERIOD
190
DETERMINE AND STORE CENTER OF HEAD FROM AREA OF REAL MOTION PIXELS IN NEXT FRAME
192
CALCULATE VELOCITY OF HEAD MOVEMENT BETWEEN SELECTED FRAME AND PREVIOUS FRAME
194
CALCULATE NORMALIZED TORTUOSITY AT THE SELECTED FRAME
196
CALCULATE VELOCITY OF HEAD MOVEMENT AND AMOUNT OF MOTION TO DETERMINE UNCERTAINTY IN HEAD MOVEMENT
198
ANOTHER FRAME?
YES
NO
200
STORE CALCULATED VALUES FOR HEAD MOVEMENT IN PERIOD

FIG. 11

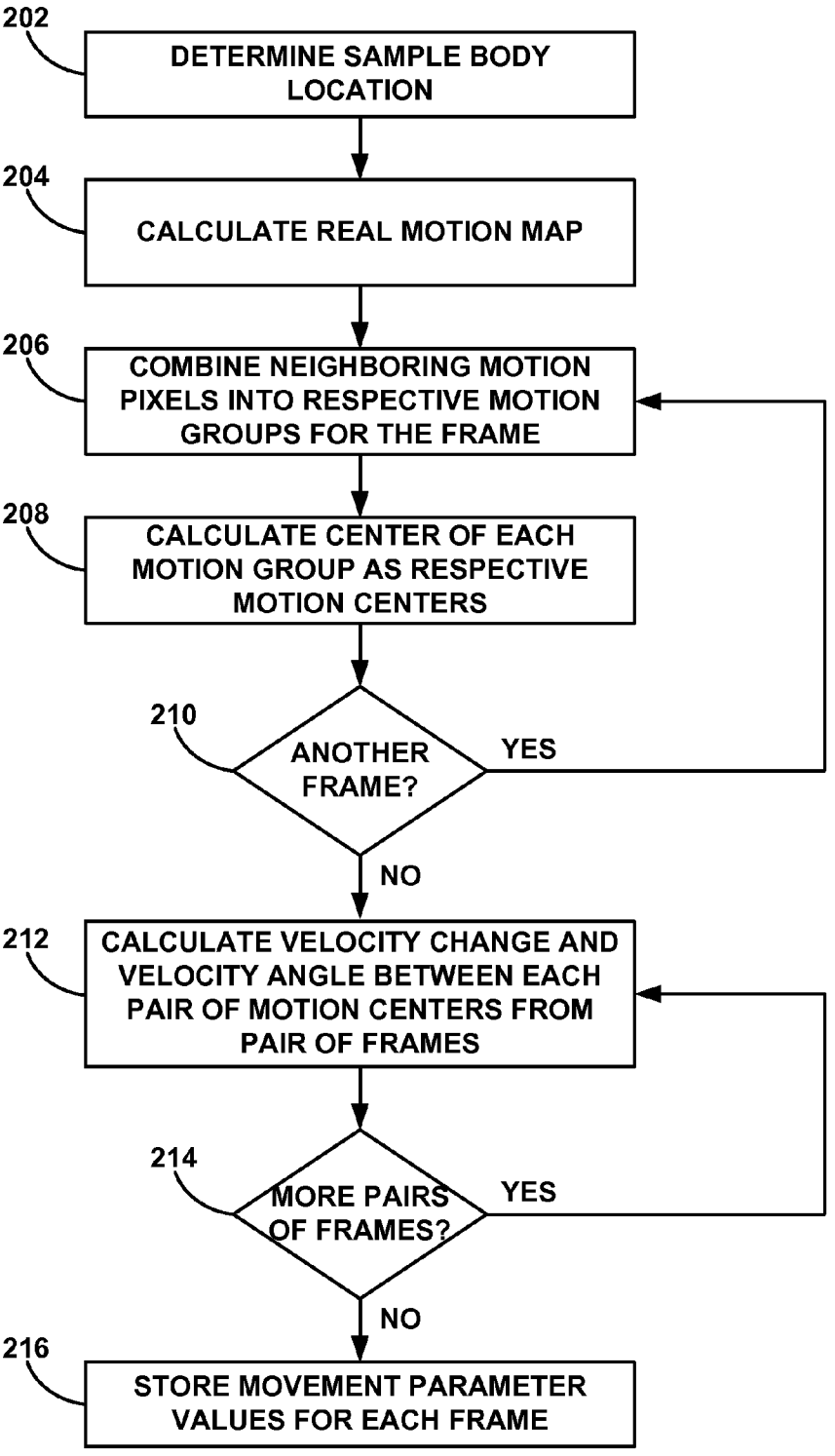

202
DETERMINE SAMPLE BODY LOCATION
204
CALCULATE REAL MOTION MAP
206
COMBINE NEIGHBORING MOTION PIXELS INTO RESPECTIVE MOTION GROUPS FOR THE FRAME
208
CALCULATE CENTER OF EACH MOTION GROUP AS RESPECTIVE MOTION CENTERS
210
ANOTHER FRAME?
YES
NO
212
CALCULATE VELOCITY CHANGE AND VELOCITY ANGLE BETWEEN EACH PAIR OF MOTION CENTERS FROM PAIR OF FRAMES
214
MORE PAIRS OF FRAMES?
YES
NO
216
STORE MOVEMENT PARAMETER VALUES FOR EACH FRAME

FIG. 12

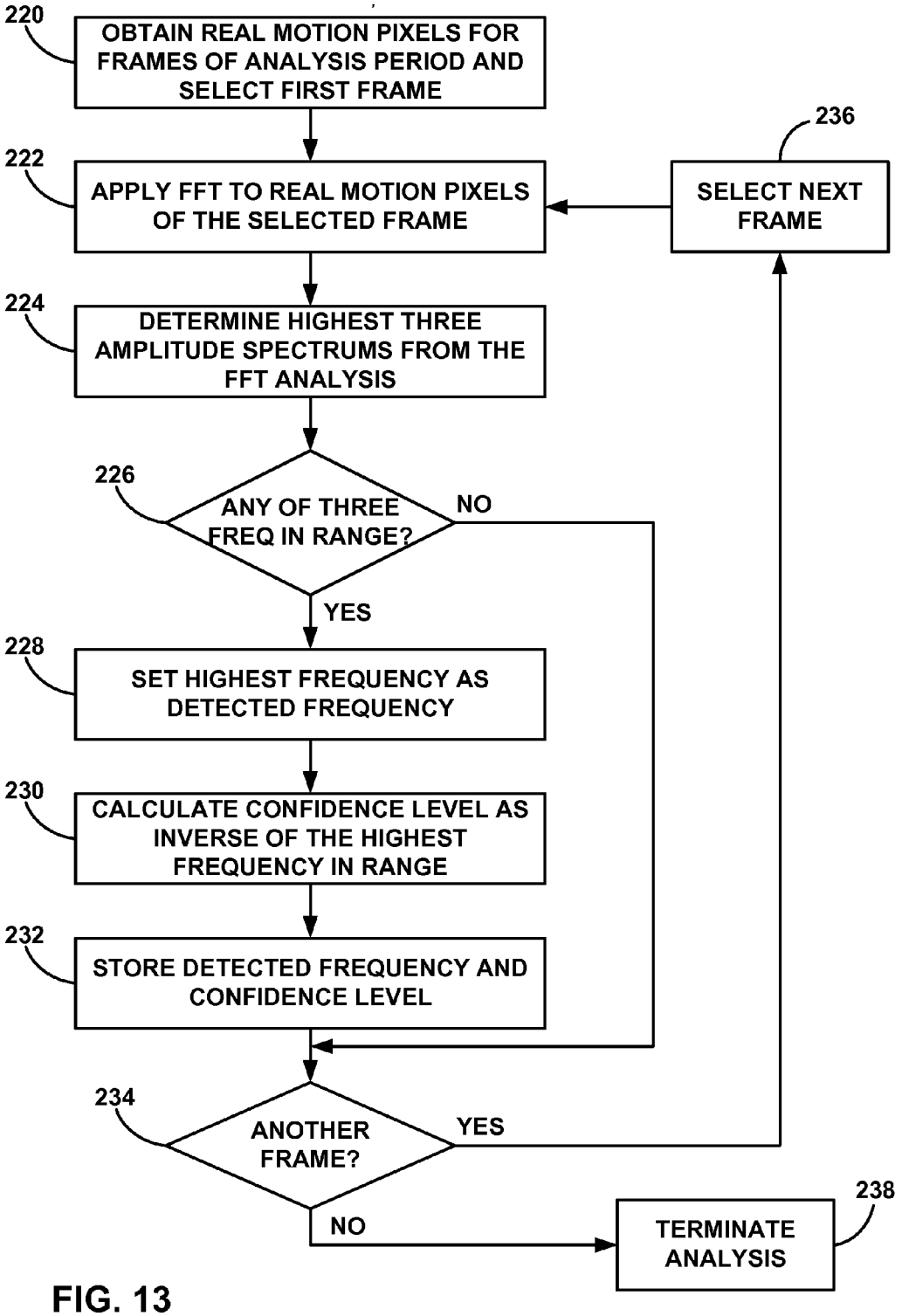

220
OBTAIN REAL MOTION PIXELS FOR FRAMES OF ANALYSIS PERIOD AND SELECT FIRST FRAME
222
APPLY FFT TO REAL MOTION PIXELS OF THE SELECTED FRAME
236
SELECT NEXT FRAME
224
DETERMINE HIGHEST THREE AMPLITUDE SPECTRUMS FROM THE FFT ANALYSIS
226
ANY OF THREE FREQ IN RANGE?
NO
YES
228
SET HIGHEST FREQUENCY AS DETECTED FREQUENCY
230
CALCULATE CONFIDENCE LEVEL AS INVERSE OF THE HIGHEST FREQUENCY IN RANGE
232
STORE DETECTED FREQUENCY AND CONFIDENCE LEVEL
234
ANOTHER FRAME?
YES
NO
238
TERMINATE ANALYSIS

FIG. 13

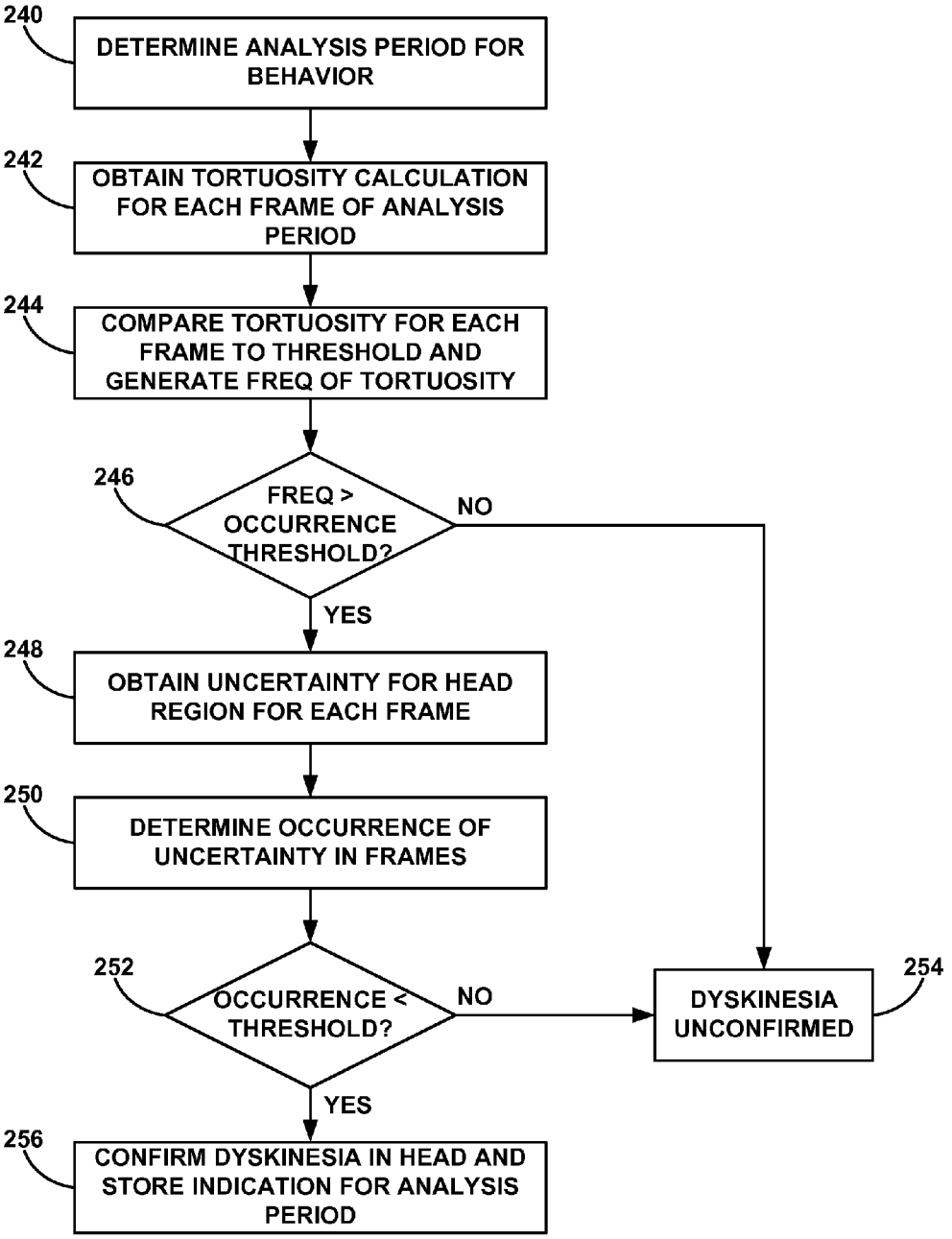

240
DETERMINE ANALYSIS PERIOD FOR BEHAVIOR
242
OBTAIN TORTUOSITY CALCULATION FOR EACH FRAME OF ANALYSIS PERIOD
244
COMPARE TORTUOSITY FOR EACH FRAME TO THRESHOLD AND GENERATE FREQ OF TORTUOSITY
246
FREQ > OCCURRENCE THRESHOLD?
NO
YES
248
OBTAIN UNCERTAINTY FOR HEAD REGION FOR EACH FRAME
250
DETERMINE OCCURRENCE OF UNCERTAINTY IN FRAMES
252
OCCURRENCE < THRESHOLD?
NO
254
DYSKINESIA UNCONFIRMED
YES
256
CONFIRM DYSKINESIA IN HEAD AND STORE INDICATION FOR ANALYSIS PERIOD

FIG. 14

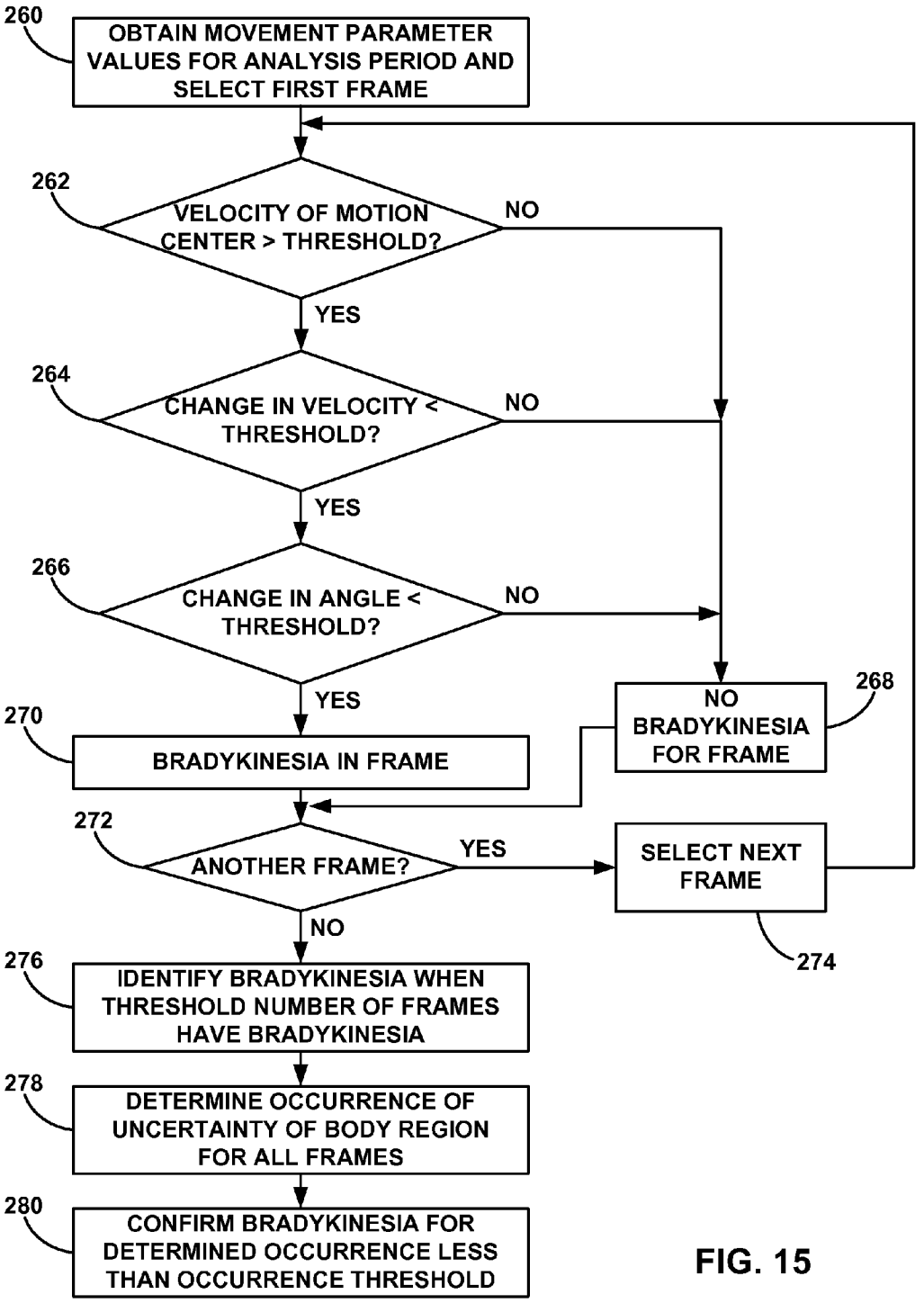

260
OBTAIN MOVEMENT PARAMETER VALUES FOR ANALYSIS PERIOD AND SELECT FIRST FRAME
262
VELOCITY OF MOTION CENTER > THRESHOLD?
NO
YES
264
CHANGE IN VELOCITY < THRESHOLD?
NO
YES
266
CHANGE IN ANGLE < THRESHOLD?
NO
YES
268
NO BRADYKINESIA FOR FRAME
270
BRADYKINESIA IN FRAME
272
ANOTHER FRAME?
YES
SELECT NEXT FRAME
274
NO
276
IDENTIFY BRADYKINESIA WHEN THRESHOLD NUMBER OF FRAMES HAVE BRADYKINESIA
278
DETERMINE OCCURRENCE OF UNCERTAINTY OF BODY REGION FOR ALL FRAMES
280
CONFIRM BRADYKINESIA FOR DETERMINED OCCURRENCE LESS THAN OCCURRENCE THRESHOLD

FIG. 15

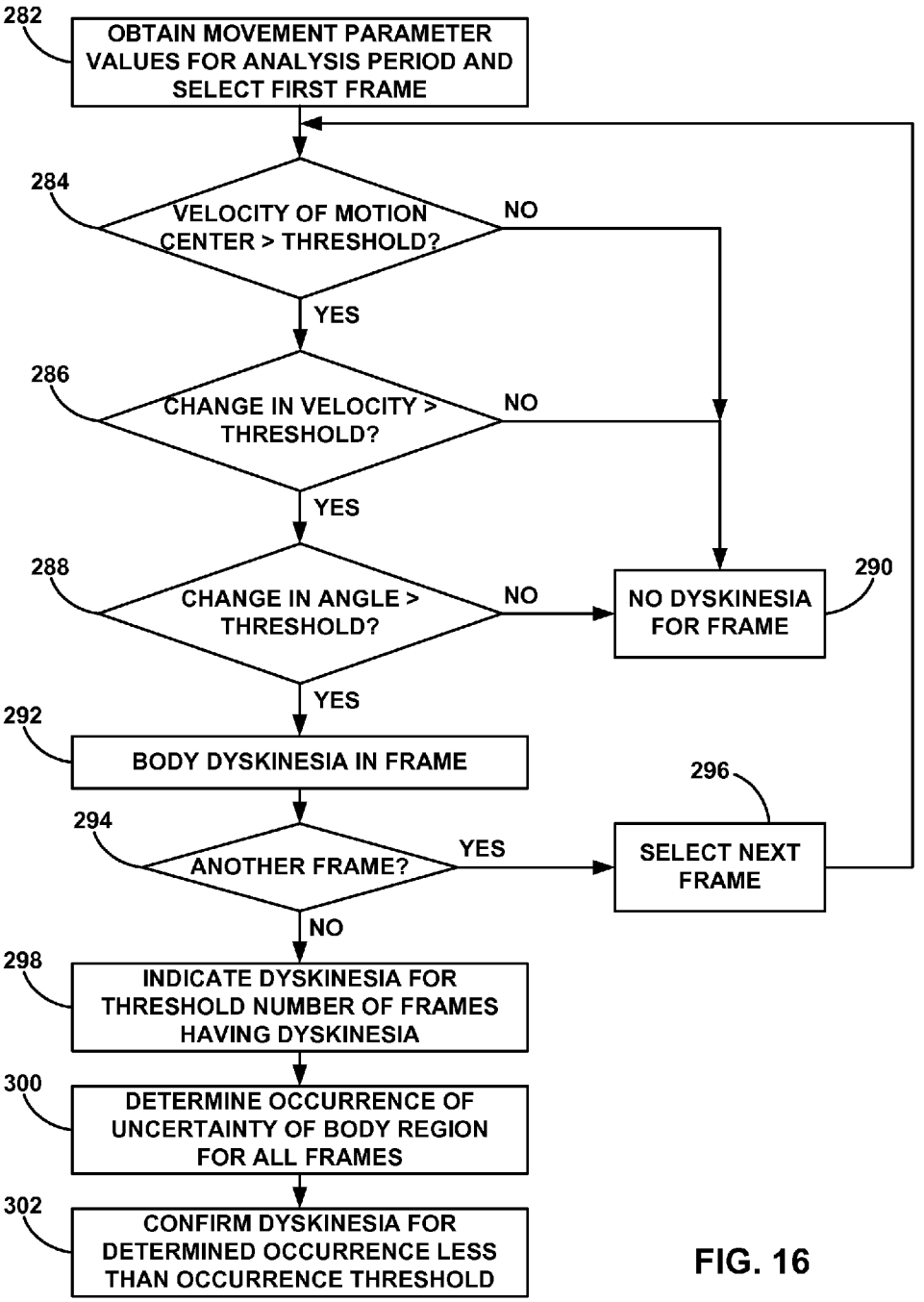

282
OBTAIN MOVEMENT PARAMETER VALUES FOR ANALYSIS PERIOD AND SELECT FIRST FRAME
284
VELOCITY OF MOTION CENTER > THRESHOLD?
NO
YES
286
CHANGE IN VELOCITY > THRESHOLD?
NO
YES
288
CHANGE IN ANGLE > THRESHOLD?
NO
290
NO DYSKINESIA FOR FRAME
YES
292
BODY DYSKINESIA IN FRAME
296
294
ANOTHER FRAME?
YES
SELECT NEXT FRAME
NO
298
INDICATE DYSKINESIA FOR THRESHOLD NUMBER OF FRAMES HAVING DYSKINESIA
300
DETERMINE OCCURRENCE OF UNCERTAINTY OF BODY REGION FOR ALL FRAMES
302
CONFIRM DYSKINESIA FOR DETERMINED OCCURRENCE LESS THAN OCCURRENCE THRESHOLD

FIG. 16

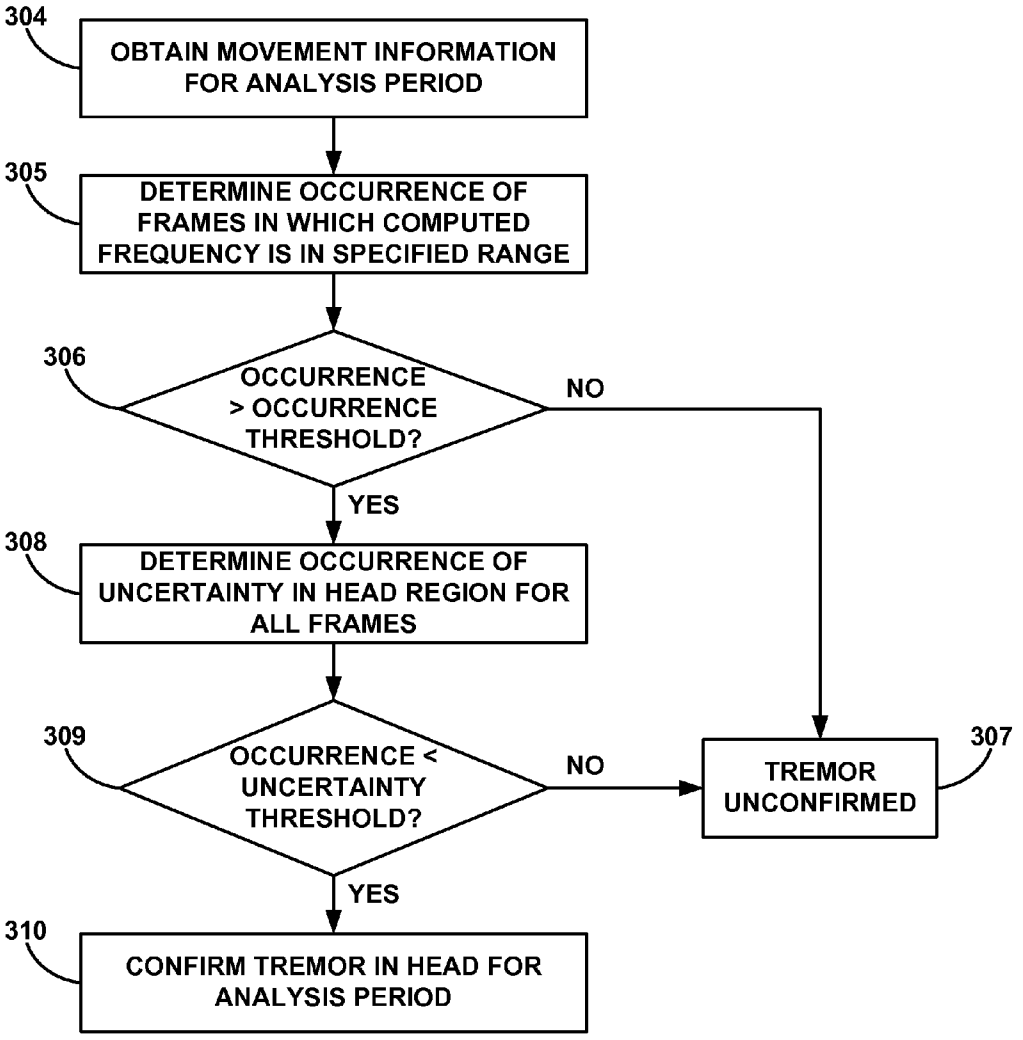

304
OBTAIN MOVEMENT INFORMATION FOR ANALYSIS PERIOD
305
DETERMINE OCCURRENCE OF FRAMES IN WHICH COMPUTED FREQUENCY IS IN SPECIFIED RANGE
306
OCCURRENCE > OCCURRENCE THRESHOLD?
NO
YES
308
DETERMINE OCCURRENCE OF UNCERTAINTY IN HEAD REGION FOR ALL FRAMES
309
OCCURRENCE < UNCERTAINTY THRESHOLD?
NO
307
TREMOR UNCONFIRMED
YES
310
CONFIRM TREMOR IN HEAD FOR ANALYSIS PERIOD

