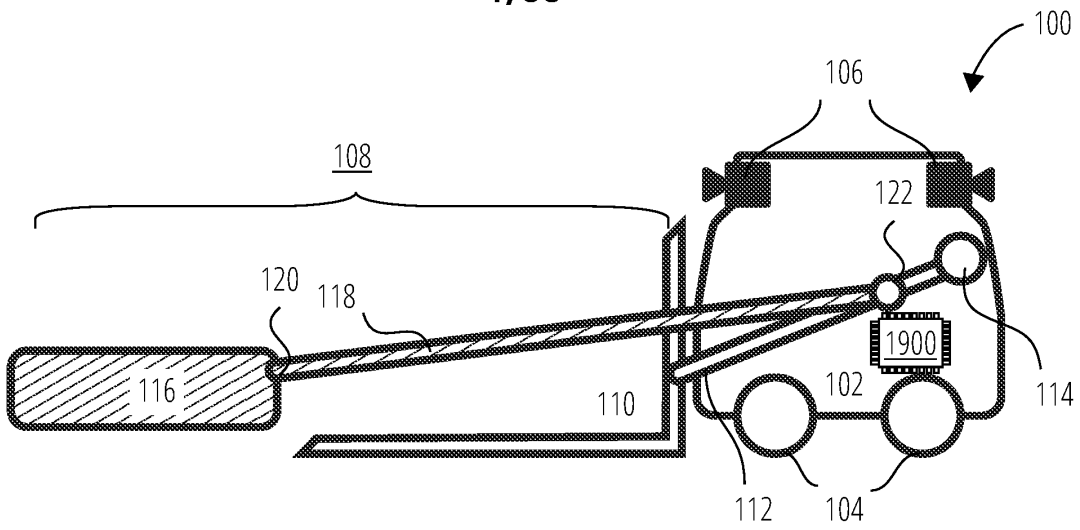

100
106
108
122
120
118
1900
116
110
102
114
112
104

FIG. 1A

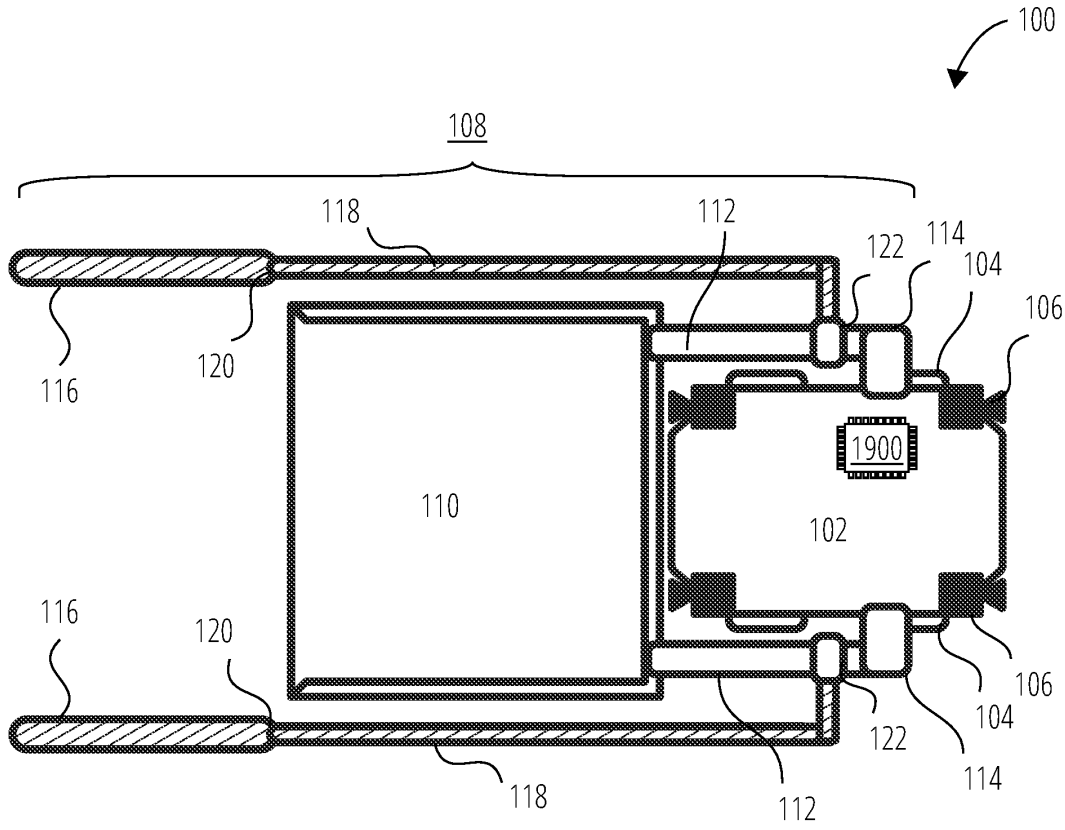

100
108
118
112
122
114
104
106
116
120
1900
110
102
116
120
106
104
122
114
118
112