FIG. 17

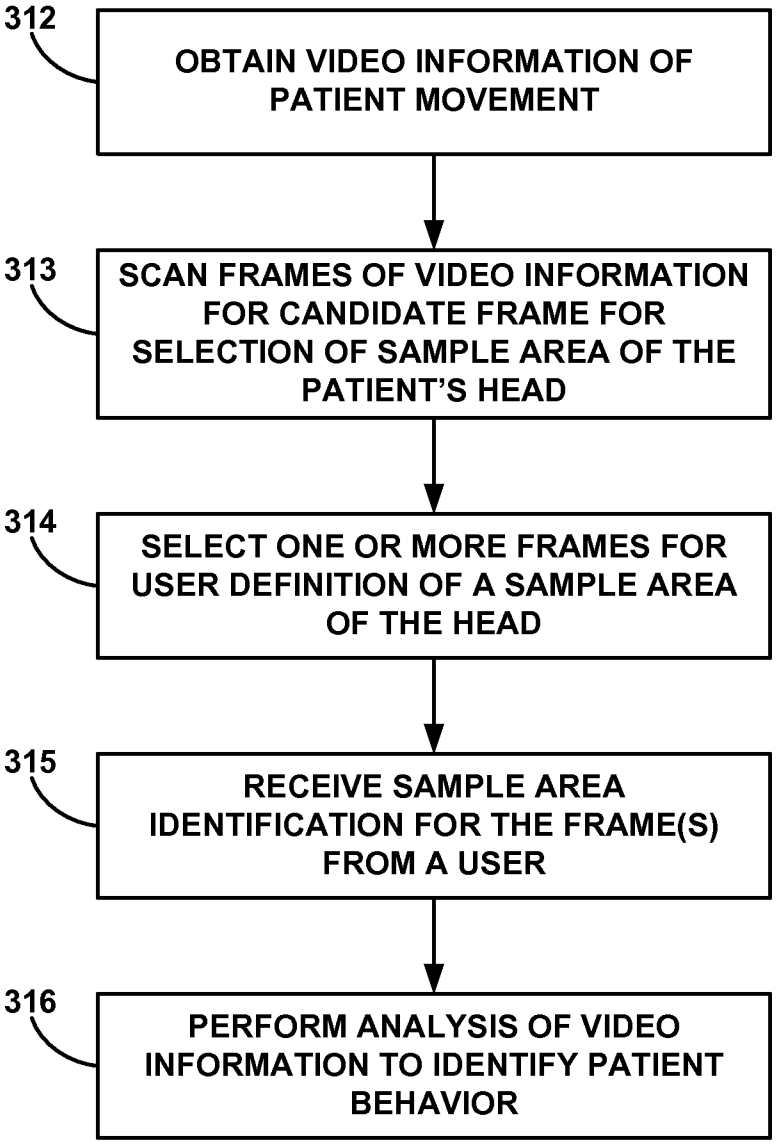

312
OBTAIN VIDEO INFORMATION OF PATIENT MOVEMENT
313
SCAN FRAMES OF VIDEO INFORMATION FOR CANDIDATE FRAME FOR SELECTION OF SAMPLE AREA OF THE PATIENT'S HEAD
314
SELECT ONE OR MORE FRAMES FOR USER DEFINITION OF A SAMPLE AREA OF THE HEAD
315
RECEIVE SAMPLE AREA IDENTIFICATION FOR THE FRAME(S) FROM A USER
316
PERFORM ANALYSIS OF VIDEO INFORMATION TO IDENTIFY PATIENT BEHAVIOR

FIG. 18

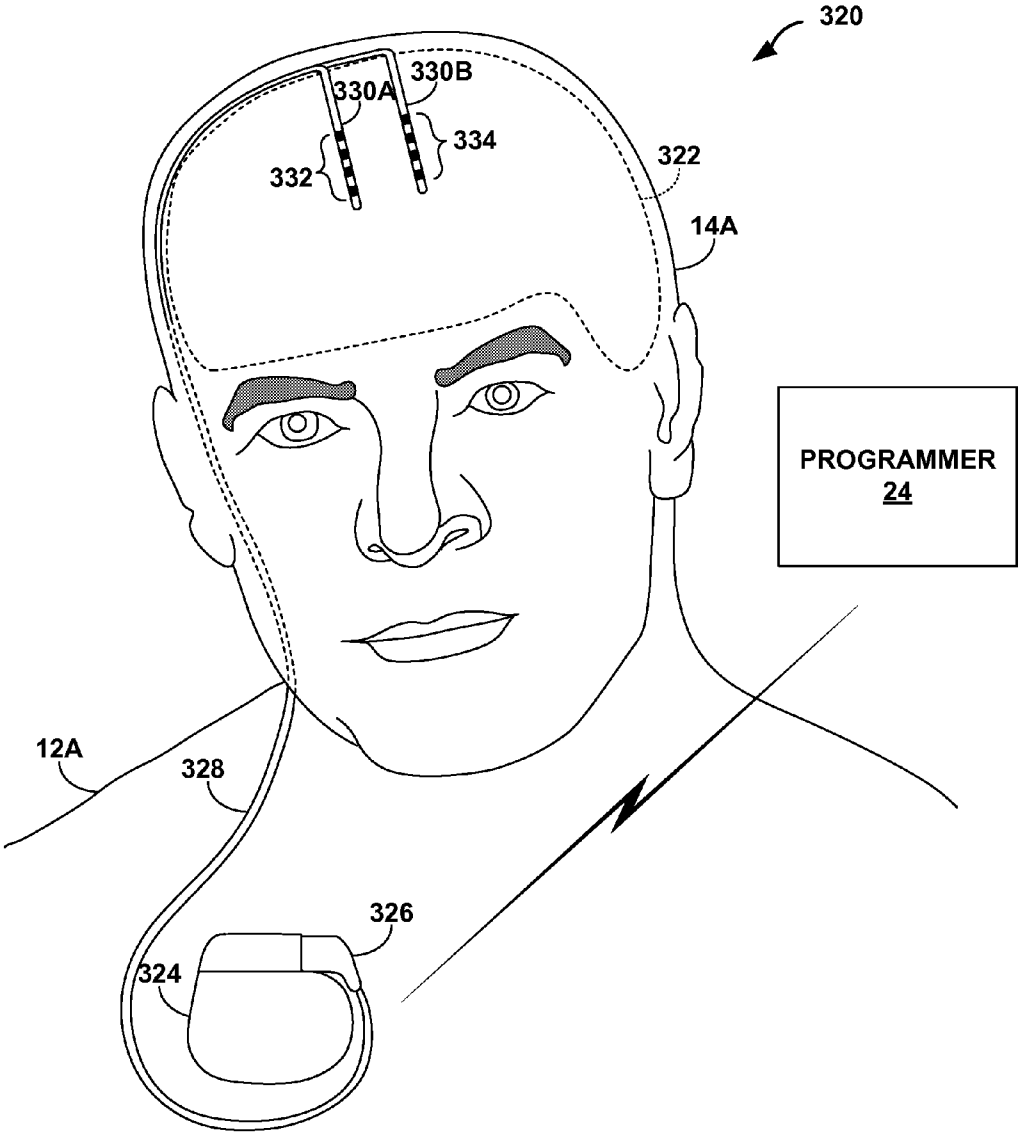


FIG. 19

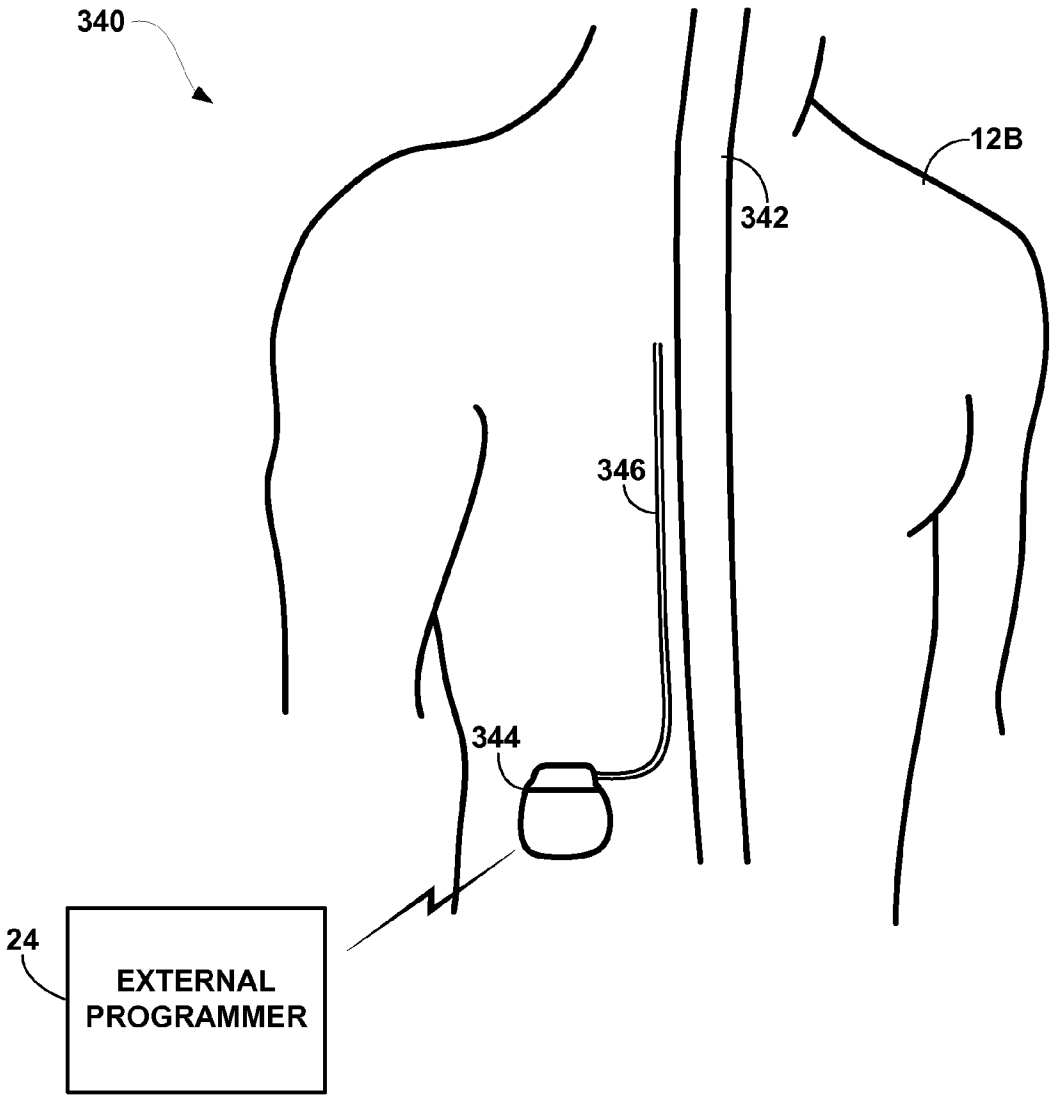


FIG. 20

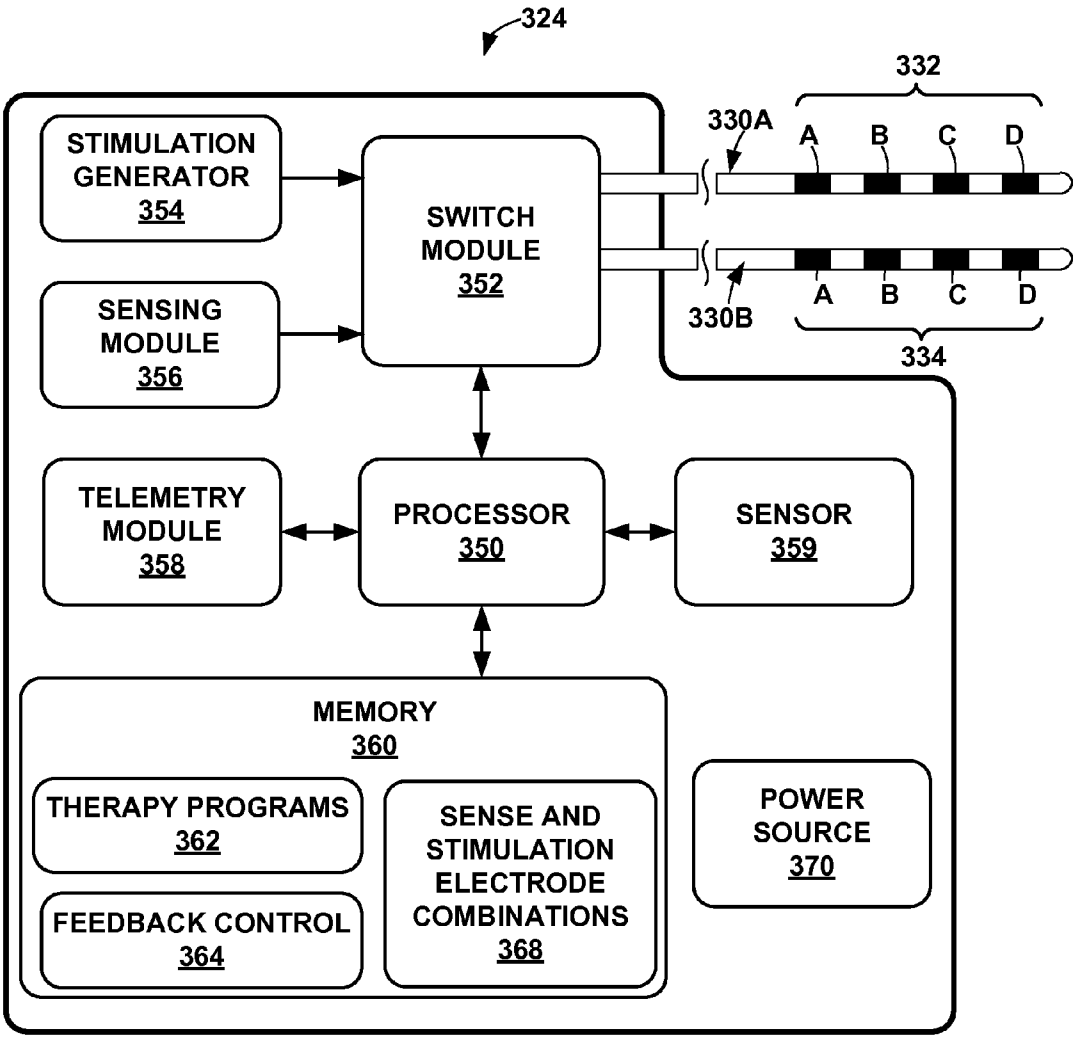
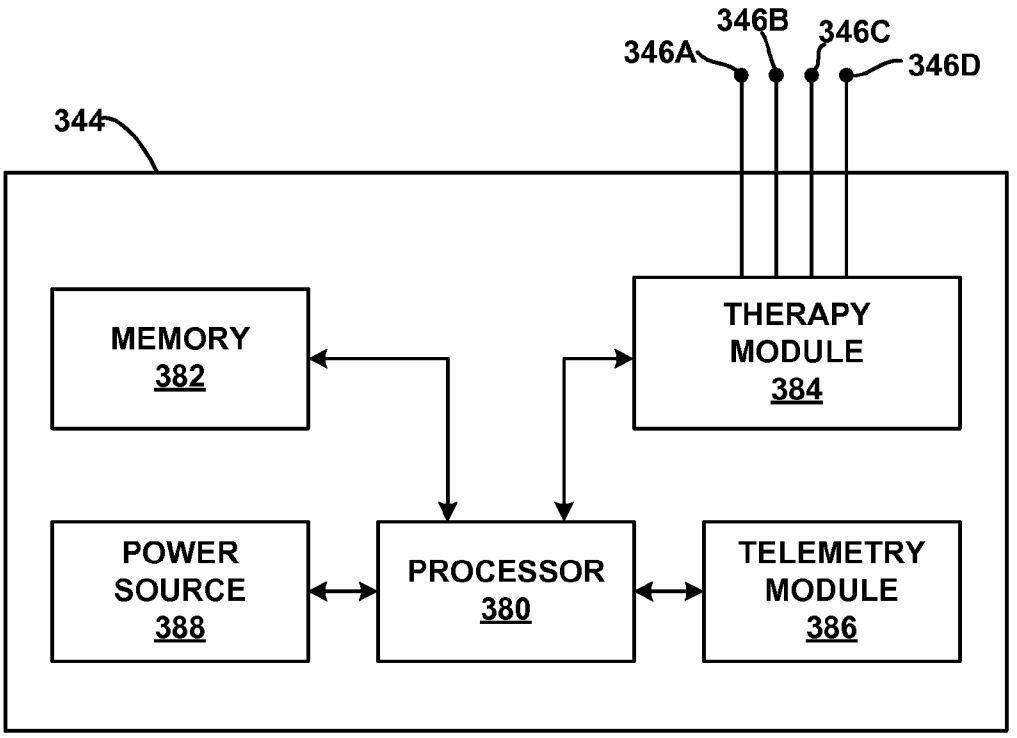

324
332
330A
A
B
C
D
STIMULATION GENERATOR 354
SWITCH MODULE 352
SENSING MODULE 356
330B
A
B
C
D
334
TELEMETRY MODULE 358
PROCESSOR 350
SENSOR 359
MEMORY 360
THERAPY PROGRAMS 362
SENSE AND STIMULATION ELECTRODE COMBINATIONS 368
POWER SOURCE 370
FEEDBACK CONTROL 364

FIG. 21


346A
346B
346C
346D
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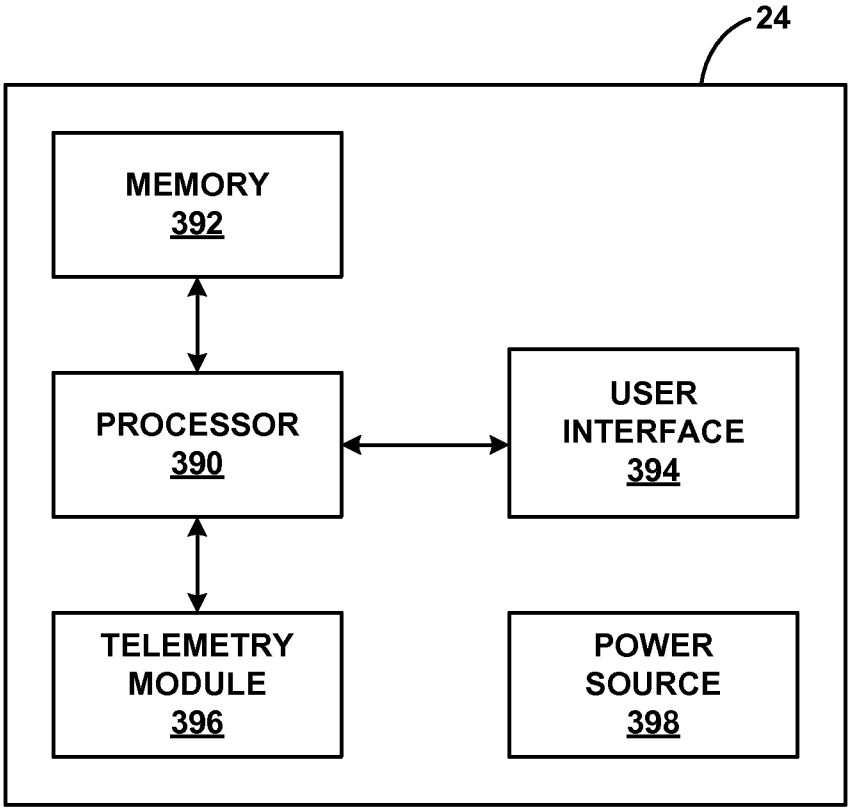
MEMORY
382
THERAPY
MODULE
384
POWER
SOURCE
388
PROCESSOR
380
TELEMETRY
MODULE
386

FIG. 22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PROCESSOR
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USER
INTERFACE
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TELEMETRY
MODULE
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POWER
SOURCE
398

FIG. 23

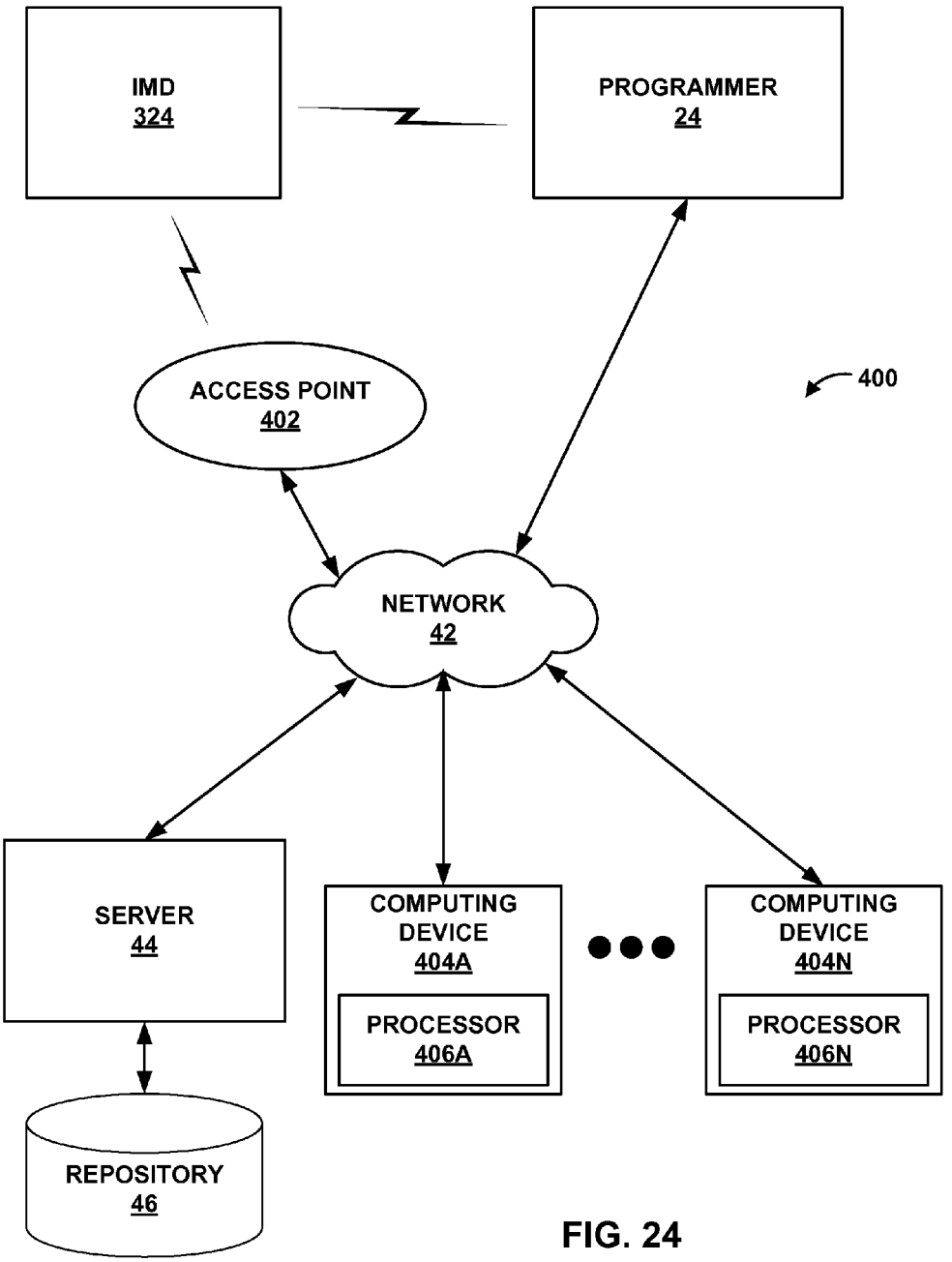
IMD
324
PROGRAMMER
24
ACCESS POINT
402
400
NETWORK
42
SERVER
44
COMPUTING
DEVICE
404A
PROCESSOR
406A
COMPUTING
DEVICE
404N
PROCESSOR
406N
REPOSITORY
46

FIG. 24

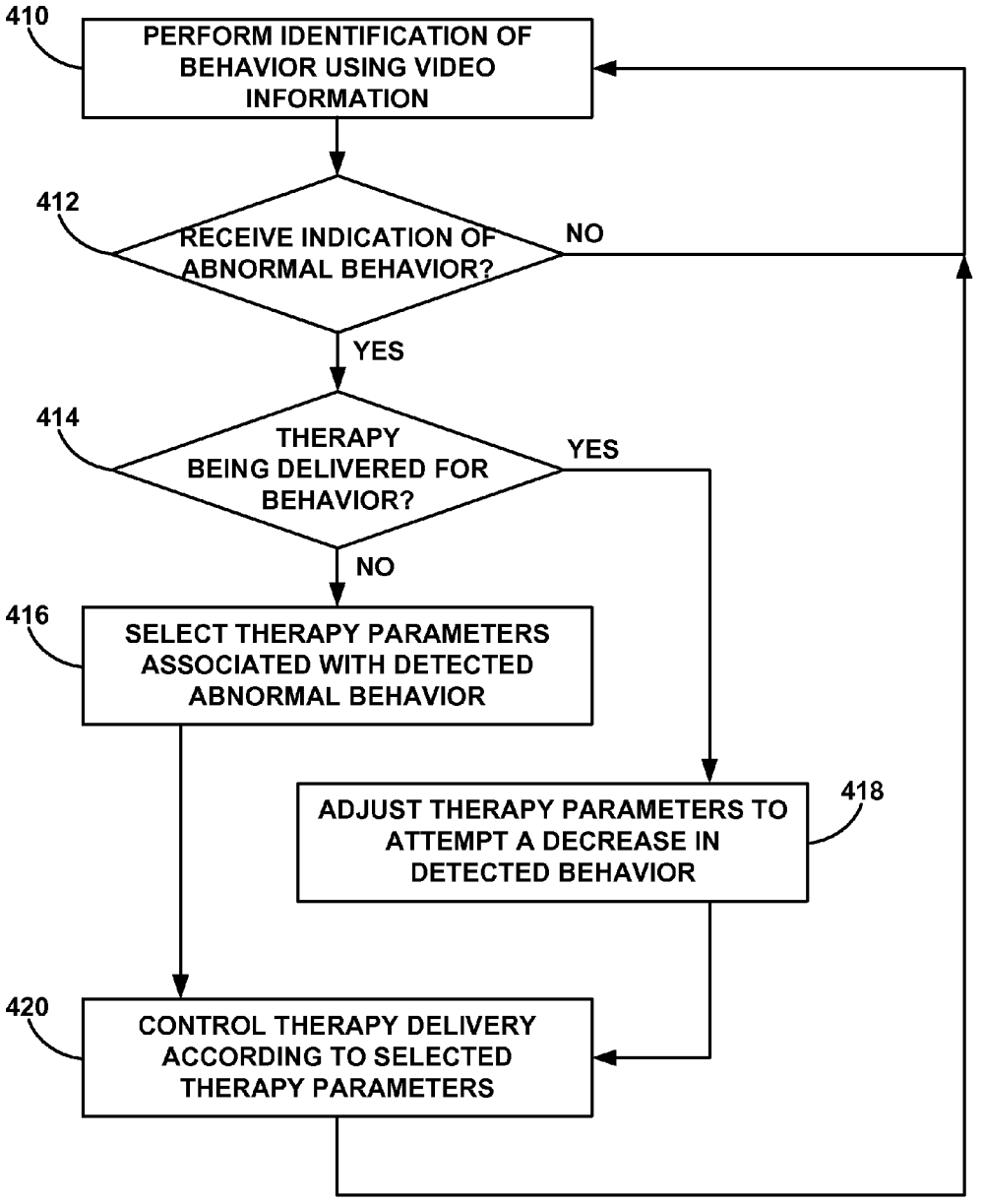
410
PERFORM IDENTIFICATION OF BEHAVIOR USING VIDEO INFORMATION
412
RECEIVE INDICATION OF ABNORMAL BEHAVIOR?
NO
YES
414
THERAPY BEING DELIVERED FOR BEHAVIOR?
YES
NO
416
SELECT THERAPY PARAMETERS ASSOCIATED WITH DETECTED ABNORMAL BEHAVIOR
418
ADJUST THERAPY PARAMETERS TO ATTEMPT A DECREASE IN DETECTED BEHAVIOR
420
CONTROL THERAPY DELIVERY ACCORDING TO SELECTED THERAPY PARAMETERS

FIG. 25

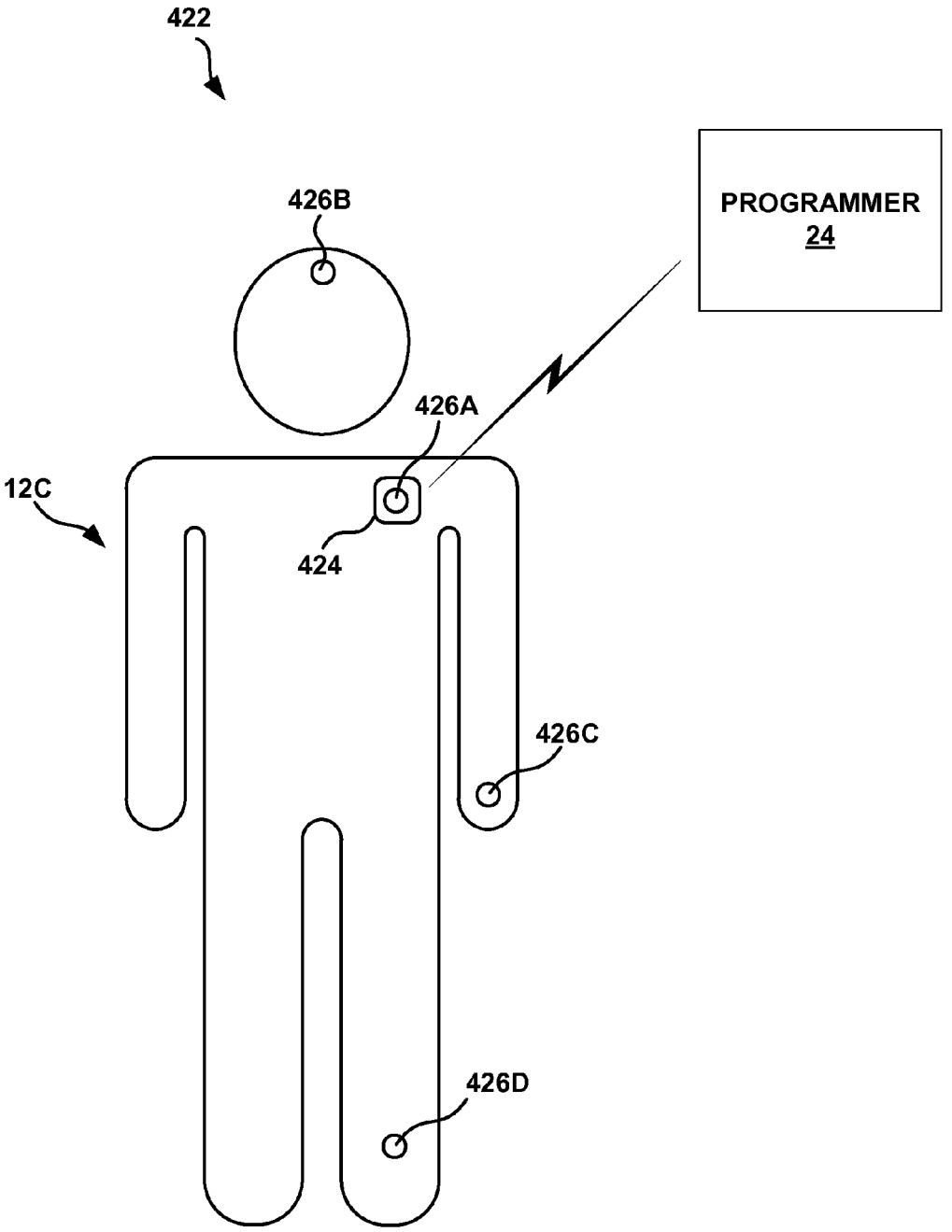

FIG. 26

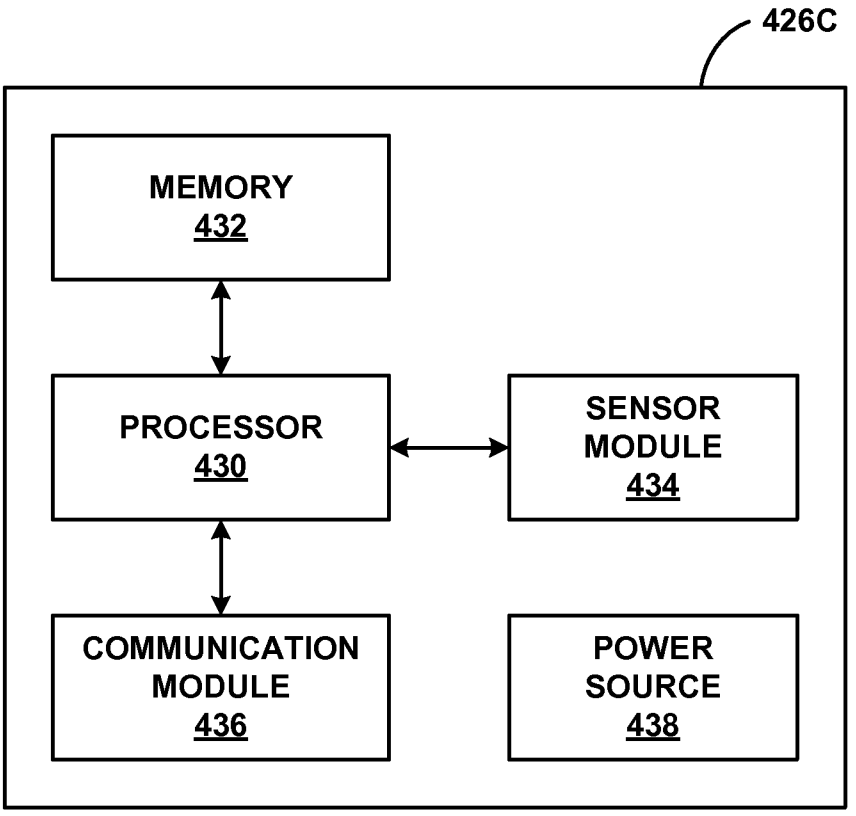
426C
MEMORY
432
PROCESSOR
430
SENSOR
MODULE
434
COMMUNICATION
MODULE
436
POWER
SOURCE
438

FIG. 27

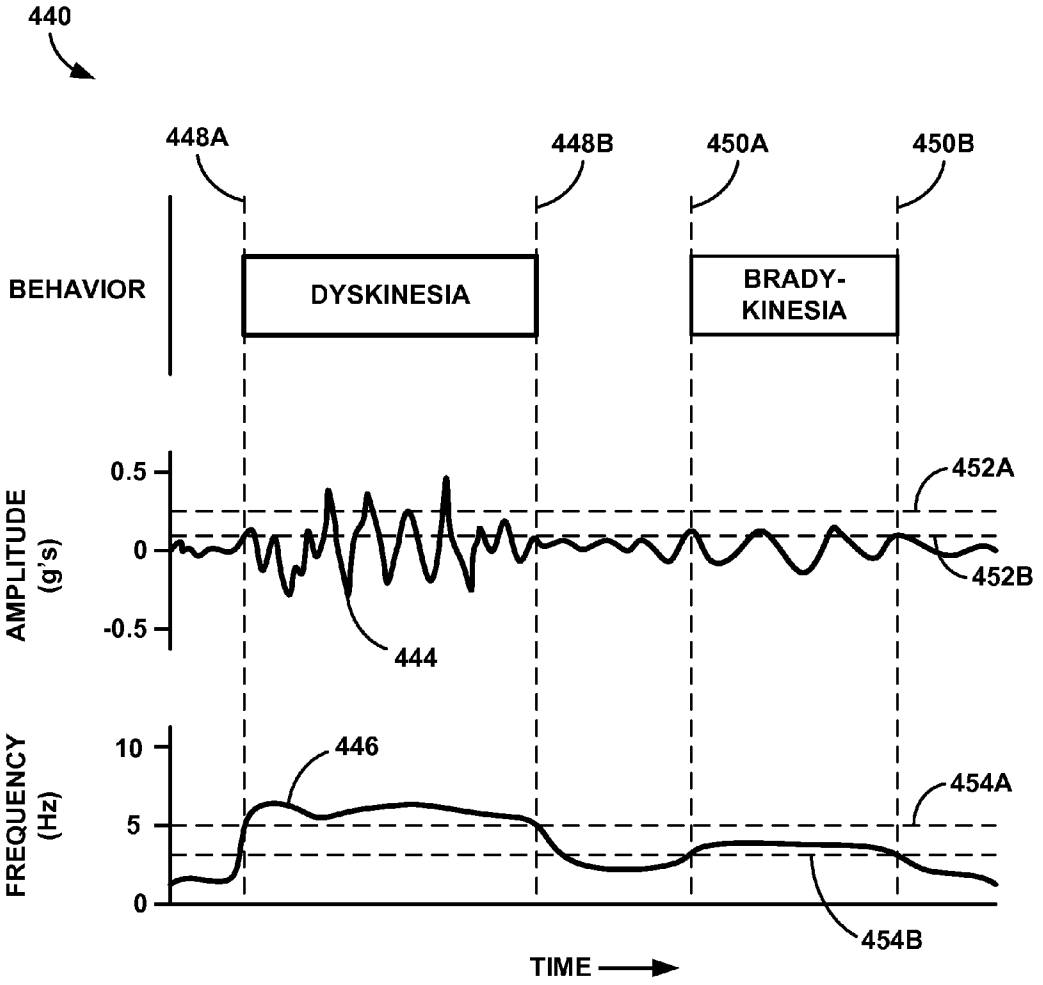
440
448A
448B
450A
450B
BEHAVIOR
DYSKINESIA
BRADY-
KINESIA
AMPLITUDE
(g's)
0.5
0
-0.5
452A
452B
444
FREQUENCY
(Hz)
10
5
0
446
454A
454B
TIME

FIG. 28

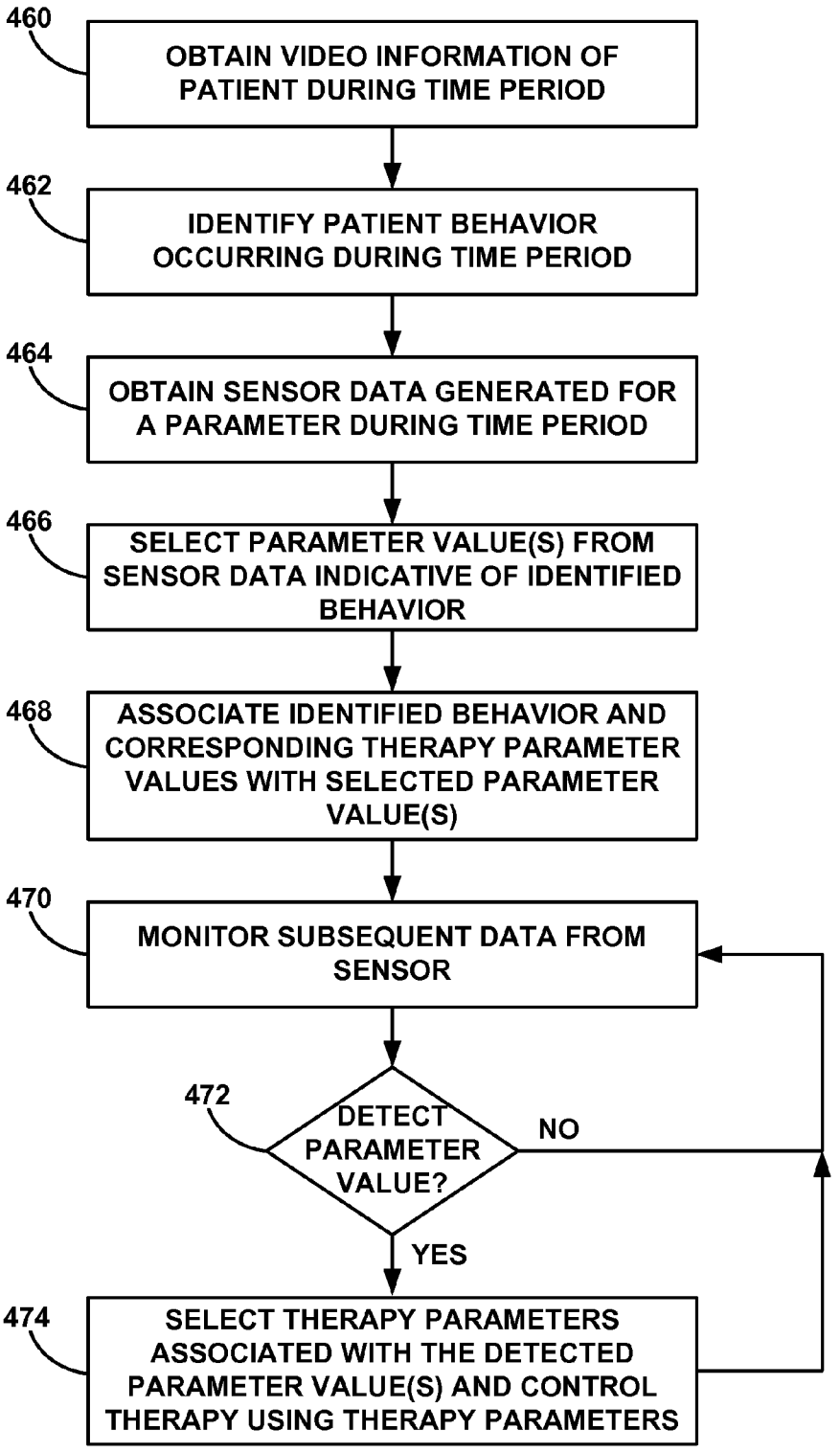
460
OBTAIN VIDEO INFORMATION OF PATIENT DURING TIME PERIOD
462
IDENTIFY PATIENT BEHAVIOR OCCURRING DURING TIME PERIOD
464
OBTAIN SENSOR DATA GENERATED FOR A PARAMETER DURING TIME PERIOD
466
SELECT PARAMETER VALUE(S) FROM SENSOR DATA INDICATIVE OF IDENTIFIED BEHAVIOR
468
ASSOCIATE IDENTIFIED BEHAVIOR AND CORRESPONDING THERAPY PARAMETER VALUES WITH SELECTED PARAMETER VALUE(S)
470
MONITOR SUBSEQUENT DATA FROM SENSOR
472
DETECT PARAMETER VALUE?
NO
YES
474
SELECT THERAPY PARAMETERS ASSOCIATED WITH THE DETECTED PARAMETER VALUE(S) AND CONTROL THERAPY USING THERAPY PARAMETERS

FIG. 29

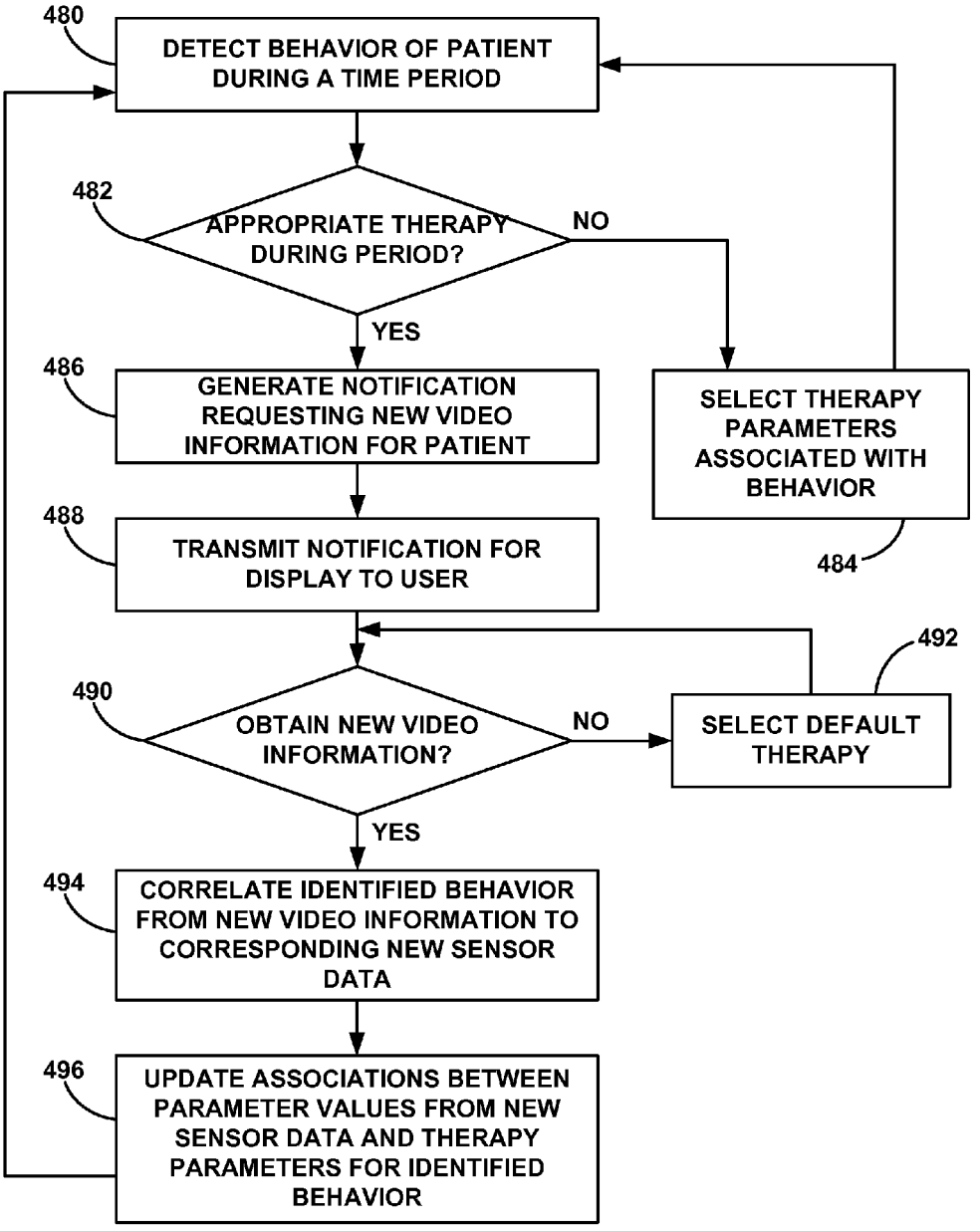
480
DETECT BEHAVIOR OF PATIENT DURING A TIME PERIOD
482
APPROPRIATE THERAPY DURING PERIOD?
NO
YES
486
GENERATE NOTIFICATION REQUESTING NEW VIDEO INFORMATION FOR PATIENT
SELECT THERAPY PARAMETERS ASSOCIATED WITH BEHAVIOR
484
488
TRANSMIT NOTIFICATION FOR DISPLAY TO USER
492
490
OBTAIN NEW VIDEO INFORMATION?
NO
SELECT DEFAULT THERAPY
YES
494
CORRELATE IDENTIFIED BEHAVIOR FROM NEW VIDEO INFORMATION TO CORRESPONDING NEW SENSOR DATA
496
UPDATE ASSOCIATIONS BETWEEN PARAMETER VALUES FROM NEW SENSOR DATA AND THERAPY PARAMETERS FOR IDENTIFIED BEHAVIOR

FIG. 30

MOTION-BASED BEHAVIOR IDENTIFICATION FOR CONTROLLING THERAPY

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/835,405, to Wu, filed Jun. 14, 2013, and entitled "MOTION ANALYSIS FOR BEHAVIOR IDENTIFICATION," which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The disclosure relates to controlling therapy and, more particularly, controlling therapy using motion analysis of a patient.

BACKGROUND

[0003] Various diseases and conditions, such as movement disorders, can cause individuals to experience certain behaviors of movement. For example, a patient diagnosed with Parkinson's Disease may exhibit movement behaviors that may include one or more of tremor, rigidity, bradykinesia, and dyskinesia. Evaluation and identification of these patient behaviors is typically performed by a clinician viewing the movements of the patient. An example evaluation technique of Parkinson's Disease involves the use the Unified Parkinson's Disease Rating Scale, motor scale (mUPDRS). During this test, the clinician asks the patient to perform a routine of passive and active motor tasks, and the clinician provides scores to characterize the movements of the patient during these tasks.

[0004] A clinician may also treat a patient with a movement disorder using one or more therapies. Oral medication may be prescribed for some patients. Patients may also or alternatively be treated using drug delivery therapy and/or electrical stimulation therapy. Electrical stimulation therapy may include deep brain stimulation (DBS), although other types of electrical stimulation therapy may be employed for some patients.

SUMMARY

[0005] In general, the disclosure is directed to devices, systems, and techniques for analyzing video information to objectively identify patient behavior. A camera may generate video information that captures patient motion, or movement. A system may obtain and analyze the video information captured during a period of time to track one or more anatomical regions through a plurality of frames of the video information. The system may then calculate one or more movement parameters that characterize the motion of the one or more anatomical regions. The system may also compare the one or more movement parameters to respective criteria (e.g., one or more thresholds and/or ranges) for each of a plurality of predetermined patient behaviors and identify the patient behaviors that occurred during the period of time.

[0006] In addition, the system (and/or another device) may control the delivery of therapy according to the identified patient behaviors. In one example, the system may control therapy in response to identifying the patient behavior from the video information. In another example, the system may control therapy in response to a sensed value of a patient parameter that has been previously associated with (or calibrated by) the patient behaviors identified from the video information. In either case, controlling therapy may include at least one of selecting an oral medication dose, selecting a dose of medication from drug delivery therapy, and selecting a set of therapy parameters that defines electrical stimulation therapy.

[0007] In one example, the disclosure is directed to a method that includes obtaining video information of patient motion captured over a period of time, wherein the video information comprises a plurality of frames, receiving, with respect to one frame of the plurality of frames, a selection of a sample area representative of an anatomical region, analyzing, by one or more processors, each of the other plurality of frames for respective areas corresponding to the sample area, calculating, by the one or more processors, one or more movement parameters of the anatomical region during the period of time from at least one difference between the sample area and one or more respective areas of at least a subset of the plurality of frames, comparing, by the one or more processors, the one or more movement parameters of the period of time to respective criteria for each of a plurality of predetermined patient behaviors, and identifying, based on the comparison and by the one or more processors, each one of the predetermined patient behaviors that occurred during the period of time.

[0008] In another example, the disclosure is directed to a system that includes one or more processors configured to obtain video information of patient motion captured over a period of time, wherein the video information comprises a plurality of frames, receive, with respect to one frame of the plurality of frames, a selection of a sample area representative of an anatomical region, analyze each of the other plurality of frames for respective areas corresponding to the sample area, calculate one or more movement parameters of the anatomical region during the period of time from at least one difference between the sample area and one or more respective areas of at least a subset of the plurality of frames, compare the one or more movement parameters of the period of time to respective criteria for each of a plurality of predetermined patient behaviors, and identify, based on the comparison, each one of the predetermined patient behaviors that occurred during the period of time.

[0009] In another example, the disclosure is directed to a computer-readable storage medium that includes instructions that cause one or more processors to obtain video information of patient motion captured over a period of time, wherein the video information comprises a plurality of frames, receive, with respect to one frame of the plurality of frames, a selection of a sample area representative of an anatomical region, analyze each of the other plurality of frames for respective areas corresponding to the sample area, calculate one or more movement parameters of the anatomical region during the period of time from at least one difference between the sample area and one or more respective areas of at least a subset of the plurality of frames, compare the one or more movement parameters of the period of time to respective criteria for each of a plurality of predetermined patient behaviors, and identify, based on the comparison, each one of the predetermined patient behaviors that occurred during the period of time.

[0010] In another example, the disclosure is directed to a method that includes receiving, from a computing device, an indication of a patient behavior for a period of time, wherein the patient behavior is determined by the computing device from video information captured during the period of time, determining, based on the indication of the patient behavior

and by one or more processors, a therapy to be delivered to the patient, and outputting the determination for at least one of delivery of the therapy to the patient and display to the user.

[0011] In another example, the disclosure is directed to a system that includes one or more processors configured to, receive, from a computing device, an indication of a patient behavior for a period of time, wherein the patient behavior is determined by the computing device from video information captured during the period of time, determine, based on the indication of the patient behavior, a therapy to be delivered to the patient, and output the determination for at least one of delivery of the therapy to the patient and display to the user.

[0012] In another example, the disclosure is directed to a computer-readable storage medium that includes instructions that cause one or more processors to receive, from a computing device, an indication of a patient behavior for a period of time, wherein the patient behavior is determined by the computing device from video information captured during the period of time, determine, based on the indication of the patient behavior, a therapy to be delivered to the patient, and output the determination for at least one of delivery of the therapy to the patient and display to the user.

[0013] The details of one or more example are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0014] FIG. **1** is a conceptual diagram illustrating an example system that includes a camera for capturing video information of patient movements during a period of time.

[0015] FIG. **2** is a conceptual diagram illustrating an example system that includes a display for presenting commands to a patient and a camera for capturing video information of patient movements that occur in response to the commands.

[0016] FIG. **3** is a conceptual diagram illustrating an example system that includes a networked server for identifying patient behavior based on the video information captured by the camera of FIG. **1** or FIG. **2**.

[0017] FIG. **4** is a block diagram of the example computing device of FIGS. **1** and **2**.

[0018] FIG. **5** is a block diagram of the example networked server of FIG. **3**.

[0019] FIG. **6** is a flow diagram that illustrates an example process for identifying patient behaviors based on analyzed video information of the patient.

[0020] FIG. **7** is a flow diagram that illustrates an example process for allocating sample areas representing a respective anatomical region captured in the video information.

[0021] FIG. **8** is a flow diagram that illustrates an example process for identifying areas of video frames corresponding to the sample area of a different frame.

[0022] FIG. **9** is a flow diagram that illustrates an example process for filtering raw motion pixels from noise in the video information.

[0023] FIG. **10** is a flow diagram that illustrates an example process for generating a motion track map with pixels indicative of patient motion.

[0024] FIG. **11** is a flow diagram that illustrates an example process for calculating movement parameters for each frame of the motion track map of FIG. **10**.

[0025] FIG. **12** is a flow diagram that illustrates an example process for generating motion groups of pixels and calculating movement parameters for each of the motion groups.

[0026] FIG. **13** is a flow diagram that illustrates an example process for calculating movement parameters representing frequency of patient motion.

[0027] FIG. **14** is a flow diagram that illustrates an example process for identifying dyskinesia in the head of a patient.

[0028] FIG. **15** is a flow diagram that illustrates an example process for identifying bradykinesia in a patient.

[0029] FIG. **16** is a flow diagram that illustrates an example process for identifying dyskinesia in a body of a patient.

[0030] FIG. **17** is a flow diagram that illustrates an example process for identifying tremor in a patient.

[0031] FIG. **18** is a flow diagram that illustrates an example process for suggesting one or more frames of the video information in which to define a sample area of an anatomical region of the patient.

[0032] FIG. **19** is a conceptual diagram illustrating an example system that includes an implantable medical device (IMD) configured to deliver deep brain stimulation to a patient.

[0033] FIG. **20** is a conceptual diagram illustrating an example system that includes an IMD configured to deliver spinal cord stimulation to a patient.

[0034] FIG. **21** is a block diagram of the example IMD of FIG. **19** for delivering deep brain stimulation therapy.

[0035] FIG. **22** is a block diagram of the example IMD of FIG. **20** for delivering spinal cord stimulation therapy.

[0036] FIG. **23** is a block diagram of the external programmer of FIGS. **1**, **19**, and **20**.

[0037] FIG. **24** is a block diagram illustrating an example system that includes a networked server coupled to an IMD and one or more computing devices via a network.

[0038] FIG. **25** is a flow diagram illustrating an example process for controlling therapy according to patient behavior identified from video information.

[0039] FIG. **26** is a conceptual diagram illustrating an example system that includes sensors configured to sense one or more patient parameters indicative of a patient behavior and monitored to control therapy.

[0040] FIG. **27** is a block diagram of an example sensor that senses a patient parameter indicative of patient behavior.

[0041] FIG. **28** is a graph illustrating a correlation of determined patient movement from video information to patient parameters sensed during the same period of time during which the video information was captured.

[0042] FIG. **29** is a flow diagram illustrating an example process for associating sensed patient parameter values with patient behavior identified from video information.

[0043] FIG. **30** is a flow diagram illustrating an example process for requesting new video information and updating the associations between sensed patient parameter values and patient behaviors identified from the new video information.

DETAILED DESCRIPTION

[0044] This disclosure is generally directed to devices, systems, and techniques for analyzing video information to objectively identify patient behavior such as patient movement. A clinician (e.g., doctor, nurse, or other healthcare professional) diagnose or evaluate a movement disorder of a patient may visually monitoring the movements of the patient. A movement disorder may be caused by neurological disorders and/or other physiological disorders. Various scales

and tests have been developed to perform such evaluations. For example, the Unified Parkinson's Disease Rating Scale, motor scale (mUPDRS) is typically used to evaluate motor performance of patients suspected or diagnosed with Parkinson's disease. During the test, the clinician asks the patient to perform a routine of passive and active motor tasks while the clinician provides scores intended to characterize the movement and/or capabilities of the patient. However, tests such as the mUPDRS test may be inaccurate, inconsistent, and/or unreliable because they rely on clinician training and experience, are only available during limited visits to a clinic, and are subject to patient and clinician fatigue.

[0045] As disclosed herein, algorithms are described to objectively identify and evaluate patient movement as one or more patient behaviors (e.g., movement disorders associated with abnormal behavior). A system may incorporate one or more devices to automatically identify patient behavior from patient motion. For example, a camera may generate video information (e.g., a plurality of image frames) that captures patient motion or movement during a period of time. This patient movement may be passive (i.e., uninstructed by a clinician or system). Alternatively, the patient movement may be active (i.e., in response to commands given to the patient).