FIG. 1B

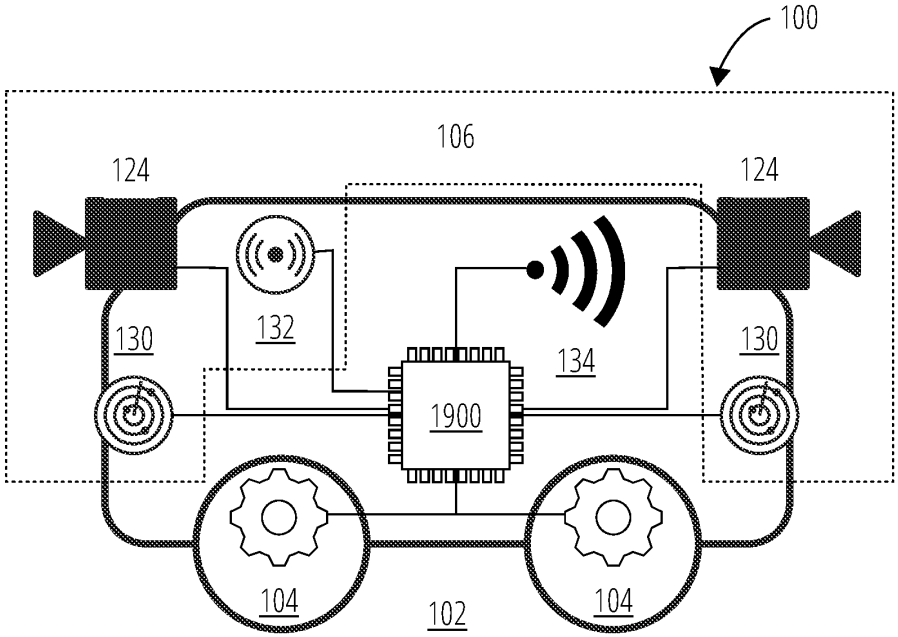

100
106
124
124
130
132
134
130
1900
104
102
104

FIG. 1C

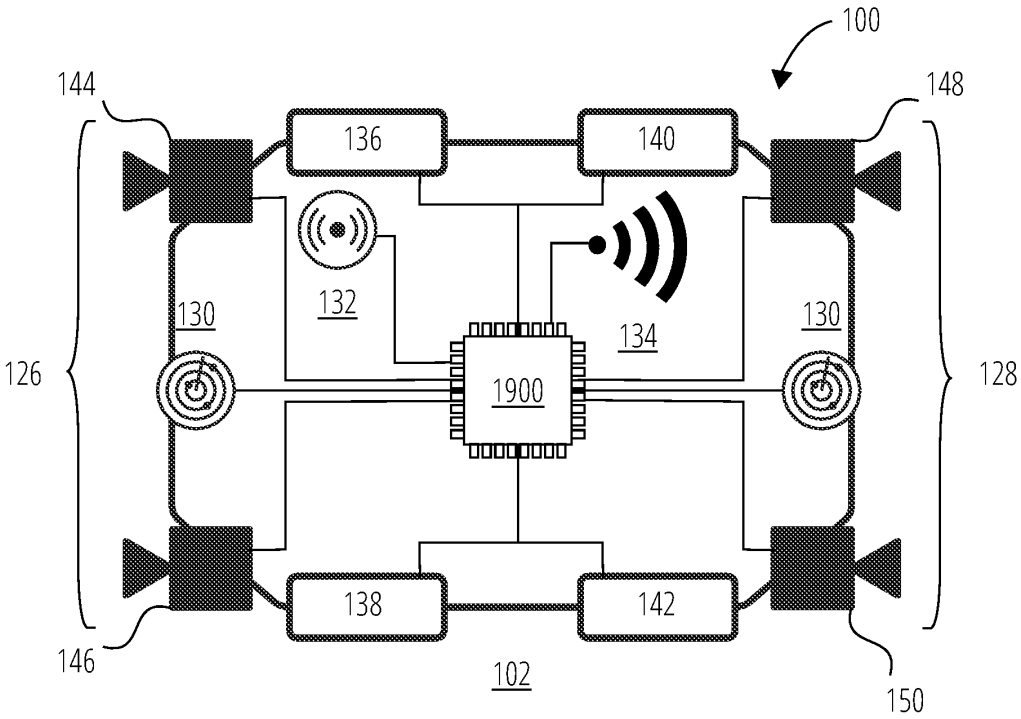

100
144
148
136