[0046] A system (e.g., a networked server or external programmer) may obtain and analyze the video information captured during the period of time. The system may determine one or more sample areas of respective anatomical regions in one or more of the frames and analyze the other frames to determine areas that correspond to the sample areas. The system may also calculate one or more movement parameters that characterize the movement of the areas within the frames of the period of time. The system may then compare the calculated values of the respective movement parameters to criteria of each of a plurality of patient behaviors (e.g., abnormal behaviors). Based on this comparison, the system may identify which ones of the patient behaviors were exhibited by the patient during the period of time in which the video information was captured. In this manner, the system can be configured to identify a plurality of different patient behaviors from the same video information and over the same period of time. Therefore, video information captured during passive patient movement, instead of instructed active patient movement, can be analyzed to identify patient behavior. However, behavior identification may still be used based on video information captured during instructed active patient movement.

[0047] The identified patient behavior may be used to diagnose movement disorders, evaluate and assess movement disorder severity, and/or monitor the progression of any disease underlying the movement disorder. In addition, a system or device may control therapy (e.g., electrical stimulation therapy, drug delivery therapy, and/or oral medication therapy) in response to identifying a patient behavior from the video information. In this manner, the identified patient behavior may be used as feedback for controlling the therapy. Video information may be captured continuously, periodically, and/or on-demand and analyzed to identify the patient behavior for feedback.

[0048] In other examples, the identified patient behavior may be correlated with other patient parameters that are used as feedback to control therapy delivery. For example, the system may obtain values for one or more patient parameters sensed during the same time as video information was captured of the patient. After identifying the patient behaviors occurring during the period of time, the system may correlate, or associate, the values of the sensed patient parameters with the patient behaviors that occurred at the same time. In this manner, the system may generate respective thresholds, ranges, formulas, look up tables, for one or more patient parameters that indicate when the patient is experiencing each of a plurality of patient behaviors. Although the video information may be used to calibrate one or more patient parameters to the patient behaviors, a device may control therapy in response to sensing one or more sensed values of the patient parameters. Patient parameters may include, local field potentials (LFPs), electrograms (EEGs), electroencephalograms (EEG), patient accelerations, relative accelerations, patient speech, physiological chemistry, or any other parameter of the patient that may be indicative of a behavior associated with a movement disorder.

[0049] FIG. **1** is a conceptual diagram illustrating example system **10** that includes camera **26** for capturing video information of patient movements during a period of time. As shown in FIG. **1**, system **10** may include camera **26**, computing device **30**, and external programmer **24**. FIG. **1** also illustrates patient **12** lying in bed **20** and clinician **22** sitting next to patient **12** and holding external programmer **24**. An implantable medical device (not shown) may be implanted within patient **12** and configured to deliver therapy to patient **12**. Programmer **24** may communicate with the implantable medical device (IMD) to adjust therapy, obtain sensed values of one or more patient parameters, and/or communicate any other commands between the two devices.

[0050] System **10** may be configured to capture video information of the motion of patient **12**. As patient **12** lies in bed **20**, patient **12** may move head **14**, torso **16**, arm **18**A or arm **18**B (example anatomical regions). In some cases, patient **12** may also move one or both legs, fingers, hands, feet, or any other anatomical regions. These movements may be voluntary and/or involuntary as a result of movement disorder experienced by patient **12**. When the movements of patient **12** are not performed in response to a command to perform a certain movement or action, the movement of patient **12** may be described as passive movement. If patient **12** has a movement disorder, various patient behaviors (e.g., the result of one or more anatomical region movements) may manifest themselves during a period of time. Camera **26** may be positioned to capture the movement of patient **12** over a period of time using a plurality of video frames. These video frames may be at least part of the video information captured of patient **12**.

[0051] Camera **26** may include one or more types of sensors for detecting patient motion. In one example, camera **26** may have one or more sensors (e.g., charge-coupled device (CCD) or complementary metal-oxide-semiconductor (CMOS)) configured to convert visible light to electrical signals representing the visible light. In other examples, camera **26** may include other sensors that are configured to capture infra-red electromagnetic radiation and/or any other medium representative of the movement of patient **12**. In other examples, two or more cameras may be placed at different locations with respect to patient **12** in order to obtain different perspectives of the patient movement that may be undetectable at some angles or vantage points. Although camera **26** may generally be positioned to capture the entire body of patient **12**, camera **26** may be focused to one or more specific anatomical regions in other examples.

[0052] Camera **26** may capture video information (e.g., video frames and, in some examples, information regarding the frames such as time and location the frames were captured) of patient movement over various periods of time. Camera **26** may capture video information for minutes, hours, days, or even months. Camera **26** may capture video information continuously (e.g., at a specified frame rate) over the period of time. In other examples, camera **26** may be configured to capture video information periodically such as at scheduled times and/or at various frame rates. For example, camera **26** may be configured to capture video information of patient **12** during the time of day at which patient **12** is likely to be active and moving (e.g., during the day time, during meals, or during scheduled activities). In this manner, camera **12** may be configured to capture video information in response to user input requesting video information. In other examples, camera **26** may be configured to capture video information in response to a request to capture video information. The request may be generated in response to receiving a user request, in response to a sensed parameter (e.g., an accelerometer indicating patient **12** is moving), or in response to a request for additional video information due to potential problems with identified patient behaviors.

[0053] Camera **26** may transmit the captured (or generated) video information to computing device **30** via wired or wireless communication protocols. Computing device **30** may be configured to temporarily or permanently store the video information from camera **26**. In some examples, computing device **30** may also be configured to control the operation of camera **26** based on stored instructions and/or commands received from another device over a network. In this manner, computing device **30** may be in wired or wireless communication with additional computing devices (e.g., a networked server, programmer **24**, and/or other computing device) via a network, such as network **42** of FIG. **3**. In other examples, programmer **24** may be configured to at least partially control the operation of camera **26**.

[0054] Although camera **26** may be a separate device, camera **26** may be integrated into a computing device. For example, camera **26** may be integrated into the housing of computing device **30** and/or a display coupled to computing device **30**. In other examples, camera **26** may be housed by a mobile computing device or notebook computer. In this manner, video information may be captured by devices other than a standalone camera positioned within a single room. Instead, a mobile computing device (e.g., a smartphone, a tablet computer, or programmer **24**) may include camera **26** configured to capture the video information used to objectively identify patient behavior. Clinician **22** or even patient **12** may then capture video information of patient movement at any location.

[0055] In some examples, computing device **30** may obtain the video information from camera **26**, analyze the video information, and identify patient behaviors from the video information. Computing device **30** may also be associated with a display configured to present the identified patient behavior to clinician **22**. Computing device **30** may instead transmit the identified patient behavior to external programmer **24** for presentation to clinician **22**. In other examples, computing device **30** may be configured to transmit the video information to a networked server via a network. Computing device **30** may continuously or periodically transfer the video information captured by camera **26** to a device configured to analyze the video information and identify any patient behavior that occurred in the video information.

[0056] As described herein, one or more processors of a computing device may be configured to identify patient behaviors from video information captured by camera **26**. For example, the computing device may be configured to obtaining video information of patient motion captured over a period of time, such that the video information comprises a plurality of frames. The computing device may then receive, with respect to one or more frames of the plurality of frames, a selection of a sample area representative of an anatomical region (e.g., head **14**, torso **16**, arm **18**A, or arm **18**B). This sample area may be defined by user input and/or the one or more processors. The computing device may also analyze each of the other plurality of frames for respective areas corresponding to the sample area. The computing device can then calculate one or more movement parameters (e.g., velocity, angle of movement, or frequency of movement) of the anatomical region during the period of time from at least one difference between the sample area and one or more respective areas of at least a subset of the plurality of frames. The computing device may also be configured to compare the one or more movement parameters of the period of time to respective criteria for each of a plurality of predetermined patient behaviors (e.g., types of movements or movement disorders) and identify, based on the comparison, each one of the predetermined patient behaviors that occurred during the period of time.

[0057] The identified patient behaviors may be abnormal behaviors that are included in or representative of respective movement disorders. The identified patient behaviors may indicate a type of movement (e.g., dyskinesia, bradykinesia, or tremor) and the severity of each type of movement. The identified patient behaviors may be transmitted to external programmer **24**, or another clinician device, for viewing by clinician **22**. Clinician **22** may diagnose patient **12** and/or monitor the progression of a disease using the identified patient behaviors. In addition, clinician **22** may establish a treatment regimen in response to receiving the identified patient behavior. In the situation in which an IMD (e.g., an electrical stimulator and/or drug pump) is within patient **12**, clinician **22** may interact with external programmer **24** to command the IMD to control therapy based on the identified patient behavior. In some examples, a computing device such as a networked server or external programmer **24** may select one or more therapies (e.g., select therapy parameters) in response to receiving the identified patient behaviors. In this manner, the identified patient behaviors may be used to influence some therapy for patient **12**.

[0058] Although video information is described as being captured as patient **12** lies in bed **20**, camera **26** may capture video information of any activity of patient **12**. Camera **26** may capture video information of patient **12** as patient **12** walks across the room, watches television, sits in a chair, maintains a selected posture, talks, eats a meal, interacts with clinician **22** or any other healthcare professional, or performs any other normal routine tasks or activities.

[0059] If the one or more anatomical regions of patient **12** are undetectable in the captured video information, the system may determine an uncertainty as to the location of the anatomical region and exclude such frames from the motion analysis. In this manner, video information captured over an extended period of time and patient activities may be ana-

lyzed to identify patient movement without unwanted patient positions affecting the accuracy of the identified patient movement.

[0060] FIG. **2** is a conceptual diagram illustrating example system **10** that includes display **32** for presenting commands to patient **12** and camera **26** for capturing video information of patient movements that occur in response to the commands. As shown in FIG. **2**, system **10** includes camera **26**, computing device **30**, and display **32**. System **10** may be configured to capture video information while display **32** presents physical commands for patient **12** to complete. In some examples, patient behavior may be identified based on the ability or inability of patient **12** to perform certain actions. System **10** may be configured to instruct patient **12** to perform these actions in an automated manner that does not require a clinician to interact with patient **12**. In some examples, system **10** may present the instructions in a game-type format that challenges patient **12** to complete a certain task to receive a certain score. In this manner, patient movement may be assessed outside of the clinic setting, such as at the home of patient **12**. In addition, the movement assessment may be performed more frequently to closely monitor the progression of any movement disorder and corresponding neurological disease or physiological issue.

[0061] Computing device **30** may be configured to conduct a movement assessment of patient **12** during which video information is captured of patient movement. The assessment may be initiated by patient input, a scheduled time to begin the assessment, or remote initiation via a network. Computing device **30** may generate and output various physical commands to be displayed to patient **12**. These physical commands may be selected according to assessment instructions stored within a memory of computing device **30** or obtained from another computing device (e.g., a networked server or remote computing device) via a network. Display **32** may be configured to display or present the physical commands to patient **12**. The physical commands may be in the form of text, audio, and/or images of a person performing the requested actions.

[0062] Camera **26** may be positioned in such a manner to capture the movements of one or more anatomical regions of patient **12**. Although camera **26** may be configured to capture the entire body of patient **12** within the field of view of camera **26**, camera **26** may be configured to capture video information for a portion of patient **12**. Computing device **30** may be configured to control camera **26** to capture video information during the period of time in which patient **12** is performing the movements instructed by the physical commands. For example, the video information may include patient **12** moving head **14**, torso **16**, arm **18**A, legs **28**A and **28**B, or any other movements. The movements may include intentional movements desired by patient **12** and unintentional movements resulting from the movement disorder of patient **12**. The physical commands may include commands to move individual anatomical regions such as an arm, perform various coordinated movements between anatomical regions, or full body motions such as walking, sitting, or standing. For instance, system **10** (or a clinician) may instruct patient **12** to perform tasks such as performing finger taps between the thumb and index finger of one or more hands in rapid succession, opening and closing one or more hands in rapid succession, performing rapid alternating movements of one or more hands, and/or any additional movements. As another example, system **10** or a clinician may instruct patient **12** to attempt to rise from a chair while maintaining the patient's arms folded across the chest. Leg and foot agility of patient **12** may be tested via heel taps instructed to be performed in rapid succession while the patient's leg is raised by predetermined magnitude or angle, such as three inches, during each tap. In other examples, a clinician may devise customized tests whereby patient **12** is instructed to go through specific motions. The clinician may, in some examples, apply resistance while patient **12** performs some motions to further test the patient's capabilities. System **10** may implement and conduct each of these tests by presenting instructions to patient **12** and/or a clinician and capturing video information of the patient's motion during each test.

[0063] Since camera **26** may be configured to capture movements of the entire body of patient **12**, the captured video information may include motions from all anatomical regions of patient **12**. Therefore, the single video information may be analyzed for the presence of multiple patient behaviors (e.g., abnormal behaviors) as described herein. The assessment described in FIG. **2** may be performed instead of or in addition to the passive movement assessment described with respect to FIG. **1**. Physical commands given to patient **12** may be time stamped, or otherwise correlated to the captured video frames, for comparison to the video information to assess the patient movement.

[0064] In other examples, one or more sensors may sense a respective patient parameter during the patient movement of FIG. **1** or **2**. These patient parameters may obtain non-video information indicative of some aspect of patient movement. The patient parameters may be calibrated with the identified patient behavior from the captured video information to provide feedback indicative of patient behavior. This feedback may be used to supplement behavior monitoring of patient **12** and/or to control therapy delivered to patient **12**. The sensors may be attached to patient **12**, implanted within patient **12**, or associated with another object in contact with patient **12**. Example sensors may include electrodes and electrical signal sensing modules, accelerometers, microphones, chemical sensors, or any other type of sensor configured to obtain information regarding the movement of patient **12**.

[0065] FIG. **3** is a conceptual diagram illustrating example system **40** that includes networked server **44** configured to identify patient behavior based on video information **50** captured by camera **26** of FIG. **1** or FIG. **2**. As shown in FIG. **3**, system **40** includes computing device **30**, camera **26**, network **42**, networked server **44** (e.g., a computing device), repository **46**, and computing device **54**. Computing device **30**, in some examples, is or is a part of a portable computing device (e.g., a mobile phone, a smartphone, a netbook computer, a notebook computer, a tablet computing device, or a smart watch). In other examples, computing device **30** may be at least a part of a workstation or other non-portable computing device. Computing device **30** may also include a display device (e.g., display **32** of FIG. **2**) and be configured to control the display device. The display device may be housed by computing device **30** or external from computing device **30**. Although camera **26** may be a separate device in communication with computing device **30**, camera **26** may be coupled to or at least partially within a housing of computing device **30**. Computing device **30** may receive video information **50** from camera **26** and/or generate at least a portion of video information **50** such as time stamps, any physical commands given to user **12**, or any other metadata associated with the video frames of video information **50**.

[0066] Computing device **30** may be configured to connect to network **42** (e.g., a wired or wireless network). In some examples, computing device **30** may also be configured to communicate with networked server **44** via network **42** to transmit captured video information **50**. Although network **42** may be a single network, network **42** may be representative of two or more networks configured to provide network access to server **44** and/or repository **46**. Computing device **30** may be configured to transmit captured video information **50** after the video information is completed generated or stream video information **50** to networked server **44** as the video information is captured. In some examples, computing device **30** may receive instructions from networked server **44** to control camera **26** to begin or terminate the capturing of video information. In other examples, networked server **44** may provide finer control of video information capture, such as video frame rates, video capture settings, compression of video information, or any other aspect related to capturing the video information of patient movement.

[0067] Computing device **30** may include various components that provide respective functionality. For example, computing device **30** may control a display device such as display **32** of FIG. **2**. Computing device **30** may include one or more input devices and/or output devices that facilitate user (e.g., a clinician or a patient) communication with computing device **30**. In one example, a user interface may include the display device and separate input devices or a display device may be touch screen interface (e.g., a presence-sensitive display that includes a presence-sensitive input device). In other examples, the display device may include a display and one or more buttons, pads, joysticks, mice, tactile devices, or any other device capable of turning user actions into electrical signals that control computing device **30**. In any example, the user clinician may interact with the display device or any other input devices to provide input prior to or during the processes described herein.

[0068] Computing device **30** may be configured to transmit video information **50** to networked server **44** via network **42**. Networked server **44** may be configured to store video information **50** in repository **46** until the video information is to be analyzed and/or for long-term storage. Both computing device **30** and networked server **44** may connect to network **42**. Network **42** may be embodied as one or more of the Internet, a wireless network, a wired network, a cellular network, or a fiber optic network. In other words, network **42** may be any data communication protocol or protocols that facilitate data transfer between two or more devices. Networked server **44** may also connect to repository **46** to store and/or retrieve video information **50** received from computing device **30**, patient information, patient parameter values, behavior identification rules, or any other data or instructions needed to identify the patient behavior exhibited during capture of video information **50**.

[0069] Networked server **44** and repository **46** may each include one or more servers or databases, respectively. In this manner, networked server **44** and repository **46** may be embodied as any hardware necessary to store video information **50**, generated behavior information **52**, or any other information related to the diagnosis, monitoring, and/or treatment of patient **12**. Networked server **44** may include one or more servers, desktop computers, mainframes, minicomputers, or other computing devices capable of executing computer instructions and storing data. In some examples, functions attributable to networked server **44** herein may be attributed to respective different servers for respective functions. Repository **46** may include one or more memories, repositories, hard disks, or any other data storage device. In some examples, repository **46** may be included within networked server **44**.

[0070] Repository **46** may be included in, or described as, cloud storage. In other words, EGM signal data, EGM summaries, patient reports, instructions, or any other such information may be stored in one or more locations in the cloud (e.g., one or more repositories **46**). Networked server **44** may access the cloud and retrieve the appropriate data as necessary. In some examples, repository **46** may include Relational Database Management System (RDBMS) software. In one example, repository **46** may be a relational database and accessed using a Structured Query Language (SQL) interface that is well known in the art. Repository **46** may alternatively be stored on a separate networked computing device and accessed by networked server **44** through a network interface or system bus. Repository **46** may thus be an RDBMS, an Object Database Management System (ODBMS), Online Analytical Processing (OLAP) database, or any other suitable data management system.

[0071] System **40** may be configured to identify patient behaviors from video information **50**. For example, networked server **44** may employ various techniques and processes described herein with respect to FIGS. **6-18** to analyze video information **50** and identify one or more patient behaviors that occurred within the video information. For example, one or more processors of networked server **44** may be configured to calculate movement parameters of one or more anatomical regions within the frames of video information **50**, compare values of the movement parameters to respective criteria for predetermined patient behaviors, and identify which patient behaviors occurred within video information **50**. Networked server **44** may also identify the severity or progression of each of the patient behaviors. Networked server **44** may compile behavior information **52** that may include the identified patient behaviors, times at which each behavior occurred, a severity of each behavior, confidence levels that such behaviors occurred, or any other information related to the analysis of video information **50** captured by camera **26**.

[0072] Networked server **44** may transmit the generated behavior information **52** to computing device **54**. Computing device **54** may be a computing device configured to deliver information to clinician **22** or patient **12** via a display device or any other such interface. Computing device **54** may be a workstation, mobile computing device, external programmer **24**, or any other such device. Computing device **54** may receive behavior information **52** continuously, periodically, in response to generation of behavior information **52** by networked server **44**, or in response to user request via computing device **54**. Computing device **54** may allow clinician **22** and/or patient **12** to view the movement disorder diagnosis included in behavior information **52**, movement parameter values calculated by server **44**, at least a portion of video information **50** (e.g., video samples) captured by camera **26**, or any other information. In some examples, networked server **44** may also generate suggested actions to take based on the identified patient behavior such as mediations and dosages to take, activities to avoid, or contacting clinician **22** or another healthcare professional.

[0073] Computing device **54** may include input/output capabilities such as a user interface configured to accept user

input. In some examples, networked server **44** may require user input to analyze video information **50** and identify the patient behaviors. For example, user input may be received by computing device **54** to define a sample area of one or more video frames that corresponds to a desired anatomical region. The sample area may be of head **14**, torso **16**, or any other anatomical region of interest. Computing device **54** may then transmit the user input and/or sample area back to networked server **44** for completion of the analysis and identification. In addition, networked sever **44** may require the user to, at least initially, set one or more criteria for one or more of the patient behaviors to be identified. The criteria may include one or more thresholds, ranges, comparisons, or any other values desired by clinician **22** or specific to patient **12**. Computing device **54** may transmit the user defined criteria to networked server **44** for use in identifying the patient behavior present within video information **50**. Networked server **44** may store the user defined criteria in repository **46**. Networked server **44** may also store any generated behavior information **52** in repository **46**.

[0074] Although server **44** is generally disclosed as the computing device configured to generate behavior information **52** and perform other tasks, different computing devices may perform these functions in other examples. For example, computing device **30** or computing device **54** may perform some or all of the steps described herein with respect to identifying patient behavior from video information **50**. In this manner, other computing devices, such as computing device **30**, may perform the operations attributed to server **44**. In still other examples, server **44**, computing device **30**, computing device **54**, and/or other computing devices may operate cooperatively to perform the processes described herein with respect to analyzing video information **50** and generating behavior information **52**.

[0075] FIG. **4** is a block diagram of example computing device **30** of FIGS. **1**, **2**, and **3**. FIG. **4** illustrates only one particular example of computing device **30**, and many other example embodiments of computing device **30** may be used in other instances. For example, computing device **30** may include additional components and run multiple different applications. Computing device **30** may be configured to obtain and/or generate video information from camera **26** and transmit the video information to networked server **44** for analysis.

[0076] As shown in FIG. **4**, computing device **30** may include processor **60**, memory **62**, user interface **66**, telemetry module **68**, and power sources **70**. Camera **26** may be located separately from computing device **30** and in communication with computing device **30** and processor **60**. In other examples, camera **26** may be incorporated within computing device **30**. Each of components **26**, **60**, **62**, **66**, **68** and **70** may be interconnected (physically, communicatively, and/or operatively) for inter-component communications and functionality.

[0077] Processor **60**, in one example, is configured to implement functionality and/or process instructions for execution, such as controlling camera **26** to capture video information and storing video information **64** (e.g., video information **50** of FIG. **3**), for temporary and/or long term storage, within memory **62**. Processor **60** may also be configured to process instructions stored within memory **62**. Processor **60** may also be configured to generate metadata or supplemental data (e.g., time stamps, video parameter values, or any other related information) to the plurality of video frames captured by camera **26** and store such data with the video frames as the video information **64**.

[0078] Memory **62**, in one example, is configured to store information within computing device **30** during operation. Memory **62**, in some examples, is described as a computer-readable storage medium. Memory **62** may also be described as a storage device or computer-readable storage device. In some examples, memory **62** is a temporary memory, meaning that a primary purpose of memory **62** is not long-term storage. However, memory **62** may also be described as non-transitory. Memory **62**, in some examples, may be described as a volatile memory, meaning that memory **62** does not maintain stored contents when the computer is turned off. Examples of volatile memories include random access memories (RAM), dynamic random access memories (DRAM), static random access memories (SRAM), and other forms of volatile memories known in the art. In some examples, memory **62** is used to store program instructions for execution by processor **60**.

[0079] Computing device **30**, in some examples, also includes a network interface **68**. Computing device **30**, in one example, utilizes network interface **68** to communicate with other computing devices (e.g., networked server **44** of FIG. **3**), programmers (e.g., programmer **24** of FIG. **1**), computing devices **54** of FIG. **3**, or more networks, such as network **42** shown in FIG. **3**. In this manner, computing device **30** may transmit captured video information **64** to other computing devices and/or receive instructions related to capturing the video information. Network interface **68** may be a network interface card, such as an Ethernet card or other wired interface. In other examples, network interface **68** may include an optical transceiver, a radio frequency transceiver, or any other type of device that can send and receive information. Other examples of such network interfaces may include Bluetooth, 3G and WiFi radios in mobile computing devices as well as USB. In some examples, computing device **30** utilizes network interface **68** to wirelessly communicate with another computing device (e.g., computing device **54** of FIG. **3**) or other networked computing devices.

[0080] Computing device **30**, in one example, also includes one or more user interfaces **66**. User interface **66** may include a touch-sensitive and/or a presence-sensitive screen, mouse, a keyboard, a voice responsive system, camera, or any other type of device for detecting a command from a user. In one example, user interface **66** may include a touch-sensitive screen, sound card, a video graphics adapter card, or any other type of device for converting a signal into an appropriate form understandable to humans or machines. In addition, user interface **66** may include a speaker, a cathode ray tube (CRT) monitor, a liquid crystal display (LCD), or any other type of device that can generate intelligible output to a user.

[0081] Computing device **30**, in some examples, includes one or more power sources **70**, which provide power to computing device **30**. Generally, power source **70** may utilize power obtained from a wall receptacle or other alternating current source. However, in other examples, power source **70**, may include one or more rechargeable or non-rechargeable batteries (e.g., constructed from nickel-cadmium, lithium-ion, or other suitable material). In other examples, power source **70** may be a power source capable of providing stored power or voltage from another power source.

[0082] FIG. **5** is a functional block diagram illustrating an example configuration of networked server **44** and repository **46** of FIG. **3**. FIG. **5** illustrates only one particular example of server **44**, and many other example embodiments of server **44**

may be used in other instances. For example, server **44** may include additional components and run multiple different applications. Server **44** may be configured to identify patient behavior from captured video information (e.g., video information **50** of FIG. **3**) and, in some examples, select one or more therapies to be delivered to patient **12** based on the identified behaviors. For example, server **44** may be configured to perform some or all of the processes described with respect to FIGS. **6-18**.

[0083] As shown in the specific example of FIG. **5**, server **44** may include and/or house one or more processors **80**, memory **82**, a network interface **84**, user interface **86**, behavior identification module **88**, and power source **90**. Server **44** may be in communication with repository **46**, such that repository **46** is located external of server **44**. In other examples, repository **46** may include one or more storage devices within an enclosure of server **44**. Server **44** may also include an operating system, which may include modules and/or applications that are executable by processors **80** and server **44**. Each of components **80**, **82**, **84**, **86**, **88**, and **90** may be interconnected (physically, communicatively, and/or operatively) for inter-component communications.

[0084] Processors **80**, in one example, are configured to implement functionality and/or process instructions for execution within server **44**, such as identifying patient behavior from video information captured of patient movement. For example, processors **80** may be capable of processing instructions stored in memory **82** or instructions stored in repository **46**. These instructions may define or otherwise control the operation of server **44**. In some examples, behavior identification module **88** (which may include one or more dedicated processors) may be configured to analyze the video information **50** and identify the patient behaviors that occurred within the video information.

[0085] Memory **82**, in one example, is configured to store information within server **44** during operation. Memory **82**, in some examples, is described as a computer-readable storage medium. Memory **82** may also be described as a storage device or computer-readable storage device. In some examples, memory **82** is a temporary memory, meaning that a primary purpose of memory **82** is not long-term storage. However, memory **82** may also be described as non-transitory. Memory **82**, in some examples, may be described as a volatile memory, meaning that memory **82** does not maintain stored contents when the computer is turned off. Examples of volatile memories include random access memories (RAM), dynamic random access memories (DRAM), static random access memories (SRAM), and other forms of volatile memories known in the art. In some examples, memory **82** is used to store program instructions for execution by processors **80**. Memory **82**, in one example, is used by software or applications running on server **44** to temporarily store information during program execution. Although memory **82** of FIG. **5** is not described as including motion detection rules **98**, movement calculation rules **100** or behavior identification rules **102**, for example, memory **82** may store such instructions and other data in other examples.

[0086] Repository **46**, in some examples, also includes one or more computer-readable storage media, such as one or more storage devices. Repository **46** may be configured to store larger amounts of information than memory **82**. Repository **46** may further be configured for long-term storage of information. In some examples, repository **46** may include non-volatile storage elements. Examples of such non-volatile storage elements include magnetic hard discs, optical discs, floppy discs, flash memories, or forms of electrically programmable memories (EPROM) or electrically erasable and programmable (EEPROM) memories.

[0087] Repository **46** may be configured to store information related to or collected from each of multiple patients. For example, repository **46** may be configured to store video information collected from one or more patients as video information **92**. Each patient, and each period of time during which video information was captured for each patient, may be have separate memories or allocated space to store such data. Repository **46** may also store the behavior information (e.g., behavior information **50**) generated for each patient. Behavior information **94** may include the patient behaviors that were identified for each period of time in which video information was captured for each respective patient. Repository **46** may also store additional data, such as movement parameter values, that is generated during the process of identifying patient behavior from video information.

[0088] Repository **46** may also include data used to allocate sample areas of respective anatomical regions represented within the plurality of frames of the video information and analyze the frames. For example, sample area information **96** may include instructions for allocating, or determining, sample areas used to track anatomical region movement between frames of the captured video information. The instructions of sample area information **96** may request a user to define a sample area corresponding to an anatomical region in a sample frame. In addition, sample area information **96** may include instructions for automatically defining a supplemental sample area based on the location of the sample area defined by the user (e.g., the sample area may represent head **14** of patient **12** and the supplemental sample area may be torso **16** of patient **12**). In some examples, sample area information **96** may include instructions for automatically analyzing, or searching, the video frames of the captured video information for one or more frames suitable for defining a sample area. Repository **46** may also store any sample areas defined by user input and/or determined by server **44**. Examiner processes and techniques stored as sample area information **96** may be included in FIGS. **7** and **18**.

[0089] In addition, repository **46** may store additional rules and instructions used to identify patient behavior from video information. Motion detection rules **98** may include rules or instructions for processors **80** to determine motion of anatomical regions between frames of video information. Motion detection rules **98** may include at least some of the processes described in example FIGS. **8-10**. For example, motion detection rules **98** may instruct processors **80** to filter the captured pixels and generate a motion track map.

[0090] Movement calculation rules **100** may be stored by repository **46** and provide instructions to processors **80** regarding calculating values of movement parameters. The calculated movement parameter values may characterize the movement of anatomical regions between frames of the video information. Movement detection rules **100** may include at least some of the processes and techniques described in example FIGS. **11-13**. For example, movement detection rules **100** may include instructions for calculating the velocities and velocity angles of anatomical region movement and/or frequencies of movement in each frame. These movement parameter values may be used to identify which patient behaviors are present within the captured video information.

[0091] Behavior identification rules **102** may be stored by repository **46** and provide instructions to processors **80** regarding the criteria for identifying behaviors from the calculated movement parameters. The patient behaviors may be predetermined and selected when the movement parameter values indicate that the patient behavior has occurred. Behavior identification rules **102** may include the processes and techniques of example FIGS. **14-17**. For example, behavior identification rules **102** may include criteria for determining when the calculated movement parameter values indicate that the predetermined patient behaviors of dyskinesia, bradykinesia, or tremor have occurred in one or more anatomical region of patient **12**.

[0092] According to the rules and information stored in repository **46**, processors **80** may thus automatically analyze video information **50** to determine which patient behaviors occurred in the frames of the video information. In one example, processors **80** may be configured to obtain video information **50** of patient motion captured over a period of time. The video information may include a plurality of frames (e.g., video frames). Processors **80** may be configured to receive, with respect to one frame of the plurality of frames, a selection of a sample area representative of an anatomical region. Processors **80** may then be configured to analyze each of the other plurality of frames for respective areas corresponding to the sample area and calculate one or more movement parameters of the anatomical region during the period of time from at least one difference between the sample area and one or more respective areas of at least a subset of the plurality of frames. Processors **80** may next be configured to compare the one or more calculated movement parameters of the period of time to respective criteria for each of a plurality of predetermined patient behaviors. Using these comparisons, processors **80** may be configured to identify, based on the comparison, each one of the predetermined patient behaviors that occurred during the period of time.

[0093] Server **44**, in some examples, also includes a network interface **84**. Server **44**, in one example, utilizes network interface **84** to communicate with other computing devices (e.g., computing device **54** of FIG. **3**), programmers (e.g., programmer **24** of FIG. **3**), medical devices, or more networks, such as network **42** shown in FIG. **3**. In this manner, server **44** may receive video information **50** and transmit information such as behavior information **50**. Network interface **84** may be a network interface card, such as an Ethernet card or other wired interface. In other examples, network interface **84** may include an optical transceiver, a radio frequency transceiver, or any other type of device that can send and receive information. Other examples of such network interfaces may include Bluetooth, 3G and WiFi radios in mobile computing devices as well as USB. In some examples, server **44** utilizes network interface **84** to wirelessly communicate with another computing device (e.g., computing device **54** of FIG. **3**) or other networked computing devices.

[0094] Server **44**, in one example, also includes one or more user interfaces **86**. User interface **86** may include a touch-sensitive and/or a presence-sensitive screen, mouse, a keyboard, a voice responsive system, camera, or any other type of device for detecting a command from a user. In one example, user interface **86** may include a touch-sensitive screen, sound card, a video graphics adapter card, or any other type of device for converting a signal into an appropriate form understandable to humans or machines. In addition, user interface **86** may include a speaker, a cathode ray tube (CRT) monitor, a liquid crystal display (LCD), or any other type of device that can generate intelligible output to a user.

[0095] Server **44**, in some examples, includes one or more power sources **90**, which provide power to server **44**. Generally, power source **90** may utilize power obtained from a wall receptacle or other alternating current source. However, in other examples, power source **90**, may include one or more rechargeable or non-rechargeable batteries (e.g., constructed from nickel-cadmium, lithium-ion, or other suitable material). In other examples, power source **90** may be a power source capable of providing stored power or voltage from another power source.

[0096] Server **44** may, in some examples, utilize behavior identification module **88** to identify which patient behaviors occurred within the video information. Behavior identification module **88** may communicate with repository **46** to retrieve, in accordance with instructions such as stored commands or user input, sample area information **96**, motion detection rules **98**, movement calculation rules **100**, and behavior identification rules **102** as needed to identify the behaviors of the patient. Behavior identification module **88** may include dedicated hardware (e.g., one or more processors), firmware, and/or software to perform the functions described herein. In other examples, one or more of processors **80** may perform some or all of the functions described herein within respect to behavior identification module **88**. Any software implemented within or executed by server **44** may be implemented or contained within, operable by, executed by, and/or be operatively/communicatively coupled to components of server **44** (e.g., processors **80**, memory **82**, network interface **84**, and/or repository **46**).

[0097] FIGS. **6-18** are flow diagrams illustrating various processes and techniques that may be used to identify patient movement behaviors from video information captured of patient **12**. Each of FIGS. **6-18** may provide portions or subparts of the overall process that may be used in some examples. Generally, one or more processors **80** of networked server **44** are described as performing the described processes in FIGS. **6-18**. However, the processes may be performed by one or more other devices or systems (e.g., computing device **30** or computing device **54** or combinations of different processors and/or devices in other examples.

[0098] FIG. **6** is a flow diagram that illustrates an example process for identifying patient behaviors based on analyzed video information **50** of patient **12**. As shown in FIG. **6**, an example overall process may be used by processors **80** to identify one or more patient behaviors that occurred during the period of time in which video information **50** was captured by camera **26**. Processors **80** may obtain video information **50** of the movement of patient **12** captured during a period of time (**104**). Video information **50** may include a plurality of frames. Processors **80** may also determine the anatomical region or regions for which motion will be detected from video information **50** (**106**). Determining the anatomical regions may include receiving user input defining one or more sample area of one or more video frames that correspond to the desired anatomical regions. In other examples, processors **80** may define a sample area for another anatomical region based on the user defined first sample area.

[0099] Processors **80** may also calculate at least one movement parameter from video information **50** and for the one or more anatomical regions defined in the one or more frames (**108**). In some examples, processors **80** may analyze the frames of video information **50** to identify the areas within

frames that correspond to each respective sample area. In this manner, processors **80** may define the anatomical region within each of the frames prior to calculating the movement parameters. In response to calculating the movement parameter values for each of the frames of video information **50**, processors **80** may identify, based on the movement parameter values, one or more patient behaviors of patient **12** during the period of time in which video information **50** was obtained (**110**). Since this identification may be based on the comparison of movement parameter values to criteria for each of a plurality of predefined patient behavior, processors **80** may generate an objective indication of the patient behavior and movement disorders. Networked server **44** may then output the identified patient behaviors to computing device **54** via network **42**, in some examples.

[0100] In some examples, processors **80** may identify patient behavior based on movement parameters for multiple anatomical regions. For example, one region may be head **14** of patient **12** and another region may be torso **16** of patient **12**. Processors **80** may determine the respective areas of each frame that correspond to the anatomical regions and calculate one or more movement parameters of the head and torso regions during the period of time from at least one difference between the respective sample areas and one or more respective areas of a subset of the plurality of frames corresponding to the respective sample areas. Processors **80** may then be configured to identify each one of the predetermined patient behaviors that occurred during the period of time based on the respective movement parameters of both the head and the torso regions of patient **12**.

[0101] FIG. **7** is a flow diagram that illustrates an example process for allocating sample areas representing a respective anatomical region captured in video information **50**. As shown in FIG. **7**, processors **80** may obtain video information **50** of patient **12** and output or control a display device to present a frame of video information **50** (**112**). For example, processors **80** may transmit the frame to computing device **54** for presentation to a user. Processors **80** may receive, with respect to the one frame presented to the user, a selection or a user input defining a first area corresponding to head **14** of patient **12** (**114**). If there is another frame in which a sample area should be defined ("YES" branch of block **116**), processors **80** may select the next frame (**118**) and continue to output or present the frame to a user (**112**). Multiple sample areas for the same anatomical region may be defined for the video information to account for variations in video quality, non-continuous video information, and/or different angles in which one sample area may not be sufficient to track the anatomical region through other frames.

[0102] If there is no other frame to select a sample area ("NO" branch of block **116**), processors **80** may check to see if there is any user input to select the body or torso **16** anatomical region of patient **12** (**120**). If there is input to receive ("YES" branch of block **120**), processors may receive indications of input identifying a second sample area of the frame that corresponds to torso **16** of patient **12** (**112**). If there is no input to receive ("NO" branch of block **120**), then processors **80** may automatically determine or select a default second sample area that corresponds to torso **16** and is based on the head sample area (**124**). For example, processors **80** may determine a rectangular area below the center of the sample area of head **14** as the area corresponding to torso **16**. Processors **80** may define the top two corners of the rectangular area as the shoulders of patient **12**. The rectangular area of the torso may be a default rectangle stored in memory.

[0103] Since the default rectangle may not be the appropriate size to the torso of patient **12** in the frame, processors **80** may scale the default rectangle to the size of the sample area of head **14** defined by the user (**126**). As described herein, various velocity and motion thresholds may be dynamically adjusted based on the size of one or more anatomical regions defined by the corresponding sample area. After processors **80** have determined each of the first and second sample areas that represent the respective anatomical regions, processors **80** may store the sample areas to track the corresponding anatomical region movement through other frames of the period of time in which the video information was captured.

[0104] Although the anatomical regions of FIG. **7** are described as head **14** and body **16** of patient **12**, any portions of the anatomy of patient **12** may be selected to perform the motion analysis. Only one anatomical region may be identified with a sample area or more than two regions may be identified by respective sample areas. In other examples, the sample area may correspond to other anatomical regions, such as one or more arms, hands, legs, feet, or any combination thereof.

[0105] FIG. **8** is a flow diagram that illustrates an example process for identifying areas of video frames corresponding to the sample area of a different frame. Once a sample area is identified, processors **80** can compare the sample area to corresponding areas in the next frame (**130**). Processors **80** may analyze each of the other frames from the frame with the sample area for respective areas that correspond to the sample area. To complete this process, processors **80** may search successive frames from the area that is temporally contiguous with another area most similar to the sample area. Processors **80** may this determine where the sample area has moved within the frames of the video information.

[0106] Since the area of the next frame that is most similar to the sample area may not be exactly the same, processors **80** may generate a correlation coefficient between the sample area and the corresponding area in the subsequent frame by comparing the sample area to the corresponding area (**132**). If the correlation coefficient is not greater than a correlation threshold ("NO" branch of block **134**), processors **80** may not identify the corresponding area in the next frame as the anatomical region of the sample area (**136**). If the correlation coefficient is greater than the correlation threshold ("YES" branch of block **134**), processors **80** may identify the corresponding area in the next frame as the anatomical region of the sample area (**138**). The correlation threshold may be user-specific, program-specific based on the anatomical region or other criteria, or predetermined.

[0107] If there is another frame to analyze for a corresponding area to the sample area ("YES" branch of block **140**), processors **80** may select the next frame (**142**) and again compare the sample area to possible corresponding areas in the next frame (**130**). If there are no other frames to analyze, ("NO" branch of block **140**), processors **80** may store indications of the identified corresponding areas for each of the respective frames (**144**). Processors **80** may perform the process of FIG. **8** for each of the sample areas and/or anatomical regions (e.g., a head and a torso) selected by a user or otherwise defined in the video information.

[0108] FIG. **9** is a flow diagram that illustrates an example process for filtering raw motion pixels from noise in video information **50**. As shown in FIG. **9**, processors **80** may obtain

video information **50** with multiple video frames and select the initial frame of the video information (**146**). Processors **80** may filter the data in each frame by subtracting the next, or subsequent, frame from the previous frame to generate raw motion pixels (**148**). In this manner, processors **80** may be configured to generate raw motion pixels for each of the plurality of frames, wherein the raw motion pixels are a difference between pixels of each of the other plurality of frames and its respective prior frame.

[0109] For each raw motion pixel of the frame, processors **80** may determine a gray intensity value (**150**). For each raw motion pixel of the frame processors **80** may compare the respective gray intensity value to a gray intensity threshold (**152**). Processors **80** may then remove any raw motion pixels with a gray intensity value below the gray intensity threshold (**154**). Stated another way, processors **80** may be configured to identify raw motion pixels having a gray intensity value greater than the gray intensity threshold as intensity motion pixels for that frame (**156**). If there is another frame to be filtered ("YES" branch of block **158**), processors **80** may select the next frame (**160**) and generate raw motion pixels for that next frame (**148**). If there are no other frames to be filtered ("NO" branch of block **158**), processors **80** may generate a motion track map comprising the intensity motion pixels of each of the other plurality of frames (**162**). The process of FIG. **9** may be referred to as gray-intensity filtering.

[0110] FIG. **10** is a flow diagram that illustrates an example process for generating a motion track map with pixels indicative of patient motion. The process of FIG. **10** may be an additional filtering mechanism to the gray-intensity filtering of FIG. **9**. Processors **80** may first select the video frames to filter, which may be all of the frames from the video information (**164**). For each intensity motion pixel generated in FIG. **9**, processors **80** may determine if the intensity motion pixel occurs in a continuous or adjacent area in a subsequent frame (**166**). If the pixels in the pair of frames are not continuous ("NO" branch of block **168**), processors **80** may remove the pixel as random noise in the original frame (**170**). If the pixels in the pair of frames are continuous with each other ("YES" branch of block **168**), processors **80** may identify and include the pixel as a real motion pixel representative of movement of the anatomical region (**172**).

[0111] If there are more intensity motion pixels to analyze ("YES" branch of block **174**), processors **80** may select the next intensity motion pixel (**176**) and again determine the continuity of the pixel to a subsequent frame (**166**). If there are no more pixels in the frame to analyze ("NO" branch of block **174**), processors may determine if there are more frames to analyze (**178**). If there are more frames to analyze ("YES" branch of block **178**), processors **80** may select the next frame (**180**) and again determine the continuity of the pixel in the next frame to a subsequent frame (**166**). After all intensity motion pixels are analyzed or filtered, processors **80** may save the real motion pixels for each frame as a motion track map (**182**). In other words, processors **80** may update the motion track map to include only the identified real motion pixels.

[0112] FIG. **11** is a flow diagram that illustrates an example process for calculating values of movement parameters for each frame of the motion track map of FIG. **10**. The process of FIG. **11** is described with respect to a head of patient **12**. However, the same process may be used for other anatomical regions. As shown in FIG. **11**, processors **80** may select a frame with the real motion pixels (**184**). Processors **80** may then determine and store a center of the head from the area of real motion pixels corresponding to the head region (**186**). After selecting the next frame for the period of time (**188**), processors **80** may determine and store the center of the head from the area of real motion pixels in this next frame (**190**). Based on the two center positions of the head in the pair of frames, processors **80** may calculate the velocity of the head movement between the selected frame and the previous frame (**192**).

[0113] Processors **80** may also calculate the normalized tortuosity at the selected frame (**194**). The normalized tortuosity may be a measure of how much effort patient **12** was using to maintain the head in a certain location. The normalized tortuosity may be a ratio of a distance the center of the corresponding area moved from the prior frame to a distance a center of the anatomical region moved during the period of time. In other words, the ratio is the movement of the head over a short period of time to the movement of the head over a long period of time. A greater ratio indicates a larger tortuosity value and the more effort that a patient needs to use to keep the head in a desired location.

[0114] Put another way, the normalized tortuosity may be defined mathematically. At any given frame, the normalized tortuosity may be calculated as:

$$R_F = 1 - \frac{EL_F}{PL_F}, \tag{1}$$

wherein R_F is the normalized tortuosity, EL_F is then end-point length or the distance the head has actually moved over a specified period, and PL_F is the path length or distance the head moved between frames (or between the two frames in which the distance is to be calculated). According to the equation (1), the normalized tortuosity will be close to 1 when the head is quivering between frames and the overall end-point length remains close to zero. Conversely, the normalized tortuosity value may be close to 0 when there is not much quivering motion or total motion of the head.

[0115] Processors **80** may also calculate the velocity of the head movement and the amount of motion in addition to the uncertainty of the head movement (**196**). Processors **80** may determine the uncertainty in the head movement by analyzing the correlation coefficient of the head, determining if the head center moves more than a distance threshold in consecutive frames, and/or a ratio of the movement displacement contradicts the velocity of the head (e.g., there is a small movement displacement and a large velocity). These uncertainty determinations may establish when the behavior may be reliable and when it is not reliable.

[0116] FIG. **12** is a flow diagram that illustrates an example process for generating motion groups of pixels and calculating movement parameters for each of the motion groups. As shown in FIG. **12**, processors **80** may determine or receive a sample body location (e.g., a sample area corresponding to the torso of patient **12**) (**202**) and calculate a real motion map (**204**) according to the processes described herein. For the identified real motion pixels each of the other plurality of frames, processor **80** may be configured to combine neighboring real motion pixels into respective motion groups (**206**). Processors **80** may then calculate a motion center for each of the respective motion groups (**208**). If there is another frame from which motion groups need to be determined

("YES" branch of block **210**), processors **80** may select the next frame and combine the neighboring motion pixels into motion groups (**206**).

[0117] If there are no additional frames to analyze ("NO" branch of block **210**), processors **80** may, for each of the motion centers, calculate a velocity for the respective frame and calculate a velocity change and a velocity angle between the motion center and the corresponding motion center from the prior frame (**212**). If there are more pairs of frames ("YES" branch of block **214**), processors **80** may again calculate the respective velocity change and velocity angle (**212**). If there are no further pairs of frames to analyze ("NO" branch of block **214**), processors **80** may store the movement parameter values (e.g., storing the velocity, the velocity change, and the velocity angle as respective movement parameter values (**216**). In some examples, the uncertainty of the body movement described in FIG. **12** may be determined by the uncertainty of the head region previously calculated or other body specific correlation coefficients.

[0118] Processors **80** may, in one example, determine the closest pair of motion centers between two consecutive frames M_F and M_{F-T}, where T is the length of an analysis period between frames. Let $C_{F,i}$ denote the i^{th} motion center in M_F and $C_{F-T,j}$ denote the j^{th} motion center in M_{F-T} (i.e. $C_{F,i} \epsilon M_F$ and $C_{F-T,j} \epsilon M_{F-T}$). Each pair of motion centers thus indicates a possible movement in a body region in the period of T. If $\{C_{F,i}, C_{F-T,j}\}$ is a matching pair of motion centers in video frame F and (F−T), a movement velocity between $\{C_{F,i}, C_{F-T,j}\}$, denoted as $V_{F,i}$, can then be calculated as $C_{F,i}-C_{F-T,j}$. The velocity angle of $V_{F,i}$, denoted as $A_{F,i}$, is computed as the angle between $V_{F,i}$ and the x-axis. The velocity change $\Delta V_{F,i}$ and angular change $\Delta A_{F,i}$ from frame (F−T) to F for motion center $C_{F,i}$ can then be obtained as $V_{F,i}-V_{F-T,j}$ and $A_{F,i}-A_{F-T,j}$, respectively.

[0119] FIG. **13** is a flow diagram that illustrates an example process for calculating movement parameters representing frequency of patient motion. As shown in FIG. **13**, processors **80** may obtain real motion pixels (e.g., from the process of FIG. **10**) for frames of an analysis period and select a first frame (**220**). Processors **80** may apply a fast Fourier transform (FFT) to the real motion pixels of the selected frame (**222**) and determine the highest three amplitude spectrums from the FFT analysis (**224**). The highest three amplitude spectrums may be the most common frequencies within the analysis. Processors **80** may determine if any of the three amplitude spectrums are within a predetermined frequency range (**226**). For example, the predetermined frequency range may be selected according to a certain behavior, such as tremor. An example range of frequency may be approximately 4-8 Hz for detecting the presence of a tremor. Other ranges of frequencies associated with other types of movement disorders may be used in addition to or alternatively from the predetermined frequency range for tremor. Frequency ranges may fall within any movement disorder frequency such as between approximately 0.1 Hz to 50 Hz.

[0120] If none of the three highest amplitude spectrums are within the predetermined frequency range ("NO" branch of block **226**), processors **80** may select another frame to analyze (**234**). If any of the three highest amplitude spectrums are within the predetermined frequency range ("YES" branch of block **226**), processors **80** may set the highest, or most common, frequency as the detected frequency (**228**). Processors **80** may also calculate the confidence level as the inverse of the highest frequency in the range (**230**) and store the detected frequency and confidence level (**232**). For example, if highest amplitude spectrum is within the predetermined frequency range, the confidence level would be 1. If the third highest amplitude spectrum is within the predetermined frequency range, the confidence level would be ⅓. This frequency analysis may allow processors **80** to extract rhythmic movements for diagnosis and treatment such as tics, blinking, twinges, spasms, hand or limb movements, and trunk movement. If there is another frame to analyze ("YES" branch of block **234**), processors **80** may select the next frame (**236**) and apply the FFT to the next frame (**232**). If there is no other frame to analyze ("NO" branch of block **234**), processors **80** may terminate the analysis (**238**). Although only the top three amplitude spectrums may be used in this example, other examples may include ranging all of the amplitude spectrums to see if any fall within the predetermined frequency range. The confidence level may then be the inverse of the rank of the frequency.

[0121] FIG. **14** is a flow diagram that illustrates an example process for identifying dyskinesia in the head of patient **12**. In other examples, the process of FIG. **14** may be used to identify dyskinesia in a limb or other location of the body. As shown in FIG. **14**, processors **80** may determine the analysis period for the behavior (e.g., the period of time that the video information was captured) (**240**) and obtain the tortuosity calculation for each frame of the analysis period (**242**). The tortuosity calculation is described in FIG. **11**.

[0122] For each of the plurality of frames, processors **80** may compare the value of the tortuosity parameter to a tortuosity threshold and generate, based on the comparison for each of the other plurality of frames, a frequency for which the value of the normalized tortuosity exceeded the tortuosity threshold during the period of time (**244**). If the frequency is less than the tortuosity threshold ("NO" branch of block **246**), processors **80** do not confirm dyskinesia of the head (**254**).

[0123] If the frequency is greater than the tortuosity threshold ("YES" branch of block **246**), processors **80** may obtain or generate, for each of the other plurality of frames, an uncertainty of the respective areas corresponding to the anatomical region (**248**). Processors **80** may also determine the occurrence of the uncertainty in the frames. If the uncertainty of the respective areas is greater than an uncertainty occurrence threshold ("NO" branch of block **252**), processors **80** may determine that dyskinesia is unconfirmed or not an issue (**254**). If the uncertainty of the respective areas is less than the occurrence threshold ("YES" branch of block **252**), processors **80** may, in response to determining the occurrence of uncertainty, processors **80** may confirm dyskinesia in the head and store the indication for the analysis period.

[0124] FIG. **15** is a flow diagram that illustrates an example process for identifying bradykinesia as a patient behavior in a patient. As shown in FIG. **15**, processors **80** may obtain the movement parameter values for the analysis period and select a first frame (**260**). For example, the movement parameter values may be calculated according to the process of FIG. **12**. Processors **80** may compare the velocity of the motion center to a velocity threshold (**262**), compare the change in velocity to a change threshold (**264**), and compare the change in velocity angle to an angle threshold (**266**). If processors **80** determine that at least one of one or more motion centers within the respective frame have a velocity greater than a velocity threshold (**262**), a velocity change less than a velocity change threshold (**264**), and a velocity angle less than a velocity angle threshold (**266**), processors **80** may indicate, based on the

determination, that bradykinesia occurred in the respective frame (**270**). If processors **80** determine that at least one of one or more motion centers within the respective frame have a velocity less than a velocity threshold (**262**), a velocity change greater than a velocity change threshold (**264**), and a velocity angle greater than a velocity angle threshold (**266**), processors **80** may indicate, based on the determination, that no bradykinesia was identified within the frame (**268**).

[0125] If processors **80** determine that there is another frame to analyze ("YES" branch of block **272**), processors **80** may select the next frame (**274**) and compare the movement parameter values to their respective thresholds. If processors **80** determine that there are no other frames to be analyzed ("NO" branch of block **272**). Processors **80** may identify bradykinesia, or determine that bradykinesia occurred, when bradykinesia has been identified in more than a threshold number of frames (**276**). Processors **80** may also determine an uncertainty of the respective areas corresponding to the anatomical region occurred at a frequency less than an uncertainty occurrence threshold (**278**). In response to determining that bradykinesia was identified in a threshold number of frames and that the occurrence uncertainty was less than the uncertainty occurrence threshold, processors **80** may confirm and identify that bradykinesia occurred for the anatomical region during the period of time in which video information was captured (**280**). The process of FIG. **15** may include various criteria for identifying the patient behavior of bradykinesia. Each of the thresholds may be user-selected, device-selected, or predefined.

[0126] FIG. **16** is a flow diagram that illustrates an example process for identifying dyskinesia in a body of a patient. As shown in FIG. **16**, processors **80** may obtain the movement parameter values for the analysis period and select a first frame (**282**). For example, the movement parameter values may be calculated according to the process of FIG. **12** for a sample area corresponding to a body area such as torso **16**. Processors **80** may compare the velocity of the motion center to a velocity threshold (**284**), compare the change in velocity to a change threshold (**286**), and compare the change in velocity angle to an angle threshold (**288**). If processors **80** determine that at least one of one or more motion centers within the respective frame have a velocity greater than a velocity threshold (**284**), a velocity change greater than a velocity change threshold (**286**), and a velocity angle greater than a velocity angle threshold (**288**), processors **80** may indicate, based on the determination, that dyskinesia occurred in the respective frame (**292**). If processors **80** determine that at least one of one or more motion centers within the respective frame have a velocity less than a velocity threshold (**284**), a velocity change less than a velocity change threshold (**286**), and a velocity angle less than a velocity angle threshold (**288**), processors **80** may indicate, based on the determination, that no dyskinesia was identified within the frame (**290**).

[0127] If processors **80** determine that there is another frame to analyze ("YES" branch of block **294**), processors **80** may select the next frame (**296**) and compare the movement parameter values to their respective thresholds. If processors **80** determine that there are no other frames to be analyzed ("NO" branch of block **294**). Processors **80** may identify dyskinesia, or determine that dyskinesia occurred, when dyskinesia has been identified in more than a threshold number of frames (**298**). Processors **80** may also determine an uncertainty of the respective areas corresponding to the anatomical region occurred at a frequency less than an uncertainty occurrence threshold (**300**). In response to determining that dyskinesia was identified in a threshold number of frames and that the occurrence uncertainty was less than the uncertainty occurrence threshold, processors **80** may confirm and identify that dyskinesia occurred for the anatomical region (such as a torso region) during the period of time in which video information was captured (**302**). The process of FIG. **16** may include various criteria for identifying the patient behavior of dyskinesia. Each of the thresholds may be user-selected, device-selected, or predefined.

[0128] FIG. **17** is a flow diagram that illustrates an example process for identifying tremor in a patient. The process of FIG. **17** may require the movement information, or movement parameter values, calculated to determine the frequency with which the patient was moving in the period of time the video information was captured. As shown in FIG. **17**, processors **80** may obtain the movement information for the analysis period (**304**). The movement information may include the calculated movement parameter values described in FIG. **13**. For example, processors **80** may be configured to apply a fast Fourier transform (FFT) to the real motion pixels of the frame to generate amplitude spectrums in a frequency domain, select three frequencies having the highest amplitude spectrums in the frequency domain, select, based on the comparison, one of the three frequencies that falls within a predetermined range of frequencies and has the highest amplitude spectrum of the three frequencies, and store the selected one of the three frequencies as a detected frequency for the respective frame. Processors **80** may perform this frequency analysis on each of the frames with real motion pixels.

[0129] Processors **80** may then determine the occurrence of frames in which the detected or computed frequency is within the specified range (**305**). In other words, this step may include a determination of the occurrence with which a subset of frames includes the detected frequency that falls within the specified, or predetermined, frequency range. If the occurrence of the frames is less than an occurrence threshold ("NO" branch of block **306**), processors **80** may determine that there is no tremor and that the tremor is unconfirmed (**307**). If the occurrence of frames is greater than the occurrence threshold ("YES" branch of block **306**), processors **80** may determine an occurrence of the uncertainty of the respective areas (such as the uncertainty of the head region) corresponding to the anatomical region for the frames of the period of time (**308**). This occurrence may be the frequency at which the uncertainty is greater than a threshold for each frame.