140
130
132
134
130
126
1900
128
138
142
146
102
150

FIG. 1D

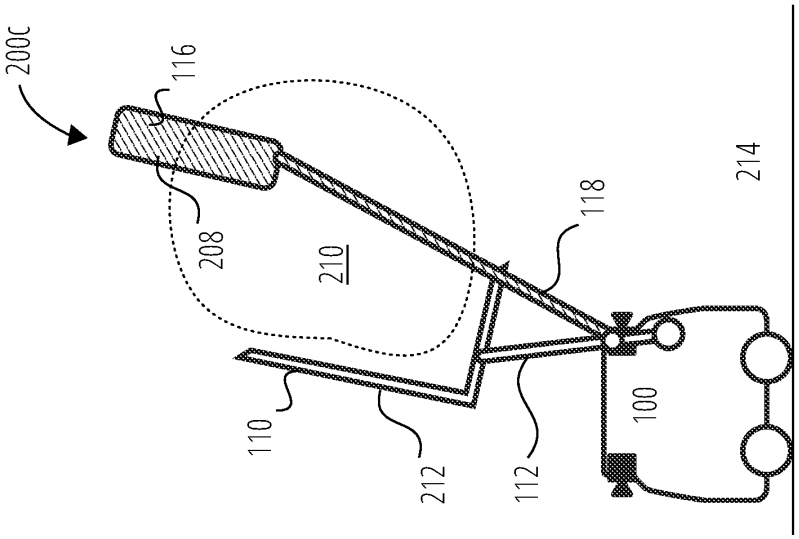


FIG. 2C

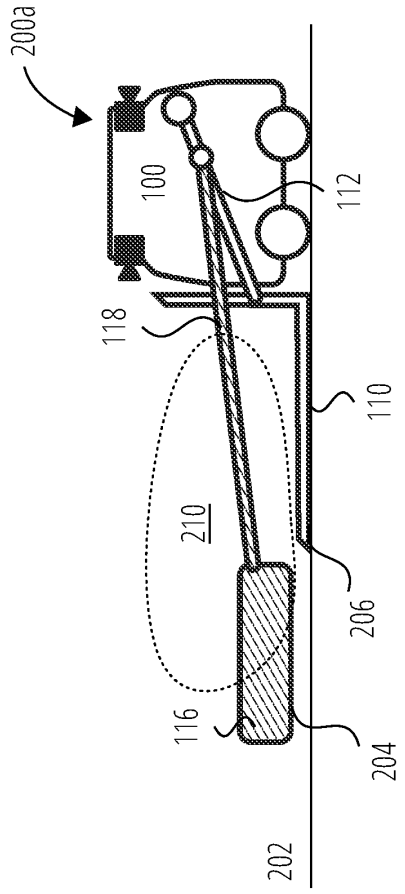


FIG. 2A