[0130] If the occurrence of the uncertainty in each frame is greater than an uncertainty occurrence threshold ("NO" branch of block **309**), processors **80** will determine that the tremor is unconfirmed and not present (**307**). If the occurrence of the uncertainty in each frame is less than the uncertainty occurrence threshold ("YES" branch of block **309**), processors **80** may be configured to confirm that the behavior of tremor was present in the frames of the analysis period (**310**). In this manner, processors **80** may identify tremor as at least one patient behavior that occurred during the period in response to determining the occurrence of the specified frequency exceeded the occurrence threshold and the uncertainty was less than the uncertainty occurrence threshold.

[0131] Each of the processes described herein may be performed on the same video information **50** such that multiple different patient behaviors may be assessed on the same video frames. In this manner, processors **80** may be configured to identify different behaviors present in the same frames and/or

same patient motions. For example, processors **80** may perform the processes of FIGS. **14-17** on the same video frames. Although dyskinesia, bradykinesia, and tremor are described herein as some predetermined patient behaviors to be identified from the video information, other patient behaviors (e.g., dystonia, rigidity, restless leg syndrome, etc.) may be identified in other examples using similar techniques. Each of the thresholds herein may be based on at least one of the type of behavior to be identified, asymptomatic movement parameter values, clinician experience, other patient data, individual patient history, patient age, currently delivered therapies, or any other related input.

[0132] In some examples, processors **80** and/or additional devices may be configured to process the video data in multiple ways to identify a single patient behavior. For instance, processors **80** may process the video data to identify tremor according to the examples above. Processors **80** may also process the same video data to identify whether the tremor occurred during patient movement, as may be determined by determining whether a velocity of a motion center of one or more body regions of the patient is greater than a threshold. An entire body region of the patient may be used to determine whether the patient is moving between two different areas of the video frame, such as between two different locations within the room where the patient resides. Processor **80** may utilize both the frequency and velocity information obtained from the video data to identify whether the patient behavior relates to tremor during rest (e.g., the patient is stationary) or tremor during motion (e.g., the patient is ambulatory).

[0133] The behaviors identifiable by processors **80** described above are some examples, but processors **80** may be configured to identify any number of alternative or additional patient behaviors. For example, processors **80** may be configured to define behaviors associated with a patient's gait, vertical stability, postural stability, posture symmetry, arm-swing size, overall body rigidity, overall poverty of movement (e.g., lack of movement), whether the patient is experiencing passive motion, and any other such behaviors. Processors **80** may define behaviors associated with any one or more parts of the patient's body. For instance, behaviors associated with facial features, such as lip movement or tongue manipulation, may be defined by processors **80** from the video data. In some cases, processors **80** may be configured to define one or more behaviors associated with multiple parts of the patient's body.

[0134] FIG. **18** is a flow diagram that illustrates an example process for suggesting one or more frames of video information **50** in which to define a sample area of an anatomical region of patient **12**. The process of FIG. **18** may be performed by processors **80** in order to present candidate video frames that may be suitable for defining a sample area. In some examples, the process of FIG. **18** may be used to identify two or more sample areas within the plurality of frames within the video information when patient **12** may have moved positions or otherwise changed how one or more anatomical regions can be viewed. In this manner, processors **80** may identify potential problematic frames for analyzing patient motion and may present candidate frames intended to resolve any analysis issues before the analysis is even performed.

[0135] As shown in FIG. **18**, processors **80** may obtain video information **50** of patient movement (**312**). Processors **80** may then scan the plurality of frames for one or more candidate frames having the anatomical region and for selection (or defining) a sample area of the anatomical region (**313**). For example, the anatomical region may be head **14** of patient **12**. Processors **80** may select, based on the scan, one or more candidate frames to be presented for user definition of respective sample areas (**314**). Processors **80** may identify frames in which certain areas change dramatically or frames associated with a continuous chain of frames including a similar area.

[0136] Processors **80** may output the one or more candidate frames for presentation to a user (e.g., clinician **22**). After the user defines one or more sample areas, processors **80** may receive the sample area identification for the respective frames (**315**). In response to receiving the sample areas, processors **80** may perform the analysis of the video information and included frames to identify the occurrence of any patient behavior within the captured video information (**316**). In some examples, processes **80** may select one or more candidate frames in response to identifying a group of frames (e.g., consecutive frames) in which calculated uncertainty levels exceed an uncertainty threshold or other issues with the analysis arise.

[0137] As described herein, a networked server **44** or any other computing device may perform one or more processes to identify patient behavior from video information captured of patient **12**. These identified patient behaviors may be used to diagnose movement disorders or underlying diseases and/or or monitor the progression of such disorders. In addition, the identified patient behaviors may be used to control or improve the delivery of therapy to patient **12**. For example, the identified patient behavior may be used as direct feedback used to control therapy delivery. In another example, the identified patient behavior may be used to calibrate other sensors that provide sensed patient parameter values used as feedback in controlling therapy. The types of therapy that may be controlled include electrical stimulation therapy, drug delivery therapy, and/or oral medication prescriptions.

[0138] FIG. **19** is a conceptual diagram illustrating example system **320** that includes implantable medical device (IMD) **324** configured to deliver deep brain stimulation to patient **12**A. Patient **12**A may be patient **12**A of FIGS. **1** and **2** or a different patient. System **320** may be configured to treat a patient condition, such as a movement disorder, neurodegenerative impairment, a mood disorder or a seizure disorder of patient **12**A. Patient **12**A ordinarily will be a human patient. In some cases, however, therapy system **320** may be applied to other mammalian or non-mammalian, non-human patients. While movement disorders and neurodegenerative impairment are primarily referred to herein, in other examples, therapy system **320** may provide therapy to manage symptoms of other patient conditions, such as, but not limited to, seizure disorders (e.g., epilepsy) or mood (or psychological) disorders (e.g., major depressive disorder (MDD), bipolar disorder, anxiety disorders, post-traumatic stress disorder, dysthymic disorder, and obsessive-compulsive disorder (OCD)). At least some of these disorders may be manifested in one or more patient movement behaviors. As described herein, a movement disorder or other neurodegenerative impairment may include symptoms such as, for example, muscle control impairment, motion impairment or other movement problems, such as rigidity, spasticity, bradykinesia, rhythmic hyperkinesia, nonrhythmic hyperkinesia, and akinesia. In some cases, the movement disorder

may be a symptom of Parkinson's disease. However, the movement disorder may be attributable to other patient conditions.

[0139] Example therapy system **320** includes medical device programmer **24**, implantable medical device (IMD) **324**, lead extension **328**, and leads **330**A and **330**B with respective sets of electrodes **332**, **334**. In the example shown in FIG. **19**, electrodes **332**, **334** of leads **330**A, **330**B are positioned to deliver electrical stimulation to a tissue site within brain **322**, such as a deep brain site under the dura mater of brain **322** of patient **12**A. In some examples, delivery of stimulation to one or more regions of brain **322**, such as the subthalamic nucleus, globus pallidus or thalamus, may be an effective treatment to manage movement disorders, such as Parkinson's disease. Electrodes **332**, **334** are also positioned to sense bioelectrical brain signals within brain **322** of patient **12**A. In some examples, some of electrodes **332**, **334** may be configured to sense bioelectrical brain signals and others of electrodes **332**, **334** may be configured to deliver electrical stimulation to brain **322**. In other examples, all of electrodes **332**, **334** are configured to both sense bioelectrical brain signals and deliver electrical stimulation to brain **322**.

[0140] IMD **324** includes a therapy module that includes a stimulation generator that generates and delivers electrical stimulation therapy to patient **12**A via a subset of electrodes **332**, **334** of leads **330**A and **330**B, respectively. The subset of electrodes **332**, **334** that are used to deliver electrical stimulation to patient **12**A, and, in some cases, the polarity of the subset of electrodes **332**, **334**, may be referred to as a stimulation electrode combination. As described in further detail below, the stimulation electrode combination can be selected for a particular patient **12**A and target tissue site (e.g., selected based on the patient condition) based on one or more frequency domain characteristics of a bioelectrical brain signal (e.g., a patient parameter) that is sensed by one or more groups of electrodes **332**, **334** that are associated with the stimulation electrode combination. The group of electrodes **332**, **334** includes at least one electrode and can include a plurality of electrodes. In some examples, the bioelectrical signals sensed within brain **322** may reflect changes in electrical current produced by the sum of electrical potential differences across brain tissue. Examples of bioelectrical brain signals include, but are not limited to, electrical signals generated from local field potentials (LFP) sensed within one or more regions of brain **322**, such as an electroencephalogram (EEG) signal, or an electrocorticogram (ECoG) signal. Local field potentials, however, may include a broader genus of electrical signals within brain **322** of patient **12**A. Each of these signals may be correlated or calibrated with the identified patient behavior and used for feedback in controlling the delivery of therapy.

[0141] In some examples, the bioelectrical brain signals that are used to select a stimulation electrode combination may be sensed within the same region of brain **322** as the target tissue site for the electrical stimulation. As previously indicated, these tissue sites may include tissue sites within the thalamus, subthalamic nucleus or globus pallidus of brain **322**, as well as other target tissue sites. The specific target tissue sites and/or regions within brain **322** may be selected based on the patient condition. Thus, in some examples, both a stimulation electrode combination and sense electrode combinations may be selected from the same set of electrodes **332**, **334**. In other examples, the electrodes used for delivering electrical stimulation may be different than the electrodes used for sensing bioelectrical brain signals.

[0142] Electrical stimulation generated by IMD **324** may be configured to manage a variety of disorders and conditions. In some examples, the stimulation generator of IMD **324** is configured to generate and deliver electrical pulses to patient **12**A via electrodes of a selected stimulation electrode combination. However, in other examples, the stimulation generator of IMD **324** may be configured to generate and deliver a continuous wave signal, e.g., a sine wave or triangle wave. In either case, a signal generator within IMD **324** may generate the electrical stimulation therapy for DBS according to a therapy program that is selected at that given time in therapy. In examples in which IMD **324** delivers electrical stimulation in the form of stimulation pulses, a therapy program may include a set of therapy parameter values, such as a stimulation electrode combination for delivering stimulation to patient **12**A, pulse frequency, pulse width, and a current or voltage amplitude of the pulses. As previously indicated, the stimulation electrode combination may indicate the specific electrodes **332**, **334** that are selected to deliver stimulation signals to tissue of patient **12**A and the respective polarity of the selected electrodes.

[0143] IMD **324** may be implanted within a subcutaneous pocket above the clavicle, or, alternatively, the abdomen, back or buttocks of patient **12**A, on or within cranium **32** or at any other suitable site within patient **12**A. Generally, IMD **324** is constructed of a biocompatible material that resists corrosion and degradation from bodily fluids. IMD **324** may comprise a hermetic housing to substantially enclose components, such as a processor, therapy module, and memory.

[0144] As shown in FIG. **19**, implanted lead extension **328** is coupled to IMD **324** via connector **30** (also referred to as a connector block or a header of IMD **324**). In the example of FIG. **19**, lead extension **328** traverses from the implant site of IMD **324** and along the neck of patient **12**A to cranium **32** of patient **12**A to access brain **322**. In the example shown in FIG. **19**, leads **330**A and **330**B (collectively "leads **330**") are implanted within the right and left hemispheres, respectively, of patient **12**A in order deliver electrical stimulation to one or more regions of brain **322**, which may be selected based on the patient condition or disorder controlled by therapy system **320**. The specific target tissue site and the stimulation electrodes used to deliver stimulation to the target tissue site, however, may be selected, e.g., according to the identified patient behaviors and/or other sensed patient parameters. Other lead **20** and IMD **324** implant sites are contemplated. For example, IMD **324** may be implanted on or within cranium **14**A, in some examples. Or leads **330** may be implanted within the same hemisphere or IMD **324** may be coupled to a single lead.

[0145] Although leads **330** are shown in FIG. **19** as being coupled to a common lead extension **328**, in other examples, leads **330** may be coupled to IMD **324** via separate lead extensions or directly to connector **326**. Leads **330** may be positioned to deliver electrical stimulation to one or more target tissue sites within brain **322** to manage patient symptoms associated with a movement disorder of patient **12**A. Leads **330** may be implanted to position electrodes **332**, **334** at desired locations of brain **322** through respective holes in cranium **32**. Leads **330** may be placed at any location within brain **322** such that electrodes **332**, **334** are capable of providing electrical stimulation to target tissue sites within brain **322** during treatment. For example, electrodes **332**, **334** may

be surgically implanted under the dura mater of brain **322** or within the cerebral cortex of brain **322** via a burr hole in cranium **32** of patient **12**A, and electrically coupled to IMD **324** via one or more leads **330**.

[0146] Example techniques for delivering therapy to manage a movement disorder are described in U.S. Patent Application Publication No. 2009/0099627 by Molnar et al., entitled, "THERAPY CONTROL BASED ON A PATIENT MOVEMENT STATE," which was filed on Sep. 25, 2008, which is incorporated herein by reference in its entirety. In some examples described by U.S. Patent Application Publication No. 2009/0099627 by Molnar et al., a brain signal, such as an EEG or ECoG signal, may be used to determine whether a patient is in a movement state or a rest state. The movement state includes the state in which the patient is generating thoughts of movement (i.e., is intending to move), attempting to initiate movement or is actually undergoing movement. The movement state or rest state determination may then be used to control therapy delivery. For example, upon detecting a movement state of the patient, therapy delivery may be activated in order to help patient **12**A initiate movement or maintain movement, and upon detecting a rest state of patient **12**A, therapy delivery may be deactivated or otherwise modified.

[0147] In the example shown in FIG. **19**, electrodes **332**, **334** of leads **330** are shown as ring electrodes. Ring electrodes may be used in DBS applications because they are relatively simple to program and are capable of delivering an electrical field to any tissue adjacent to electrodes **332**, **334**. In other examples, electrodes **332**, **334** may have different configurations. For example, in some examples, at least some of the electrodes **332**, **334** of leads **330** may have a complex electrode array geometry that is capable of producing shaped electrical fields. The complex electrode array geometry may include multiple electrodes (e.g., partial ring or segmented electrodes) around the outer perimeter of each lead **330**, rather than one ring electrode. In this manner, electrical stimulation may be directed in a specific direction from leads **330** to enhance therapy efficacy and reduce possible adverse side effects from stimulating a large volume of tissue. In some examples, a housing of IMD **324** may include one or more stimulation and/or sensing electrodes. In alternative examples, leads **330** may have shapes other than elongated cylinders as shown in FIG. **19**. For example, leads **330** may be paddle leads, spherical leads, bendable leads, or any other type of shape effective in treating patient **12**A and/or minimizing invasiveness of leads **330**.

[0148] In the example shown in FIG. **19**, IMD **324** includes a memory (shown in FIG. **21**) to store a plurality of therapy programs that each define a set of therapy parameter values. In some examples, IMD **324** may select a therapy program from the memory based on various parameters, such as sensed patient parameters and the identified patient behaviors. IMD **324** may generate electrical stimulation based on the selected therapy program to manage the patient symptoms associated with a movement disorder.

[0149] External programmer **24** wirelessly communicates with IMD **324** as needed to provide or retrieve therapy information. Programmer **24** is an external computing device (e.g., computing device **54** of FIG. **3**) that the user, e.g., clinician **22** and/or patient **12**A, may use to communicate with IMD **324**. For example, programmer **24** may be a clinician programmer that the clinician uses to communicate with IMD **324** and program one or more therapy programs for IMD **324**. Alternatively, programmer **24** may be a patient programmer that allows patient **12**A to select programs and/or view and modify therapy parameters. The clinician programmer may include more programming features than the patient programmer. In other words, more complex or sensitive tasks may only be allowed by the clinician programmer to prevent an untrained patient from making undesirable changes to IMD **324**.

[0150] When programmer **24** is configured for use by the clinician, programmer **24** may be used to transmit initial programming information to IMD **324**. This initial information may include hardware information, such as the type of leads **330** and the electrode arrangement, the position of leads **330** within brain **322**, the configuration of electrode array **332**, **334**, initial programs defining therapy parameter values, and any other information the clinician desires to program into IMD **324**. Programmer **24** may also be capable of completing functional tests (e.g., measuring the impedance of electrodes **332**, **334** of leads **330**).

[0151] The clinician may also store therapy programs within IMD **324** with the aid of programmer **24**. During a programming session, the clinician may determine one or more therapy programs that may provide efficacious therapy to patient **12**A to address symptoms associated with the patient condition, and, in some cases, specific to one or more different patient states, such as a sleep state, movement state or rest state. For example, the clinician may select one or more stimulation electrode combination with which stimulation is delivered to brain **322**. During the programming session, patient **12**A may provide feedback to the clinician as to the efficacy of the specific program being evaluated or the clinician may evaluate the efficacy based on one or more physiological parameters of patient **12**A (e.g., muscle activity or muscle tone). Alternatively, the identified patient behavior from video information **50** may be used as feedback during the initial, and subsequent programming sessions. Programmer **24** may assist the clinician in the creation/identification of therapy programs by providing a methodical system for identifying potentially beneficial therapy parameter values.

[0152] Programmer **24** may also be configured for use by patient **12**A. When configured as a patient programmer, programmer **24** may have limited functionality (compared to a clinician programmer) in order to prevent patient **12**A from altering critical functions of IMD **324** or applications that may be detrimental to patient **12**A. In this manner, programmer **24** may only allow patient **12**A to adjust values for certain therapy parameters or set an available range of values for a particular therapy parameter.

[0153] Programmer **24** may also provide an indication to patient **12**A when therapy is being delivered, when patient input has triggered a change in therapy or when the power source within programmer **24** or IMD **324** needs to be replaced or recharged. For example, programmer **24** may include an alert LED, may flash a message to patient **12**A via a programmer display, generate an audible sound or somatosensory cue to confirm patient input was received, e.g., to indicate a patient state or to manually modify a therapy parameter.

[0154] Therapy system **320** may be implemented to provide chronic stimulation therapy to patient **12**A over the course of several months or years. However, system **320** may also be employed on a trial basis to evaluate therapy before committing to full implantation. If implemented temporarily, some components of system **320** may not be implanted within

patient **12**A. For example, patient **12**A may be fitted with an external medical device, such as a trial stimulator, rather than IMD **324**. The external medical device may be coupled to percutaneous leads or to implanted leads via a percutaneous extension. If the trial stimulator indicates DBS system **320** provides effective treatment to patient **12**A, the clinician may implant a chronic stimulator within patient **12**A for relatively long-term treatment.

[0155] As described herein, IMD **324** may use identified patient behavior from video information to determine delivery of therapy. For example, one or more processors of IMD **324** may be configured to receive, from a computing device such as networked server **44** or programmer **24**, an indication of one or more patient behaviors that occurred during a period of time. These patient behaviors may have been identified from video analysis of the frames capturing the movement of patient **12**A. In other words, the patient behavior may be determined by a computing device from video information **50** captured during the period of time. In response to receiving the indication of the patient behavior, IMD **324** may be configured to determine, based on the indication of the patient behavior, a therapy to be delivered to patient **12**A. IMD **324** may also output the determination for at least one of delivery of the therapy to patient **12**A and display to a user.

[0156] For example, IMD **324** may determine the therapy by selecting one or more therapy parameter values (e.g., a set of therapy parameters or a therapy program) that at least partially defines the therapy. In other examples, other computing devices may be configured to determine the therapy based on the identified patient behavior (e.g., movement disorder). For example, networked server **44**, programmer **24**, or any other computing device may determine the therapy. The therapy may include one or more of electrical stimulation therapy, drug delivery therapy (e.g., drug delivered from an implantable or external drug pump), or oral medication therapy.

[0157] In some examples, the therapy may be determined directly from the identified patient behavior. For example, IMD **324** may be configured to select one of a plurality of predetermined therapies, each of the plurality of therapies corresponding to at least one of the plurality of patient behaviors associated with a respective one or more movement parameters generated from video information **50**. IMD **324** may store associations between the patient behaviors and predetermined therapies to be delivered upon detection of each behavior. The patient behaviors may be identified continuously, in response to receiving new video information, or on demand from a user. In some examples, programmer **24** may be configured to select the appropriate therapy associated with an identified patient behavior and transmit one or more therapy parameters associated with the patient behavior to IMD **324**.

[0158] In other examples, the identified patient behaviors may be used as an objective measure of patient movement and to calibrate one or more patient parameters to the identified patient behaviors. IMD **324** may then utilize the calibrated patient parameters as direct feedback to control therapy. For example, networked server **44** may be configured to calculate, from video information **50** captured during a period of time, one or more movement parameters of patient **12**A and identify, based on the one or more movement parameters, each of one of a plurality of patient behaviors that occurred during the period of time. Networked server **44** may then obtain values of a patient parameter (e.g., LFP signal or patient accelerations) sensed during the period of time. Networked server **44** may then correlate the values of the patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time. These patient parameter values may then be associated with respective therapy parameter sets selected to manage the movements of patient **12** in response to subsequent detection of the patient parameter values.

[0159] IMD **324** may receive the patient parameter values and associated therapy parameter sets from networked server **44** and store the associations in memory. IMD **324** may then use the sensed patient parameter values as feedback to control therapy delivery. For example, subsequent to the correlation of patient behaviors with the sensed patient parameter values, IMD **324** may be configured to obtain a sensed patient parameter value and identify one or more of the plurality of patient behaviors associated with the sensed patient parameter value. IMD **324** may then determine, based on the identification of the patient behaviors, the therapy to be delivered to the patient. Although networked server **44** was described as performing the correlation between identified patient behaviors and sensed patient parameter values, any other computing device may perform these tasks. For example, programmer **24** and/or IMD **324** may perform the correlations and associations for subsequent feedback.

[0160] In some examples, the therapy may be controlled based on feedback from two or more different patient parameters. For example, networked server **44** may be configured to obtain values of a second patient parameter sensed during the period of time and correlate the values of the second patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time. Subsequently, IMD **324** or programmer **24** may be configured to determine that the values of both the first patient parameter and the second patient parameter are associated with the same patient behavior and identify the same patient behavior as the one or more of the plurality of patient behaviors experienced by patient **12**A. In this manner, therapy may be selected only when the values of two or more different patient parameter values indicate the same movement behavior is occurring with patient **12**A. Requiring multiple patient parameters as feedback may provide a confirmation and safety check to reduce therapy changes due to false positives.

[0161] A variety of different patient parameters may be monitored and used to provide feedback to control stimulation therapy. For example, a patient parameter may be a local field potential (LFP), an electroencephalogram (ECG), an electrogram (EEG), an acceleration of the patient, a relative motion between two locations of the patient, blood pressure, heart rate, patient speech pattern, patient breathing pattern, sleep indication, or a chemical indication. In this manner, one or more sensors may sense a respective patient parameter. IMD **324** may include one or more sensors or be coupled to one or more sensors via lead **328**. For example, electrodes **332**,**334** may be used to sense LFP or ECG signals and an accelerometer or gyroscope may be included within IMD **324** or on lead **328** to sense accelerations or rotations of the patient.

[0162] In some examples, video information may be recaptured of patient **12**A if therapy is no longer efficacious for patient **12**A. For example, programmer **24** may receive user input identifying that the therapy is insufficient even though therapy is being controlled based on previously correlated and calibrated patient parameters or patient behavior. Programmer **24** may transmit an indication of the user input to

networked server **44**. In response to receiving the indication, networked server **44** may be configured to request capture of supplemental video information of patient motion during a second period of time different than the first period of the previous video information **50**. Based on the supplemental video information, networked server **44** may identify any patient behavior within the supplemental video information. Networked server **44** may receive an indication of the patient behavior during the second period and use the patient behavior to determine a different therapy to be delivered to patient **12**A based on the indication of the patient behavior during the second period of time. In some examples, networked server **44** may update the correlations or calibrations of the patient parameter values obtained during the second period of time to the newly identified patient behaviors. The updated calibrations may improve the precision with which therapy is directed to patient behavior. Although networked server **44** is described as updating the calibrations of the patient parameters, other devices such as programmer **24** or IMD **324** may perform the updates to the calibrations and/or associations of patient parameter values to therapy parameters.

[0163] Although IMD **324** is described as delivering electrical stimulation therapy to brain **322**, IMD **324** may be configured to direct electrical stimulation to other anatomical regions of patient **12**A. In other examples, system **320** may include an implantable drug pump in addition to, or in place of, electrical stimulator **324**. Further, as described in FIG. **20**, an IMD may provide other electrical stimulation such as spinal cord stimulation to treat a movement disorder.

[0164] FIG. **20** is a conceptual diagram illustrating example system **340** that includes IMD **344** configured to deliver spinal cord stimulation (SCS) to a patient **12**B. Patient **12**B may be similar to patient **12**A of FIG. **19**. System **340** may provide similar therapy and utilize similar feedback (e.g., identified patient behavior and/or sensed patient parameters) to control therapy. In some examples, system **340** may additionally or alternatively be configured to provide peripheral nerve field stimulation (PNFS), occipital nerve stimulation, sacral nerve stimulation (SNS), pelvic floor stimulation, or any other electrical stimulation therapy.

[0165] As shown in FIG. **20**, system **340** includes an IMD **344** and external programmer **24** shown in conjunction with a patient **12**B, who is ordinarily a human patient. In the example of FIG. **20**, IMD **344** is an implantable electrical stimulator that delivers neurostimulation therapy to patient **12**B, e.g., for relief of chronic pain or other symptoms such as abnormal movements. Generally IMD **344** may be a chronic electrical stimulator that remains implanted within patient **12**B for weeks, months, or even years. IMD **344** may be similar to IMD **324** of FIG. **19**. In the example of FIG. **20**, IMD **344** and lead **346** may be directed to delivering SCS therapy. In other examples, IMD **344** may be a temporary, or trial, stimulator used to screen or evaluate the efficacy of electrical stimulation for chronic therapy. IMD **344** may be implanted in a subcutaneous tissue pocket, within one or more layers of muscle, or other internal location. IMD **344** may be coupled to one or more lead **346**.

[0166] Electrical stimulation energy, which may be constant current or constant voltage based pulses, for example, is delivered from IMD **344** to one or more targeted locations within patient **12**B via one or more electrodes (not shown) of lead **346**. The parameters for a program that controls delivery of stimulation energy by IMD **344** may include information identifying which electrodes have been selected for delivery of stimulation according to a stimulation program, the combination of the selected electrodes, and the polarities of the selected electrodes, i.e., the electrode configuration for the program, and voltage or current amplitude, pulse frequency (or pulse rate), pulse shape, and pulse width of stimulation delivered by the electrodes. Electrical stimulation may be delivered in the form of stimulation pulses or continuous waveforms, for example.

[0167] In the example of FIG. **20**, lead **346** is disposed within patient **12**B, e.g., implanted within patient **12**B. Lead **346** tunnels through tissue of patient **12**B from along spinal cord **342** to a subcutaneous tissue pocket or other internal location where IMD **344** is disposed. Although lead **346** may be a single lead, lead **346** may include a lead extension or other segments that may aid in implantation or positioning of lead **346**. In addition, a proximal end of lead **346** may include a connector (not shown) that electrically couples to a header of IMD **344**. Although only one lead **346** is shown in FIG. **20**, system **340** may include two or more leads, each coupled to IMD **344** and directed to similar or different target tissue sites. For example, multiple leads may be disposed along spinal cord **342** or leads may be directed to spinal cord **342** and/or other locations within patient **12**B.

[0168] Lead **346** may carry one or more electrodes that are placed adjacent to the target tissue, e.g., spinal cord **342** for spinal cord stimulation (SCS) therapy. One or more electrodes may be disposed at or near a distal tip of lead **346** and/or at other positions at intermediate points along lead **346**, for example. Electrodes of lead **346** transfer electrical stimulation generated by an electrical stimulation generator in IMD **344** to tissue of patient **12**B. The electrodes may be electrode pads on a paddle lead, circular (e.g., ring) electrodes surrounding the body of the lead, conformable electrodes, cuff electrodes, segmented electrodes (e.g., electrodes disposed at different circumferential positions around the lead instead of a continuous ring electrode), or any other type of electrodes capable of forming unipolar, bipolar or multipolar electrode combinations for therapy. In general, ring electrodes arranged at different axial positions at the distal ends of lead **346** will be described for purposes of illustration.