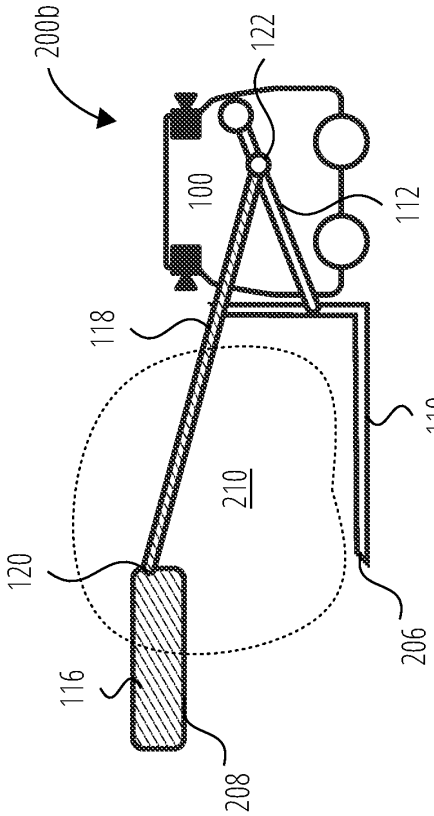


FIG. 2B

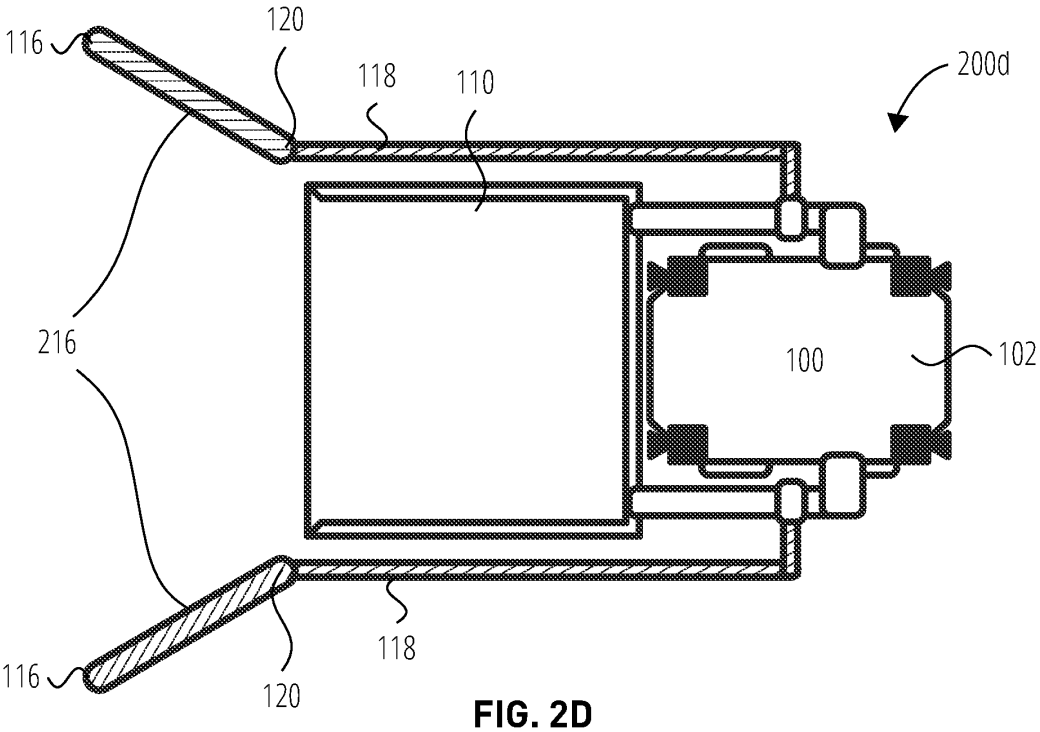

116
120
118
110
200d
216
100
102
116
120
118

FIG. 2D

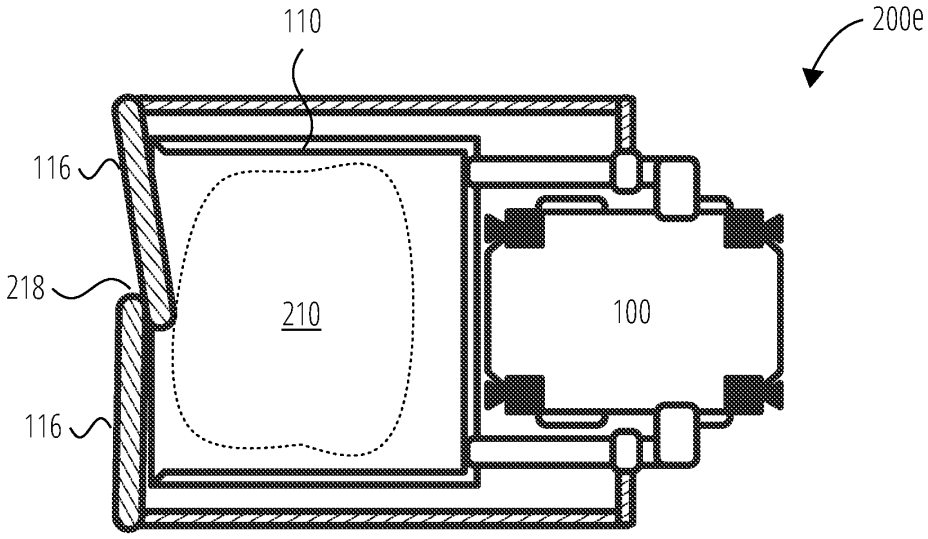