[0169] Similar to IMD **324** of FIG. **19**, IMD **344** delivers electrical stimulation therapy to patient **12**B via selected combinations of electrodes carried by lead **346**. The target tissue for the electrical stimulation therapy may be any tissue affected by electrical stimulation energy, which may be in the form of electrical stimulation pulses or waveforms. In some examples, the target tissue includes nerves, smooth muscle, and skeletal muscle. In the example illustrated by FIG. **20**, the target tissue for electrical stimulation delivered via lead **346** is tissue proximate spinal cord **342** (e.g., one or more target locations of the dorsal columns or one or more dorsal roots that branch from spinal cord **342**). Lead **346** may be introduced into spinal cord **342** via any suitable region, such as the thoracic, cervical or lumbar regions. Stimulation of dorsal columns, dorsal roots, and/or peripheral nerves (e.g., afferent nerves) may, for example, prevent pain signals from traveling through spinal cord **342** and to the brain of the patient. Patient **12**B may perceive the interruption of pain signals as a reduction in pain and, therefore, efficacious therapy results. For treatment of other disorders, lead **346** may be introduced at any exterior location of patient **12**B.

[0170] Although lead **346** is described as generally delivering or transmitting electrical stimulation signals, lead **346** may additionally transmit electrical signals obtained via elec-

trodes or various sensors carried by the lead from patient **12**B to IMD **344** for monitoring. For example, IMD **344** may utilize detected nerve impulses or muscle impulses to diagnose the condition of patient **12**B or adjust the delivered stimulation therapy. Lead **346** may thus transmit electrical signals to and from patient **12**B.

[0171] A user, such as a clinician or patient **12**B, may interact with a user interface of an external programmer **24** to program IMD **344**. Programming of IMD **344** may refer generally to the generation and transfer of commands, programs, or other information to control the operation of IMD **344**. In this manner, IMD **344** may receive the transferred commands and programs from programmer **24** to control stimulation therapy. For example, external programmer **24** may transmit programs, parameter adjustments, program selections, group selections, user input, or other information to control the operation of IMD **344**, e.g., by wireless telemetry or wired connection.

[0172] IMD **344** may be constructed of any polymer, metal, or composite material sufficient to house the components of IMD **344** (e.g., components illustrated in FIG. **22**) within patient **12**B. In this example, IMD **344** may be constructed with a biocompatible housing, such as titanium or stainless steel, or a polymeric material such as silicone or polyurethane, and surgically implanted at a site in patient **12**B near the pelvis, abdomen, or buttocks. The housing of IMD **344** may be configured to provide a hermetic seal for components, such as a rechargeable power source. In addition, the housing of IMD **344** may be selected of a material that facilitates receiving energy to charge rechargeable power source **18**.

[0173] As described herein, information may be transmitted between external programmer **24** and IMD **344**. Therefore, IMD **344** and programmer **24** may communicate via wireless communication using any techniques known in the art. Examples of communication techniques may include, for example, radiofrequency (RF) telemetry and inductive coupling, but other techniques are also contemplated. In some examples, programmer **24** may include a communication head that may be placed proximate to the patient's body near the IMD **344** implant site in order to improve the quality or security of communication between IMD **344** and programmer **24**. Communication between programmer **24** and IMD **344** may occur during power transmission or separate from power transmission.

[0174] Although IMD **344** is generally described in FIG. **20**, techniques of this disclosure may also be applicable to external or partially external medical device in other examples. For example, IMD **344** may instead be configured as an external medical device coupled to one or more percutaneous medical leads. The external medical device may be a chronic, temporary, or trial electrical stimulator. In addition, an external electrical stimulator may be used in addition to one or more IMDs **344** to deliver electrical stimulation described herein.

[0175] FIG. **21** is a block diagram of the example IMD **324** of FIG. **19** for delivering deep brain stimulation therapy. In the example shown in FIG. **21**, IMD **324** includes processor **350**, memory **360**, stimulation generator **354**, sensing module **356**, switch module **352**, telemetry module **358**, sensor **359**, and power source **370**. Memory **360** may include any volatile or non-volatile media, such as a random access memory (RAM), read only memory (ROM), non-volatile RAM (NVRAM), electrically erasable programmable ROM (EEPROM), flash memory, and the like. Memory **360** may store computer-readable instructions that, when executed by processor **350**, cause IMD **324** to perform various functions. Memory **360** may be a storage device or other non-transitory medium.

[0176] In the example shown in FIG. **21**, memory **360** stores therapy programs **362**, sense electrode combinations and associated stimulation electrode combinations **368**, and feedback control **364** in separate memories within memory **360** or separate areas within memory **360**. Each stored therapy program **362** defines a particular set of electrical stimulation parameters (e.g., a therapy parameter set), such as a stimulation electrode combination, electrode polarity, current or voltage amplitude, pulse width, and pulse rate. In some examples, individual therapy programs may be stored as a therapy group, which defines a set of therapy programs with which stimulation may be generated. The stimulation signals defined by the therapy programs of the therapy group may be delivered together on an overlapping or non-overlapping (e.g., time-interleaved) basis.

[0177] Sense and stimulation electrode combinations **368** stores sense electrode combinations and associated stimulation electrode combinations. As described above, in some examples, the sense and stimulation electrode combinations may include the same subset of electrodes **332**, **334**, or may include different subsets of electrodes. Thus, memory **360** can store a plurality of sense electrode combinations and, for each sense electrode combination, store information identifying the stimulation electrode combination that is associated with the respective sense electrode combination. The associations between sense and stimulation electrode combinations can be determined, e.g., by a clinician or automatically by processor **350**. In some examples, corresponding sense and stimulation electrode combinations may comprise some or all of the same electrodes. In other examples, however, some or all of the electrodes in corresponding sense and stimulation electrode combinations may be different. For example, a stimulation electrode combination may include more electrodes than the corresponding sense electrode combination in order to increase the efficacy of the stimulation therapy. In some examples, as discussed above, stimulation may be delivered via a stimulation electrode combination to a tissue site that is different than the tissue site closest to the corresponding sense electrode combination but is within the same region, e.g., the thalamus, of brain **322** in order to mitigate any irregular oscillations or other irregular brain activity within the tissue site associated with the sense electrode combination.

[0178] Feedback control **364** may include instructions that determine what feedback to use when controlling therapy delivery such as which therapy programs, therapy parameter sets, or individual therapy parameter values to select. Feedback control **364** may include associations of identified patient behaviors from video information to respective therapy parameter sets intended to treat the identified patient behaviors. In addition, or alternatively, feedback control **364** may include associations of values for one or more sensed patient parameters (e.g., LFP signals or patient accelerations) to respective therapy parameter sets. The values of the sensed patient parameters may be calibrated or correlated with identified patient behaviors from captured video information. In any case, IMD **324** may use the instructions within feedback control **364** to adjust the therapy delivered to patient **12**A.

[0179] Stimulation generator **354**, under the control of processor **350**, generates stimulation signals for delivery to

patient **12**A via selected combinations of electrodes **332**, **334**. An example range of electrical stimulation parameters believed to be effective in DBS to manage a movement disorder of patient include:

[0180] 1. Frequency: between approximately 100 Hz and approximately 500 Hz, such as approximately 130 Hz.

[0181] 2. Voltage Amplitude: between approximately 0.1 volts and approximately 50 volts, such as between approximately 0.5 volts and approximately 20 volts, or approximately 5 volts.

[0182] 3. Current Amplitude: A current amplitude may be defined as the biological load in which the voltage is delivered. In a current-controlled system, the current amplitude, assuming a lower level impedance of approximately 500 ohms, may be between approximately 0.2 milliAmps to approximately 100 milliAmps, such as between approximately 1 milliAmps and approximately 40 milliAmps, or approximately 10 milliAmps. However, in some examples, the impedance may range between about 200 ohms and about 2 kiloohms.

[0183] 4. Pulse Width: between approximately 10 microseconds and approximately 5000 microseconds, such as between approximately 100 microseconds and approximately 1000 microseconds, or between approximately 180 microseconds and approximately 450 microseconds.

[0184] Accordingly, in some examples, stimulation generator **354** generates electrical stimulation signals in accordance with the electrical stimulation parameters noted above. Other ranges of therapy parameter values may also be useful, and may depend on the target stimulation site within patient **12**A. While stimulation pulses are described, stimulation signals may be of any form, such as continuous-time signals (e.g., sine waves) or the like.

[0185] In each of the examples described herein, if stimulation generator **354** shifts the delivery of stimulation energy between two therapy programs, processor **350** of IMD **324** may provide instructions that cause stimulation generator **354** to time-interleave stimulation energy between the electrode combinations of the two therapy programs, as described in commonly-assigned U.S. patent application Ser. No. 11/401,100 by Steven Goetz et al., entitled, "SHIFTING BETWEEN ELECTRODE COMBINATIONS IN ELECTRICAL STIMULATION DEVICE," and filed on Apr. 10, 2006, the entire content of which is incorporated herein by reference. In the time-interleave shifting example, the amplitudes of the electrode combinations of the first and second therapy program are ramped downward and upward, respectively, in incremental steps until the amplitude of the second electrode combination reaches a target amplitude. The incremental steps may be different between ramping downward or ramping upward. The incremental steps in amplitude can be of a fixed size or may vary, e.g., according to an exponential, logarithmic or other algorithmic change. When the second electrode combination reaches its target amplitude, or possibly before, the first electrode combination can be shut off. Other techniques for shifting the delivery of stimulation signals between two therapy programs may be used, in other examples.

[0186] Processor **350** may include any one or more of a microprocessor, a controller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), discrete logic circuitry, and the functions attributed to processor **350** herein may be embodied as firmware, hardware, software or any combination thereof. Processor **350** controls stimulation generator **354** according to therapy programs **54** stored in memory **360** to apply particular stimulation parameter values specified by one or more of programs, such as amplitude, pulse width, and pulse rate.

[0187] In the example shown in FIG. **21**, the set of electrodes **332** includes electrodes **332**A, **332**B, **332**C, and **332**D, and the set of electrodes **334** includes electrodes **334**A, **334**B, **334**C, and **334**D. Processor **350** also controls switch module **352** to apply the stimulation signals generated by stimulation generator **354** to selected combinations of electrodes **332**, **334**. In particular, switch module **352** may couple stimulation signals to selected conductors within leads **330**, which, in turn, deliver the stimulation signals across selected electrodes **332**, **334**. Switch module **352** may be a switch array, switch matrix, multiplexer, or any other type of switching module configured to selectively couple stimulation energy to selected electrodes **332**, **334** and to selectively sense bioelectrical brain signals with selected electrodes **332**, **334**. Hence, stimulation generator **354** is coupled to electrodes **332**, **334** via switch module **352** and conductors within leads **330**. In some examples, however, IMD **324** does not include switch module **352**.

[0188] Stimulation generator **354** may be a single channel or multi-channel stimulation generator. In particular, stimulation generator **354** may be capable of delivering a single stimulation pulse, multiple stimulation pulses, or a continuous signal at a given time via a single electrode combination or multiple stimulation pulses at a given time via multiple electrode combinations. In some examples, however, stimulation generator **354** and switch module **352** may be configured to deliver multiple channels on a time-interleaved basis. For example, switch module **352** may serve to time divide the output of stimulation generator **354** across different electrode combinations at different times to deliver multiple programs or channels of stimulation energy to patient **12**A.

[0189] Although sensing module **356** is incorporated into a common housing with stimulation generator **354** and processor **350** in FIG. **21**, in other examples, sensing module **356** may be in a separate housing from IMD **324** and may communicate with processor **350** via wired or wireless communication techniques. Example bioelectrical brain signals include, but are not limited to, a signal generated from local field potentials within one or more regions of brain **28**. EEG and ECoG signals are examples of local field potentials that may be measured within brain **28**. However, local field potentials may include a broader genus of electrical signals within brain **322** of patient **12**A.

[0190] Sensor **359** may include one or more sensing elements that sense values of a respective patient parameter. For example, sensor **359** may include one or more accelerometers, optical sensors, chemical sensors, temperature sensors, pressure sensors, or any other types of sensors. Sensor **359** may output patient parameter values that may be used as feedback to control delivery of therapy. Feedback control **364** may include instructions for processor **350** on how to utilize the signals or values provided by sensor **359**. IMD **324** may include additional sensors within the housing of IMD **324** and/or coupled via one of leads **330** or other leads. In addition, IMD **324** may receive sensor signals wirelessly from remote sensors via telemetry module **358**, for example. In some examples, one or more of these remote sensors may be external to patient (e.g., carried on the external surface of the skin, attached to clothing, or otherwise positioned external to the

patient). Each of the sensor signals may be calibrated by identified patient behavior from video information and incorporated in the feedback control of therapy.

[0191] Telemetry module **358** supports wireless communication between IMD **324** and an external programmer **24** or another computing device under the control of processor **350**. Processor **350** of IMD **324** may receive, as updates to programs, values for various stimulation parameters such as amplitude and electrode combination, from programmer **24** via telemetry module **358**. The updates to the therapy programs may be stored within therapy programs **362** portion of memory **360**. Telemetry module **358** in IMD **324**, as well as telemetry modules in other devices and systems described herein, such as programmer **24**, may accomplish communication by radiofrequency (RF) communication techniques. In addition, telemetry module **358** may communicate with external medical device programmer **24** via proximal inductive interaction of IMD **324** with programmer **24**. Accordingly, telemetry module **358** may send information to external programmer **24** on a continuous basis, at periodic intervals, or upon request from IMD **324** or programmer **24**.

[0192] Power source **370** delivers operating power to various components of IMD **324**. Power source **370** may include a small rechargeable or non-rechargeable battery and a power generation circuit to produce the operating power. Recharging may be accomplished through proximal inductive interaction between an external charger and an inductive charging coil within IMD **324**. In some examples, power requirements may be small enough to allow IMD **324** to utilize patient motion and implement a kinetic energy-scavenging device to trickle charge a rechargeable battery. In other examples, traditional batteries may be used for a limited period of time.

[0193] Throughout the disclosure, a group of electrodes may refer to any electrodes located at the same position along the longitudinal axis of one or more leads. A group of electrodes may include one or more electrodes.

[0194] FIG. **22** is a block diagram of example IMD **344** of FIG. **20** for delivering spinal cord stimulation therapy. IMD **344** may be similar to IMD **324** of FIG. **21**, such as providing similar feedback function for controlling SCS therapy. As shown in the example of FIG. **22**, IMD **344** includes processor **380**, therapy module **384**, power source **388**, memory **382**, and telemetry module **386**. In other examples, IMD **344** may include a greater or fewer number of components. For example, IMD **344** may also include one or more sensors such as sensor **359** of FIG. **21**.

[0195] In general, IMD **344** may comprise any suitable arrangement of hardware, alone or in combination with software and/or firmware, to perform the various techniques described herein attributed to IMD **344** and processor **380**. In various examples, IMD **344** may include one or more processors **30**, such as one or more microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components. IMD **344** also, in various examples, may include a memory **382**, such as random access memory (RAM), read only memory (ROM), programmable read only memory (PROM), erasable programmable read only memory (EPROM), electronically erasable programmable read only memory (EEPROM), flash memory, comprising executable instructions for causing the one or more processors to perform the actions attributed to them. Moreover, although processor **380**, therapy module **384**, and telemetry module **386** are described as separate modules, in some examples, processor **380**, therapy module **384**, and telemetry module **386** may be functionally integrated. In some examples, processor **380**, therapy module **384**, and telemetry module **386** may correspond to individual hardware units, such as ASICs, DSPs, FPGAs, or other hardware units.

[0196] Memory **382** (e.g., a storage device) may store therapy programs or other instructions that specify therapy parameter values for the therapy provided by therapy module **384** and IMD **344**. In some examples, memory **382** may also store instructions for communication between IMD **344** and programmer **24**, or any other instructions required to perform tasks attributed to IMD **344**. Memory **382** may also store feedback control instructions similar to feedback control **364** of IMD **324**.

[0197] Generally, therapy module **384** may generate and deliver electrical stimulation under the control of processor **380**. In some examples, processor **380** controls therapy module **384** by accessing memory **382** to selectively access and load at least one of the stimulation programs to therapy module **384**. For example, in operation, processor **380** may access memory **382** to load one of the stimulation programs to therapy module **384**. In such examples, relevant stimulation parameters may include a voltage amplitude, a current amplitude, a pulse frequency, a pulse width, a duty cycle, one or more spatial electrode movement patterns that define the combination of electrodes **346**A, **346**B, **346**C, and **346**D that therapy module **384** uses to deliver the electrical stimulation signal. Although therapy module **384** may be configured to generate and deliver electrical stimulation therapy via one or more of electrodes **346**A, **346**B, **346**C, and **346**D of lead **346**, a different therapy module may be configured to provide different therapy to patient **12**B, such as drug delivery therapy via a catheter. These and other therapies may be provided by IMD **344**.

[0198] An exemplary range of electrical stimulation parameters that may be used to deliver effective treatment for chronic pain, e.g., when applied to spinal cord **342**, are listed below. While stimulation pulses are described, stimulation signals may be of any of a variety of forms such as sine waves or the like.

[0199] Pulse Frequency: between approximately 0.5 Hz and 10,000 Hz. In one example, pulse frequency may be between approximately 5 Hz and 250 Hz or between approximately 30 Hz and 130 Hz. In other examples, pulse frequency may be greater than 250 Hz or even greater than 1,000 Hz. Pulse frequencies greater than 1,000 Hz may be considered to be greater than the nerve firing potential of affected nerve fibers to inhibit nerve firing. For example, the pulse frequency may be between approximately 1,000 Hz and 10,000 Hz.

[0200] Amplitude: between approximately 0.1 volts and 50 volts, more preferably between approximately 0.5 volts and 20 volts, and still more preferably between approximately 1 volt and 10 volts. In other embodiments, a current amplitude may be defined as the biological load in the voltage that is delivered. For example, the range of current amplitude may be between approximately 0.1 milliamps (mA) and 50 mA. In other examples, current amplitude may be between approximately 1.0 mA and 10 mA.

[0201] Pulse Width: between about 10 microseconds and 5000 microseconds. In some examples, the pulse width may be between approximately 100 microseconds and 1000 microseconds or between approximately 180 microseconds

and 450 microseconds. With higher frequency pulses, the pulse width may be smaller to accommodate the increased frequency. For example, the pulse width may be between approximately 10 microseconds and 50 microseconds.

[0202] IMD **344** also includes components to receive power from programmer **24** or a separate charging device to recharge a batter of power source **388**. Power source **388** may include one or more capacitors, batteries, or other energy storage devices. IMD **344** may thus also include an inductive coil and a recharge module (both not shown) configured to manage the recharging session for power source **388**. Although inductive coupling may be used to recharge power source **388**, other wireless energy transfer techniques may alternatively be used. Alternatively, power source **388** may not be rechargeable.

[0203] Processor **380** may also control the exchange of information with programmer **24** using telemetry module **386**. Telemetry module **386** may be configured for wireless communication using radio frequency protocols or inductive communication protocols. Telemetry module **386** may include one or more antennas configured to communicate with programmer **24**, for example. Processor **380** may transmit operational information and receive therapy programs or therapy parameter adjustments via telemetry module **386**. Also, in some examples, IMD **344** may communicate with other implanted devices, such as stimulators, control devices, or sensors, via telemetry module **386**. For example, telemetry module **386** may receive user input, spatial electrode movement patterns, or other commands from programmer **24**.

[0204] FIG. **23** is a block diagram of external programmer **24** of FIGS. **1**, **19**, and **20**. Although programmer **24** may generally be described as a hand-held device, programmer **24** may be a larger portable device or a more stationary device. In addition, in other examples, programmer **24** may be included as part of an external charging device or include the functionality of an external charging device. As illustrated in FIG. **23**, programmer **24** may include a processor **390**, memory **392**, user interface **394**, telemetry module **396**, and power source **398**. Memory **392** may store instructions that, when executed by processor **390**, cause processor **390** and external programmer **24** to provide the functionality ascribed to external programmer **24** throughout this disclosure. For example, processor **390** may be configured to select therapy parameters in response to receiving an indication of an identified patient behavior from video information **50** captured from patient **12** and/or receiving sensed patient parameter values calibrated to be representative of patient behavior.

[0205] In general, programmer **24** comprises any suitable arrangement of hardware, alone or in combination with software and/or firmware, to perform the techniques attributed to programmer **24**, and processor **390**, user interface **394**, and telemetry module **396** of programmer **24**. In various examples, programmer **24** may include one or more processors, such as one or more microprocessors, DSPs, ASICs, FPGAs, or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components. Programmer **24** also, in various examples, may include a memory **392**, such as RAM, ROM, PROM, EPROM, EEPROM, flash memory, a hard disk, a CD-ROM, comprising executable instructions for causing the one or more processors to perform the actions attributed to them. Moreover, although processor **390** and telemetry module **396** are described as separate modules, in some examples, processor **390** and telemetry module **396** are functionally integrated. In some examples, processor **390** and telemetry module **396** correspond to individual hardware units, such as ASICs, DSPs, FPGAs, or other hardware units.

[0206] Memory **392** (e.g., a storage device) may store instructions that, when executed by processor **390**, cause processor **390** and programmer **24** to provide the functionality ascribed to programmer **24** throughout this disclosure. For example memory **392** may include instructions that cause processor **390** to obtain a parameter set from memory, select a spatial electrode movement pattern, or receive a user input and send a corresponding command to IMD **14**, or instructions for any other functionality. In addition, memory **392** may include a plurality of programs, where each program includes a parameter set that defines stimulation therapy

[0207] User interface **394** may include a button or keypad, lights, a speaker for voice commands, a display, such as a liquid crystal (LCD), light-emitting diode (LED), or organic light-emitting diode (OLED). In some examples the display may be a touch screen. User interface **394** may be configured to display any information related to the delivery of stimulation therapy, identified patient behaviors, sensed patient parameter values, patient behavior criteria, or any other such information. User interface **394** may also receive user input via user interface **394**. The input may be, for example, in the form of pressing a button on a keypad or selecting an icon from a touch screen. The input may request starting or stopping electrical stimulation, the input may request a new spatial electrode movement pattern or a change to an existing spatial electrode movement pattern, of the input may request some other change to the delivery of electrical stimulation.

[0208] Telemetry module **396** may support wireless communication between IMD **14** and programmer **24** under the control of processor **390**. Telemetry module **396** may also be configured to communicate with another computing device via wireless communication techniques, or direct communication through a wired connection. In some examples, telemetry module **396** may be substantially similar to telemetry module **358** of IMD **324** described herein, providing wireless communication via an RF or proximal inductive medium. In some examples, telemetry module **396** may include an antenna, which may take on a variety of forms, such as an internal or external antenna.

[0209] Examples of local wireless communication techniques that may be employed to facilitate communication between programmer **24** and IMD **324** include RF communication according to the 802.11 or Bluetooth specification sets or other standard or proprietary telemetry protocols. In this manner, other external devices may be capable of communicating with programmer **24** without needing to establish a secure wireless connection. As described herein, telemetry module **396** may be configured to transmit a spatial electrode movement pattern or other stimulation parameter values to IMD **324** for delivery of stimulation therapy.

[0210] In some examples, selection of therapy parameters or therapy programs may be transmitted to a medical device (e.g., IMD **324** or IMD **344**) for delivery to patient **12**. In other examples, the therapy may include medication, activities, or other instructions that patient **12** must perform themselves or a caregiver perform for patient **12**. For example, in response to receiving an indication of an identified patient behavior or sensed patient parameter value, processor **390** may select a medication and/or dosage of the medication to treat the movement disorder. Processor **390** may control user interface **394** to display such information to the user. In some examples,

programmer **24** may provide visual, audible, and/or tactile notifications that indicate there are new instructions. Programmer **24** may require receiving user input acknowledging that the instructions have been completed in some examples.

[0211] In other examples, programmer **24** may be configured to receive user input or indications of user input indicating the type of medication, dosage, and/or time the medication was taken by patient **12**. Programmer **24** may create a log of the medications or other therapies manually taken by patient **12** in this manner. In some examples, programmer **24** may adjust electrical stimulation therapy and/or drug delivery therapy based on the medication that patient **12** has consumed. For example, programmer **24** may determine (e.g., adjust or maintain) one or more electrical stimulation therapy parameters based on the indication of the drug dosage taken by patient **12**. This adjustment may be made due to physiological alterations of patient **12** by the medication.

[0212] FIG. **24** is a block diagram illustrating example system **400** that includes networked server **44** coupled to IMD **324** (and/or IMD **344**) and one or more computing devices **404** via network **42**. System **400** may be similar to system **40** of FIG. **3**. As shown in FIG. **24**, server **44** (e.g., a networked external computing device) and one or more computing devices **404**A-**404**N that are coupled to the IMD **324** and programmer **24** shown in FIG. **19** via a network **42**. Network **42** may be generally used to transmit video information **50**, behavior information **52**, therapy parameter information, or any other data between IMD **324** programmer **24**, server **44** and/or computing devices **404**.

[0213] In some examples, the information transmitted by IMD **324** may allow a clinician or other healthcare professional to monitor patient **12** remotely. In some examples, IMD **324** may use a telemetry module to communicate with programmer **24** via a first wireless connection, and to communicate with access point **402** via a second wireless connection, e.g., at different times. In the example of FIG. **24**, access point **402**, programmer **24**, server **44** and computing devices **404**A-**404**N are interconnected, and able to communicate with each other through network **42**. In some cases, one or more of access point **402**, programmer **24**, server **44** and computing devices **404**A-**404**N may be coupled to network **42** via one or more wireless connections. IMD **324**, programmer **24**, server **44**, and computing devices **404**A-**404**N may each comprise one or more processors, such as one or more microprocessors, DSPs, ASICs, FPGAs, programmable logic circuitry, or the like, that may perform various functions and operations, such as those described herein.

[0214] Access point **402** may comprise a device that connects to network **42** via any of a variety of connections, such as telephone dial-up, digital subscriber line (DSL), or cable modem connections. In other examples, access point **402** may be coupled to network **42** through different forms of connections, including wired or wireless connections. In some examples, access point **402** may be co-located with patient **14** and may comprise one or more programming units and/or computing devices (e.g., one or more monitoring units) that may perform various functions and operations described herein. For example, access point **402** may include a home-monitoring unit that is co-located with patient **14** and that may monitor the activity of IMD **324**. In some examples, server **44** or computing devices **404** may control or perform any of the various functions or operations described herein.

[0215] In some cases, server **44** may be configured to provide a secure storage site for archival of video information, therapy parameters, patient parameters, or other data that has been collected and generated from IMD **324** and/or programmer **24**. Network **42** may comprise a local area network, wide area network, or global network, such as the Internet. The system of FIG. **24** may be implemented, in some aspects, with general network technology and functionality similar to that provide by the Medtronic CareLink® Network developed by Medtronic, Inc., of Minneapolis, Minn.

[0216] FIG. **25** is a flow diagram illustrating an example process for controlling therapy according to patient behavior identified from video information **50**. The process of FIG. **25** will be described with respect to processors **80** of networked server **44** and processor **390** of programmer **24**. However, one or more aspects of the process may be performed by other devices such as networked server **44**, IMD **324**, IMD **344**, or computing devices **404**.

[0217] As shown in FIG. **25**, networked server **44** may be configured to perform identification of patient behavior using video information **50** as described herein (**410**). The identification of patient behavior may be performed as an on-going process to provide feedback for controlling therapy to patient **12**A, for example. In other words, video information may be continually, or periodically, capturing new video information of patient **12**A. If programmer **24** does not receive any indication of abnormal behavior ("NO" branch of block **412**), networked server **44** continues to identify patient behavior (**410**). If programmer **23** does receive an indication of abnormal behavior ("YES" branch of block **412**), programmer **24** checks to determine if therapy is currently being delivered for the identified patient behavior (**414**).

[0218] If therapy is not being delivered to manage the identified therapy ("NO" branch of block **414**), programmer **24** may select therapy parameters associated with the detected abnormal behavior (i.e., the identified patient behavior) (**416**). Programmer **24** may transmit the therapy parameters to IMD **324** such that IMD **324** may control therapy according to the selected therapy parameters (**420**). If therapy is currently being delivered to manage the identified therapy ("YES" branch of block **414**), programmer **24** may adjust one or more therapy parameters to attempt to decrease the severity or presence of the identified behavior (**418**). Programmer **24** may then transmit the updated therapy parameters to IMD **324** such that IMD **324** may control therapy according to the selected therapy parameters (**420**).

[0219] In some examples, programmer **24** may directly control IMD **324** to deliver therapy according to the selected parameters. In other examples, IMD **324** may select therapy parameters based on the identified patient behavior feedback and control therapy delivery according to the selected therapy parameters instead of programmer **24**. Alternatively, networked server **44** may select therapy parameters and/or control therapy delivery. In any case, patient behavior identified from captured video information may be used as feedback to control the delivery of therapy to patient **12**A. In addition, therapy parameters may be adjusted if an identified behavior persists even though therapy is currently being delivered to manage the specific identified behavior. This adjustment may be made to improve the efficacy of the delivered therapy.