110
200e
116
218
210
100
116

FIG. 2E

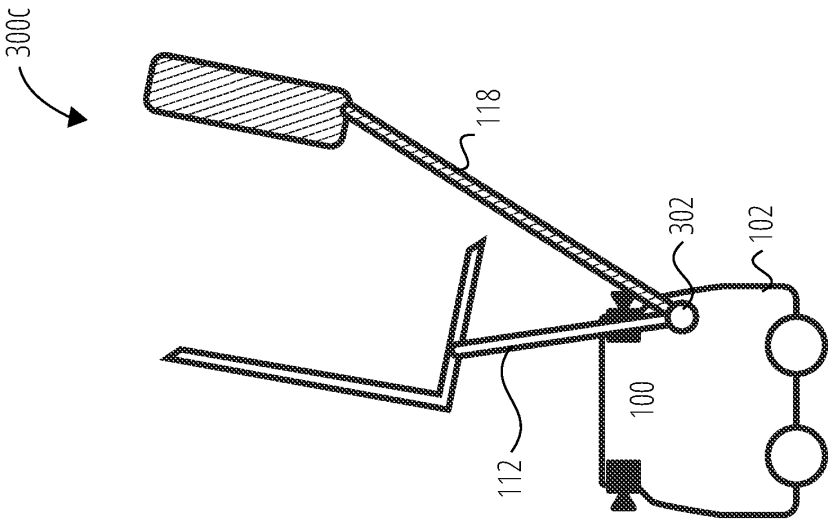


FIG. 3C

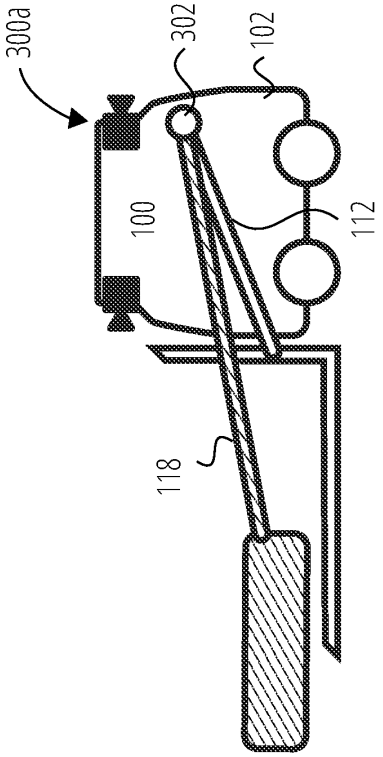


FIG. 3A