[0220] In other examples, a device (e.g., IMD **324**, programmer **24**, or networked device **44**) may be configured to determine a therapy for a patient from a patient behavior identified from both video information and the values of one or more patient parameters. The patient parameters may be monitored by one or more non-video sensors (e.g., acceler-

ometers, gyroscopes, pressure sensors, or temperature sensors), such that these non-video sensors may generate and transmit a value of the respective patient parameter. Therefore, the values of these patient parameters may be used in combination with video information to identify a behavior of the patient. A device may also use the identified behavior to adjust, select, and/or manage therapy delivered to the patient.

[0221] For example, IMD **324** may include one or more processors (e.g., processor **350**) configured to obtain one or more values of a patient parameter sensed during the period of time. The value of the patient parameter may, for example, be generated by sensor **359** (e.g., a non-video sensor) or any other non-video sensors. Processor **350** may also obtain video information regarding movement of the patient during the same period of time in which the value of the patient parameter was detected. Processor **350** may then determine, based on video information captured during the period of time and the one or more values of the patient parameter, the patient behavior for the period of time. Responsive to determining the patient behavior, processors **350** may select the appropriate therapy (e.g., select or adjust one or more therapy parameters) for delivery to the patient to treat the determined behavior. In some examples, other devices (e.g., programmer **24** or networked server **44**) may contribute to the analysis of the video information, determination of the patient behavior, and/or generation of patient parameter values used to select the appropriate therapy.

[0222] FIG. **26** is a conceptual diagram illustrating example system **422** that includes sensors configured to sense one or more patient parameters indicative of a patient behavior and monitored to control therapy. System **422** includes an implantable medical device (IMD) **424** (e.g., such as IMD **324** or IMD **344**) that monitors and/or delivers a therapy to patient **12**A. IMD **424** delivers the therapy according to a set of therapy parameters, i.e., a set of values for a number of parameters that define the therapy delivered according to that therapy parameter set, which may also be referred to as a therapy program. In addition, IMD **424** may incorporate the values of sensed patient parameters from one or more sensors located at respective locations of patient **12**C (e.g., patient **12**). Programmer **24** may be used to communicate with IMD **424** and/or one or more of activity sensors **426**.

[0223] IMD **424** includes or is coupled to activity sensors **426**A-**426**D (collectively, "activity sensors **426**") that detect activity or motion of patient **12**A. In one embodiment, activity sensors **426** may comprise accelerometers, gyroscopes, global position system (GPS) units and any other sensors that detect motions of patient **12**A. Activity sensors **426** may be multi-axis accelerometers or single-axis accelerometers. As illustrated in FIG. **1**, activity sensors **426** may be located at different locations on patient **12**A. Activity sensor **426**A may, for example, be located on or within a housing of IMD **424**. Activity sensor **426**B may be located on or within a lead that extends from IMD **424** into the brain of patient **12**A. Alternatively, activity sensor **426**B may be a stand-alone sensor, i.e., not coupled to any lead, that is located externally or implanted within a head of patient **12**A. Activity sensor **426**C is located at a limb of patient **12**A. In the example illustrated in FIG. **1**, activity sensor **426**C is located at an arm and, more particularly, at a wrist or hand of patient **12**A. Activity sensor **426**C may, however, be located on a different limb of patient **12**A, such as on the other arm or on a leg. Activity sensors may be worn externally, e.g., on a piece of clothing or a watch, or implanted at the specific locations within patient **12**A. Although the example illustrated in FIG. **26** includes three activity sensors, system **422** may include more or less sensors, located at different locations on patient **12**C. The techniques of this disclosure may be utilized in any system that includes two or more activity sensors at different locations of patient **12**C.

[0224] Activity sensors **426** detect activity or motion at respective locations of patient **12**C. In particular, as patient **12**C moves, activity sensors **426** detect the motion of the respective locations of the body of patient **12**C. Activity sensors **426** may, for example, generate signals as a function the motion of the respective portion of the body in terms of magnitude and direction. In the example illustrated in FIG. **26**, activity sensor **426**A detects motion of a torso of patient **12**C, activity sensor **426**B detects motion of a head of patient **12**C and activity sensor **426**C detects motion of the limb of patient **12**C.

[0225] IMD **424** receives the signals from activity sensors **426**. IMD **424** may receive the signals from at least a portion of activity sensors **426** via a wired connection. For example, IMD **424** may receive the signals from activity sensor **426**A and **426**B, if coupled to a lead, via a wired connection. Alternatively, IMD **424** may receive the signals from at least a portion of activity sensors **426** via wireless telemetry. For example, IMD **424** may receive a signal from activity sensor **426**C via wireless telemetry. In this case, activity sensor **426**C may include transmit circuitry to transmit the signals to IMD **424**. Alternatively, one or more of activity sensors **426** may transmit the signals to a separate monitoring device, which relays the measurements to IMD **424**. Activity sensor **426**D may be located on a leg or foot of patient **12**C.

[0226] IMD **424** may analyze the signals from activity sensors **426** to determine when any of the values of the patient parameters indicate a need to control therapy delivery. One or more of the sensed patient parameter values from activity sensors **426** may thus be used to indicate when a patient behavior may be occurring. In some examples, each sensor may provide an individual patient parameter value that is analyzed. In other examples, IMD **424** compares signals of at least two of activity sensors **426** to determine a relative motion between activity sensors **426**, and analyzes the relative motion between activity sensors **426**. The relative motion represents the manner in which one location of patient **12**C moves relative to another location of patient **12**C. Using relative motion, therefore, provides a different frame of reference, thus providing for more accurate detection of certain relevant patient motion, such as symptoms of a movement disorder. In this manner one of the patient parameters monitored for indications of patient behavior may be the relative motion between two or more activity sensors **426**. In some examples, the relative motions between each pair of activity sensors **426** may be separate patient parameters and calibrated based on the identified patient behavior.

[0227] Although four activity sensors **426** are shown in the example of FIG. **26**, one, two, three, or more than four activity sensors may be used to provide patient parameter values. Other sensors may also or alternatively be implanted or attached to patient **12**C. Such sensors may include temperature sensors. EMG sensors and strain or force gauges to detect muscle movement or flexation, or external electrodes for electrogram generation. In addition, one or more sensors may be located on furniture such as a bed or chair. For example, a hospital bed may include one or more pressure sensors that provide a patient parameter value indicative of patient motion

that can be correlated to identified patient behavior from video information captured at the same time. Any and all of these patient parameters may be used as feedback to control therapy delivered to patient **12**C.

[0228] FIG. **27** is a block diagram of an example sensor **426**C that senses a patient parameter indicative of patient behavior. Sensor **426**C may be similar to sensors **426**B, **426**D, or any other sensor described herein that may not be included within another device. As illustrated in FIG. **27**, sensor **426**C may include a processor **430**, memory **432**, sensor module **434**, communication module **436**, and power source **438**. Memory **432** may store instructions that, when executed by processor **430**, cause processor **430** to control the sensing of sensor module **434**, communication via communication module **436**, and/or the storage and retrieval of data from memory **432**.

[0229] In general, sensor **426**C comprises any suitable arrangement of hardware, alone or in combination with software and/or firmware, to perform the techniques attributed to sensor **426**C, and processor **430**, sensor module **434**, and communication module **436** of sensor **426**C. In various examples, sensor **426**C may include one or more processors, such as one or more microprocessors, DSPs, ASICs, FPGAs, or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components. Sensor **426**C also, in various examples, may include a memory **432** (e.g., a storage device), such as RAM, ROM, PROM, EPROM, EEPROM, flash memory, a hard disk, a CD-ROM, comprising executable instructions for causing the one or more processors to perform the actions attributed to them. Moreover, although processor **430** and communication module **436** are described as separate modules, in some examples, processor **430** and communication module **436** are functionally integrated. In some examples, processor **430** and communication module **436** correspond to individual hardware units, such as ASICs, DSPs, FPGAs, or other hardware units.

[0230] Memory **432** (e.g., a storage device) may store instructions that, when executed by processor **432**, cause processor **432** and sensor **426**C to provide the functionality ascribed to sensor **426**C such as generating values of the patient parameter and transmitting the generated values to another device such as IMD **424** and/or programmer **24**. Sensor module **434** may include any components, membranes, devices, etc. configured to translate mechanical, chemical, electromagnetic signal into an electrical signal for use by processor **430**. For example, sensor module **434** may include one or more accelerometers that translate mechanical acceleration into an electrical signal representative of the acceleration.

[0231] Communication module **436** may support wireless or wired communication according to any protocol known in the art or described herein. Power source **438** may include any rechargeable or non-rechargeable battery, energy scavenging device, or any other such element configured to provide operational power to activity sensor **426**C.

[0232] FIG. **28** is a graph illustrating a correlation of determined patient movement from video information to patient parameters sensed during the same period of time during which video information **50** was captured. As shown in graph **440**, signal **442** may be a calculated velocity of an anatomical region over time and a plurality of captured video frames. Networked server **44**, for example, may identify which patient behaviors occurred over time when the video information was captured, as described herein. In this manner, networked server **44** may be configured to calculate, from video information **50** captured during a period of time, one or more movement parameters of patient **12**C and identify, based on the one or more movement parameters, each of one of a plurality of patient behaviors that occurred during the period of time. As shown in FIG. **28**, networked server **44** has identified dyskinesia as occurring between times **448**A and **448**B and bradykinesia as occurring between times **450**A and **450**B.

[0233] During the same period of time in which video information **50** was captured of patient **12**C, for example, values of patient parameters were obtained that also reflect some aspect of the patient behavior. In the example of FIG. **28**, accelerations from an accelerometer were obtained and processed to calculate an acceleration signal **444** and a frequency signal **446**. Frequency signal **446** may be indicative of the frequency with which the accelerations oscillated back and forth due to patient movement. Networked server **44** may correlate acceleration signal **444** and frequency signal **446** to the identified patient behaviors. This process may be referred to as calibrating the patient parameters to respective patient behaviors.

[0234] For example, networked server **44** may determine thresholds at which the values of each patient parameter are indicative of the respective behaviors. Acceleration signal **444** is shown in "g's" or the acceleration due to gravity. Based on the magnitude of acceleration signal **444**, networked server **44** may determine threshold **452**A as indicative of dyskinesia because acceleration signal **444** included magnitudes above threshold **452**A between times **448**A and **448**B. Based on the magnitude of acceleration signal **444**, networked server **44** may determine threshold **452**B as indicative of bradykinesia because acceleration signal **444** included magnitudes above threshold **452**B between times **450**A and **450**B. Networked server **44** may also set threshold **452**A as a maximum threshold for bradykinesia such as amplitudes between thresholds **452**A and **452**B are interpreted as indicative of bradykinesia.

[0235] Frequency signal **446** is shown in Hz over time. Based on the magnitude of frequency signal **446**, networked server **44** may determine threshold **454**A as indicative of dyskinesia because frequency signal **446** included magnitudes above threshold **454**A between times **448**A and **448**B. Based on the magnitude of frequency signal **446**, networked server **44** may determine threshold **454**B as indicative of bradykinesia because frequency signal **446** included frequencies above threshold **454**B between times **450**A and **450**B. Networked server **44** may also set threshold **454**A as a maximum threshold for bradykinesia such as frequencies between thresholds **454**A and **454**B are interpreted as indicative of bradykinesia.

[0236] The example of FIG. **28** is just one technique to calibrate values of patient parameters with identified patient behaviors from video information **50**. In some examples, the thresholds may be based on a change in patient parameter value instead of an absolute value of the patient parameter. In other examples, thresholds may not be used. Instead, actual values of the patient parameter value may be matched to each type of patient behavior. In some examples, networked server **44** may be configured to correlate sensed parameter values obtained prior to the patient behavior being identified in time to the patient behavior. In some situations, a patient parameter value may "lead" or be indicative of the patient behavior. In this manner, one or more patient parameters may be predictive of observable patient behaviors.

[0237] FIG. **29** is a flow diagram illustrating an example process for associating sensed patient parameter values with patient behavior identified from video information **50**. Although FIG. **29** will be described with respect to processors **80** of networked server **44** and processor **350** of IMD **324**, other devices or combination of devices may perform similar functions such as calibrating patient parameters to identified patient behaviors from video information.

[0238] As shown in FIG. **29**, processors **80** may obtain video information **50** of patient **12**A captured by camera **26** during a period of time (**460**). Processors **80** then identify any patient behavior that occurred during the period of time from the video frames of video information **50** (**462**). Processors **80** also obtain sensor data from a sensor (e.g., sensor **359**) generated for a patient parameter and during the time period of the video information (**464**). Processors **80** may then select patient parameter values from the sensor data that are indicative, or representative, of the identified patient behavior from the video information (**466**). Processors **80** may then associate the identified patient behavior and corresponding therapy parameter values with the selected patient parameter values (**468**). This correlation (or calibration) may, in some examples, include the determination of one or more thresholds or ranges within which the representative patient parameter values will occur.

[0239] Once the correlations have been made, networked server **44** may store the correlations in repository **46** and transmit the correlations to programmer **24** and/or IMD **324** for use as feedback to control therapy. Processor **350** of IMD **324** may then monitor the subsequent patient parameter data from the sensor (**470**). If processor **350** does not detect a patient parameter value indicative of any patient behavior ("NO" branch of block **472**), processor **350** may continue to monitor the data from the sensor. If processor **350** detects a patient parameter value indicative of a behavior ("YES" branch of block **472**), processor **350** may select the one or more therapy parameters associated with the detected patient parameter values and control therapy delivery using the selected therapy parameters (**474**).

[0240] The example of FIG. **29** may be used for monitoring multiple different patient parameters as well. For example, processor **350** may monitor the values of respective patient parameters and select the therapy parameters associated with the patient parameter values associated with the values that are sensed. In some examples, if multiple patient parameter values are indicative of a particular behavior, each of the patient parameters might need to be indicative of the same behavior before processor **350** will select the associated therapy parameters. Although IMD **324** is described as monitoring the patient parameter values, programmer **24**, networked server **44**, and/or another computing device may monitor one or more patient parameters.

[0241] FIG. **30** is a flow diagram illustrating an example process for requesting new video information and updating the associations between sensed patient parameter values and patient behaviors identified from the new video information. At some point during therapy, one or more therapies may no longer be as effective as they once were. In addition, patient disease progression may cause changes to the severity, duration, or type of exhibited behavior. Therefore, it may be desirable to capture new video information and update the correlations between patient behaviors and sensed patient parameter values. Although FIG. **30** will be described with respect to processors **80** of networked server **44** and processor **350** of IMD **324**, other devices or combination of devices may perform similar functions such as calibrating patient parameters to identified patient behaviors from video information.

[0242] Processor **350** of IMD **324** may detect a patient behavior from sensor data during a time period (**480**). If the appropriate therapy for the behavior was not being delivered when the behavior was detected ("NO" branch of block **482**), processor **350** may select therapy parameters associated with the behavior (**484**) and continue to detect patient behavior (**480**). If the appropriate therapy for the detected behavior was being delivered when the behavior was detected ("YES" branch of block **482**), processor **350** may generate a notification requesting new video information capturing motion of patient **12**A (**486**). Processor **350** may transmit the notification for display to a user (e.g., patient **12**A or clinician **22**) such that video information can be captured (**488**). The user or clinician may then arrange for new video information to be captured of patient **12**A. If camera **26** is already in place to capture video, processor **350** may transmit the notification to computing device **30** for initiation of video capture.

[0243] If networked server **44** has not received new video information or updated associations between the patient parameter values and the therapy parameters ("NO" branch of block **490**), processor **350** may be instructed to select a default therapy (**492**) and wait for updated instructions. The default therapy may be a known acceptable therapy, a minimal therapy based on the last identified behavior, or even a therapy selected by the patient or clinician. If networked server **44** receives new video information captured from patient **12**A ("YES" branch of block **490**), networked server **44** may analyze the new video information to identify any patient behaviors, obtain new sensor data, and correlate the patient parameter values of the sensor data to the newly identified patient behaviors (**494**). Networked server **44** may then update the associations between the patient parameter values of the new sensor data and the therapy parameter values for the identified patient behaviors (**496**).

[0244] Although networked server **44** may initially identify patent behaviors by using only video information, networked server **44** may alternatively obtain patient parameter data from various other sources (e.g., any sensors described herein) and determine one or more patient behaviors from a combination of the video information and the obtained patient parameter data. As one example, networked server **44** may use video information in conjunction with patient parameter data from accelerometers, gyroscopes or GPS devices to distinguish between tremor during patient rest, tremor during patient action, or tremor while a patient is attempting to hold a static posture. The patient parameter data used in the initial behavior identification process may then also be associated with the identified behavior for use in detecting subsequent instances of the behavior. A determined behavior may then be used to selecting corresponding therapy parameters as discussed herein. Thus, in some examples, networked server **44** may be configured to identify one or more patient behaviors from video information and information obtained from other sources, such as one or more sensors from which patient parameters are derived. In a similar manner, networked server **44** (or any other similarly configured device) may detect a previously-identified patient behavior by monitoring both patient parameter data as well as video data. For instance, a patient may have one or more video systems installed in his or her home. While the patient remains in this environment, networked server **44** may obtain

video information from the one or more video systems and obtain patient parameter values detected by one or more non-video sensors (e.g., accelerometers, pressure sensors, etc.) in an on-going or intermittent basis to subsequently determine one or more behaviors of the patient. For example, a video system may transfer video information wirelessly, either in raw format or in a processed format, to IMD **324**, **344**, programmer **24**, and/or networked server **44** for use in determining the patient behavior. The one or more patient parameters may be combined with the video information to determine the patient behavior, or the patient parameters may be used to confirm a patient behavior determined from the video information. Any devices described herein may, in some examples, adjust therapy from the determined patient behavior

[0245] As discussed herein, networked server **44**, IMD **324**, or programmer **24**, for example, may periodically obtain and/or request new video information from one or more video systems. The new video information may then be used to re-identify patient behaviors following the initial identification, or calibration, of the patient behaviors. Subsequently determined patient behaviors (e.g., re-identified patient behaviors) may be used by one or more systems to track changes in one or more symptoms and/or disease progression. Additionally, the determined patient behaviors may be used to adjust therapy based on the stage of the disease. In some cases, networked device **44** (or another device such as programmer **24**) may generate a notification based on one of more determined patient behaviors. The notification may instruct the patient to take one or more actions, such as take a medication, perform an activity, call a clinician, or schedule an appointment with a clinician. Networked server **44** may also transmit the notification to the clinician or otherwise follow up with the patient regarding the determined patient behavior. In this manner, determination of patient behaviors from video information (and patient parameters in some examples) can be used by a device or system to identify symptom or disease trends for the patient and take other appropriate actions (e.g., adjust therapy or provide instructions to a patient) in response to various behaviors that may indicate one or more disease states.

[0246] The disclosure contemplates computer-readable storage media comprising instructions to cause a processor to perform any of the functions and techniques described herein. The computer-readable storage media may take the example form of any volatile, non-volatile, magnetic, optical, or electrical media, such as a RAM, ROM, NVRAM, EEPROM, or flash memory that is tangible. The computer-readable storage media may be referred to as non-transitory. A programmer, such as patient programmer or clinician programmer, or other computing device may also contain a more portable removable memory type to enable easy data transfer or offline data analysis.

[0247] The techniques described in this disclosure, including those attributed to server **44** and programmer **24**, and various constituent components, may be implemented, at least in part, in hardware, software, firmware or any combination thereof. For example, various aspects of the techniques may be implemented within one or more processors, including one or more microprocessors, DSPs, ASICs, FPGAs, or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components, embodied in programmers, such as physician or patient programmers, stimulators, remote servers, or other devices. The term "processor" or "processing circuitry" may generally refer to any of the foregoing logic circuitry, alone or in combination with other logic circuitry, or any other equivalent circuitry.

[0248] Such hardware, software, firmware may be implemented within the same device or within separate devices to support the various operations and functions described in this disclosure. For example, any of the techniques or processes described herein may be performed within one device or at least partially distributed amongst two or more devices, such as between programmer **24** and server **44**. In addition, any of the described units, modules or components may be implemented together or separately as discrete but interoperable logic devices. Depiction of different features as modules or units is intended to highlight different functional aspects and does not necessarily imply that such modules or units must be realized by separate hardware or software components. Rather, functionality associated with one or more modules or units may be performed by separate hardware or software components, or integrated within common or separate hardware or software components.

[0249] The techniques described in this disclosure may also be embodied or encoded in an article of manufacture including a computer-readable storage medium encoded with instructions. Instructions embedded or encoded in an article of manufacture including a computer-readable storage medium encoded, may cause one or more programmable processors, or other processors, to implement one or more of the techniques described herein, such as when instructions included or encoded in the computer-readable storage medium are executed by the one or more processors. Example computer-readable storage media may include random access memory (RAM), read only memory (ROM), programmable read only memory (PROM), erasable programmable read only memory (EPROM), electronically erasable programmable read only memory (EEPROM), flash memory, a hard disk, a compact disc ROM (CD-ROM), a floppy disk, a cassette, magnetic media, optical media, or any other computer readable storage devices or tangible computer readable media. The computer-readable storage medium may also be referred to as storage devices.

[0250] In some examples, a computer-readable storage medium comprises non-transitory medium. The term "non-transitory" may indicate that the storage medium is not embodied in a carrier wave or a propagated signal. In certain examples, a non-transitory storage medium may store data that can, over time, change (e.g., in RAM or cache).

[0251] Various examples have been described herein. Any combination of the described operations or functions is contemplated. These and other examples are within the scope of the following claims.

1: A method comprising:

receiving, from a computing device, an indication of a patient behavior for a period of time, wherein the patient behavior is determined by the computing device from video information captured during the period of time;

determining, based on the indication of the patient behavior and by one or more processors, a therapy to be delivered to the patient; and

outputting the determination for at least one of delivery of the therapy to the patient and display to the user.

2: The method of claim **1**, wherein determining the therapy to be delivered comprises selecting, by the one or more processors, one or more therapy parameter values that at least partially define the therapy

3: The method of claim **1**, wherein the period of time is a first period of time and the therapy is a first therapy, and wherein the method further comprises:

receiving an indication of user input identifying insufficient therapy;

requesting capture of supplemental video information of patient motion during a second period of time different than the first period;

receiving an indication of patient behavior during the second period of time; and

determining, based on the indication of patient behavior during the second period of time, a second therapy different than the first therapy.

4: The method of claim **1**, wherein determining the therapy comprises selecting one of a plurality of predetermined therapies, each of the plurality of therapies corresponding to at least one of a plurality of patient behaviors associated with a respective one or more movement parameters generated from the video information, and wherein the patient behavior is one of the plurality of patient behaviors.

5: The method of claim **1**, further comprising:

calculating, from the video information captured during the period of time, one or more movement parameters of the patient;

identifying, based on the one or more movement parameters, each of one of a plurality of patient behaviors that occurred during the period of time;

obtaining values of a patient parameter sensed during the period of time; and

correlating the values of the patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time.

6: The method of claim **5**, further comprising:

subsequent to the correlation, obtaining a sensed patient parameter value; and

identifying one or more of the plurality of patient behaviors associated with the sensed patient parameter value, and wherein determining the therapy comprises, determining, based on the identification, the therapy to be delivered to the patient.

7: The method of claim **5**, wherein the patient parameter is a first patient parameter, and wherein the method further comprises:

obtaining values of a second patient parameter sensed during the period of time;

correlating the values of the second patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time;

determining that the values of both the first patient parameter and the second patient parameter are associated with the same patient behavior; and

identifying the same patient behavior as the one or more of the plurality of patient behaviors.

8: The method of claim **5**, wherein the patient parameter comprises one of a local field potential, an electroencephalogram, an electrogram, an electromyogram, an acceleration of the patient, a relative motion between two locations of the patient, blood pressure, heart rate, patient speech pattern, patient breathing pattern, sleep indication, or chemical.

9: The method of claim **1**, further comprising:

obtaining, by the computing device, one or more values of a patient parameter sensed during the period of time; and

determining, based on video information captured during the period of time and the one or more values of the patient parameter, the patient behavior for the period of time.

10: The method of claim **1**, further comprising delivering, by an implantable medical device, the therapy to the patient.

11: The method of claim **1**, wherein the therapy is one of electrical stimulation therapy, drug delivery therapy, or oral medication therapy.

12: The method of claim **1**, wherein the patient behavior is a movement disorder.

13: The method of claim **1**, wherein the one or more processors are housed within one of a networked server, a medical device programmer, and an implantable medical device.

14: A system comprising:

one or more processors configured to:

receive, from a computing device, an indication of a patient behavior for a period of time, wherein the patient behavior is determined by the computing device from video information captured during the period of time;

determine, based on the indication of the patient behavior, a therapy to be delivered to the patient; and

output the determination for at least one of delivery of the therapy to the patient and display to the user.

15: The system of claim **14**, wherein the one or more processors are configured to determine the therapy by selecting one or more therapy parameter values that at least partially define the therapy.

16: The system of claim **14**, wherein the period of time is a first period of time and the therapy is a first therapy, and wherein the one or more processors are configured to:

receive an indication of user input identifying insufficient therapy;

request capture of supplemental video information of patient motion during a second period of time different than the first period;

receive an indication of patient behavior during the second period of time; and

determine, based on the indication of patient behavior during the second period of time, a second therapy different than the first therapy.

17: The system of claim **14**, wherein the one or more processors are configured to determine the therapy by selecting one of a plurality of predetermined therapies, each of the plurality of therapies corresponding to at least one of a plurality of patient behaviors associated with a respective one or more movement parameters generated from the video information, and wherein the patient behavior is one of the plurality of patient behaviors.

18: The system of claim **14**, wherein the one or more processors are configured to:

calculate, from the video information captured during the period of time, one or more movement parameters of the patient;

identify, based on the one or more movement parameters, each of one of a plurality of patient behaviors that occurred during the period of time;

obtain values of a patient parameter sensed during the period of time; and

correlate the values of the patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time.

19: The system of claim **18**, wherein the one or more processors are configured to:

subsequent to the correlation, obtain a sensed patient parameter value; and

identify one or more of the plurality of patient behaviors associated with the sensed patient parameter value; and

determine, based on the identification, the therapy to be delivered to the patient.

20: The system of claim **18**, wherein the patient parameter is a first patient parameter, and wherein the one or more processors are further configured to:

obtain values of a second patient parameter sensed during the period of time;

correlate the values of the second patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time;

determine that the values of both the first patient parameter and the second patient parameter are associated with the same patient behavior; and

identify the same patient behavior as the one or more of the plurality of patient behaviors.

21: The system of claim **18**, wherein the patient parameter comprises one of a local field potential, an electroencephalogram, an electrogram, electromyogram, an acceleration of the patient, a relative motion between two locations of the patient, blood pressure, heart rate, patient speech pattern, patient breathing pattern, sleep indication, or chemical.

22. (canceled)

22. (canceled)

23: The system of claim **14**, wherein the therapy is one of electrical stimulation therapy, drug delivery therapy, or oral medication therapy.

24: The system of claim **14**, wherein the patient behavior is a movement disorder.

25: The system of claim **14**, further comprising one of a networked server, a medical device programmer, or an implantable medical device that houses the one or more processors.

26: A computer-readable storage medium comprising instructions that cause one or more processors to:

receive, from a computing device, an indication of a patient behavior for a period of time, wherein the patient behavior is determined by the computing device from video information captured during the period of time;

determine, based on the indication of the patient behavior, a therapy to be delivered to the patient; and

output the determination for at least one of delivery of the therapy to the patient and display to the user.

27: The computer-readable storage medium of claim **26**, wherein the instructions that cause the one or more processors to determine the therapy comprises instructions that cause the one or more processors to select one of a plurality of predetermined therapies, each of the plurality of therapies corresponding to at least one of a plurality of patient behaviors associated with a respective one or more movement parameters generated from the video information, and wherein the patient behavior is one of the plurality of patient behaviors.

28: The computer-readable storage medium of claim **26**, further comprising instructions that cause the one or more processors to:

calculate, from the video information captured during the period of time, one or more movement parameters of the patient;

identify, based on the one or more movement parameters, each of one of a plurality of patient behaviors that occurred during the period of time;

obtain values of a patient parameter sensed during the period of time;

correlate the values of the patient parameter to each of the one of the plurality of patient behaviors that occurred during the period of time;

subsequent to the correlation, obtain a sensed patient parameter value; and

identify one or more of the plurality of patient behaviors associated with the sensed patient parameter value, and wherein the instructions that cause the one or more processors to determine the therapy comprises instructions that cause the one or more processors to determine, based on the identification, the therapy to be delivered to the patient.

29: The system of claim **14**, wherein the one or more processors are configured to:

obtain one or more values of a patient parameter sensed during the period of time; and

determine, based on video information captured during the period of time and the one or more values of the patient parameter, the patient behavior for the period of time.

30: The system of claim **14**, further comprising an implantable medical device configured to deliver the therapy to the patient.

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