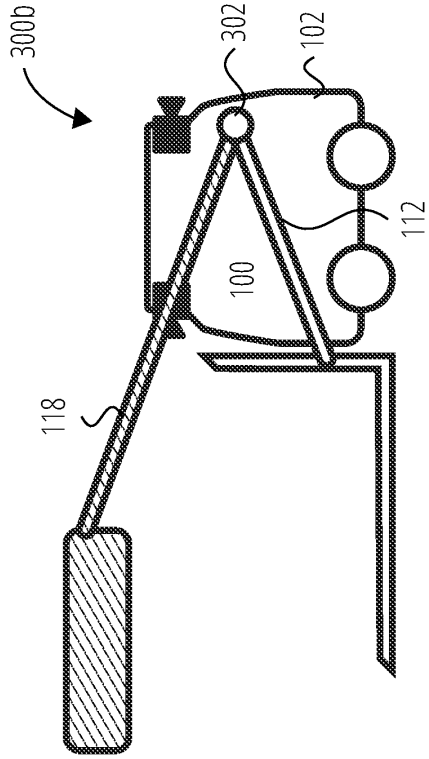


FIG. 3B

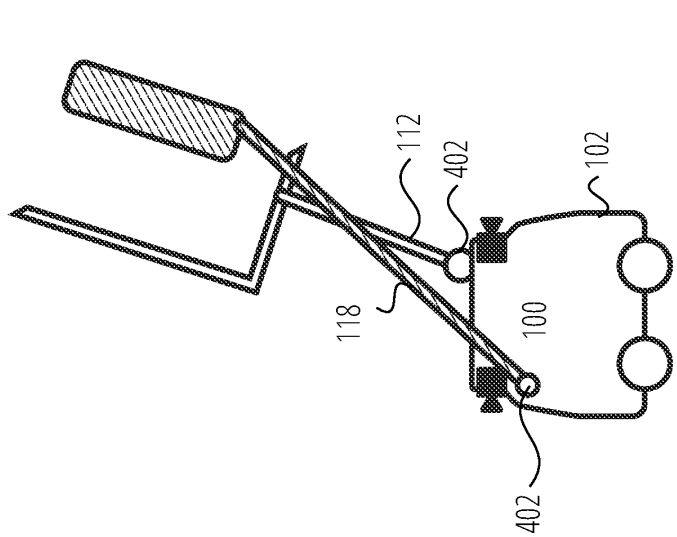


FIG. 4C

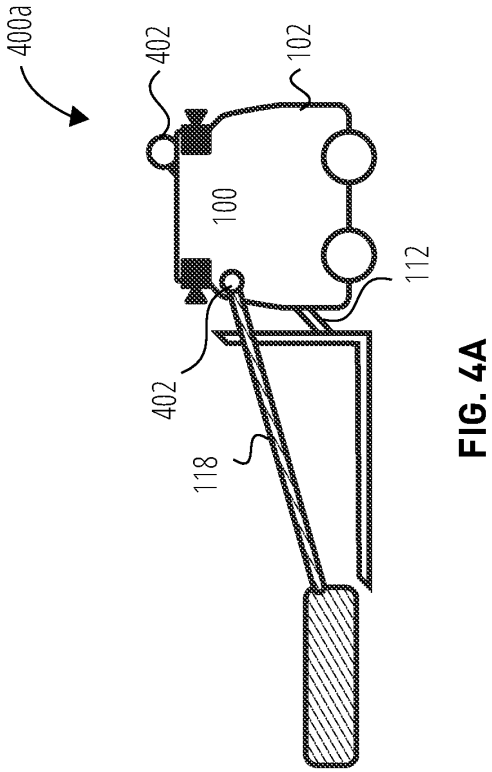


FIG. 4A

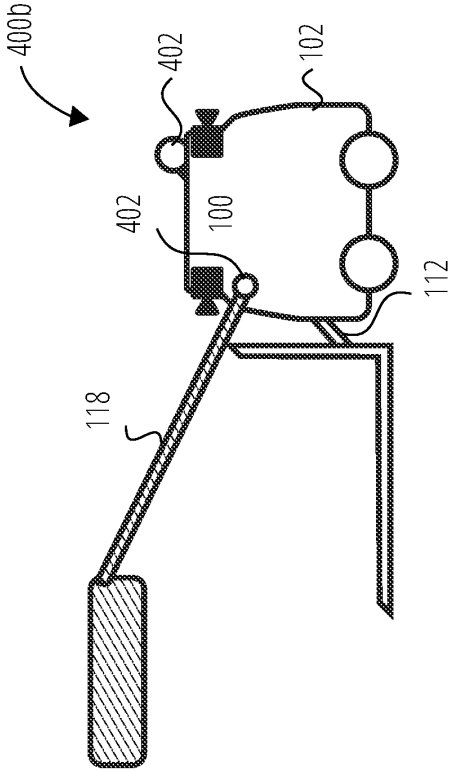


FIG. 4B

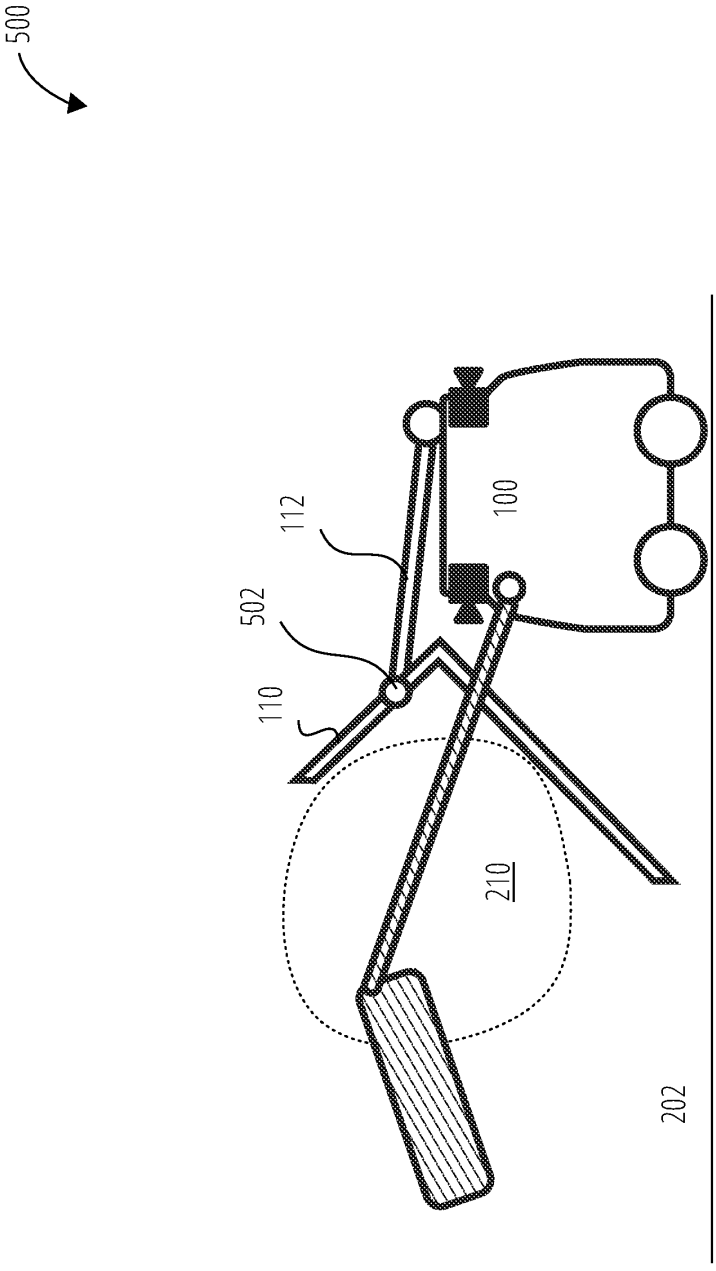


FIG. 5

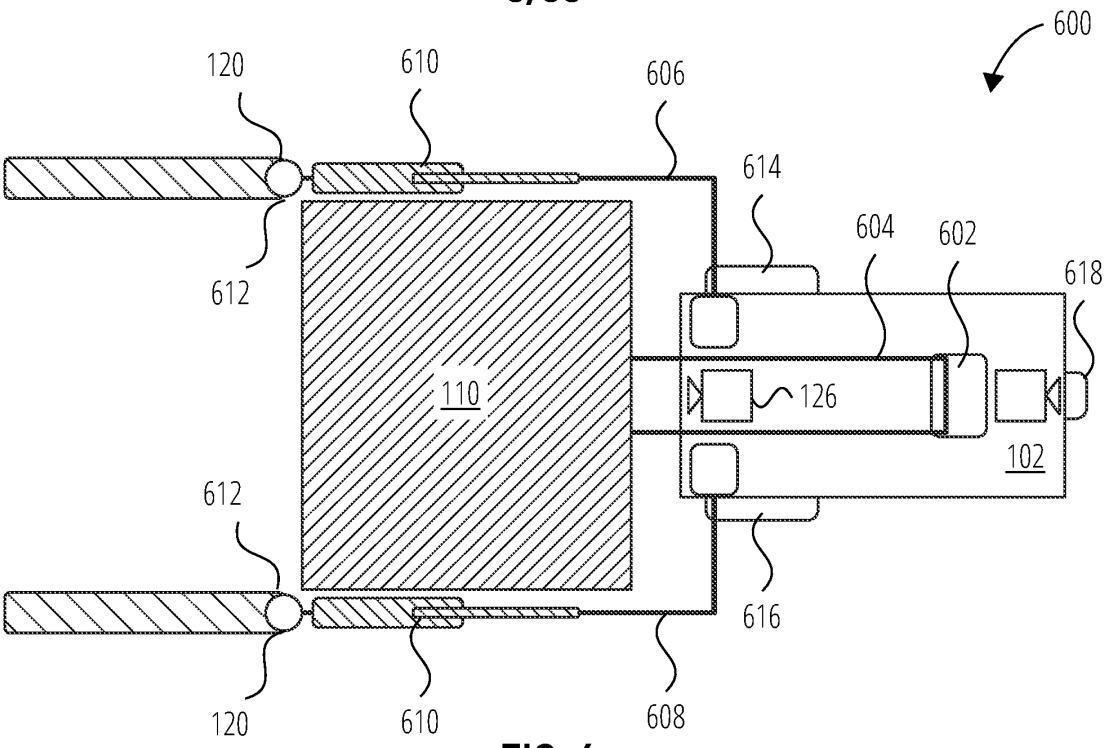

600
120
610
606
614
604
602
618
612
110
126
102
612
616
120
610
608

FIG. 6

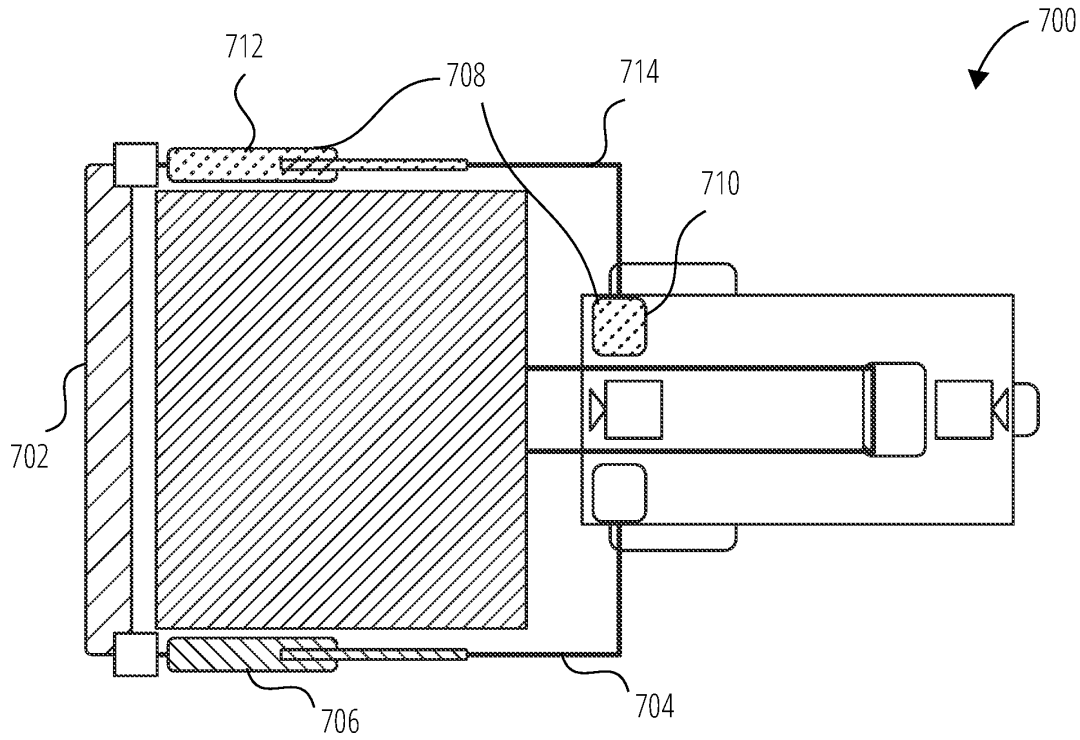

700
712
708
714
710
702
706
704

FIG. 7

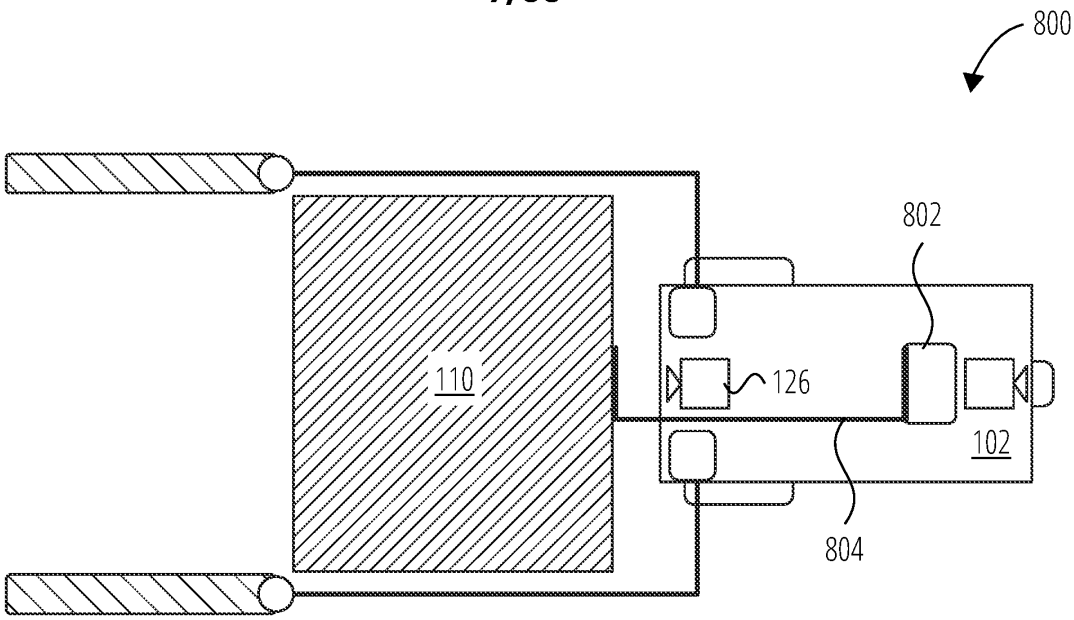


FIG. 8

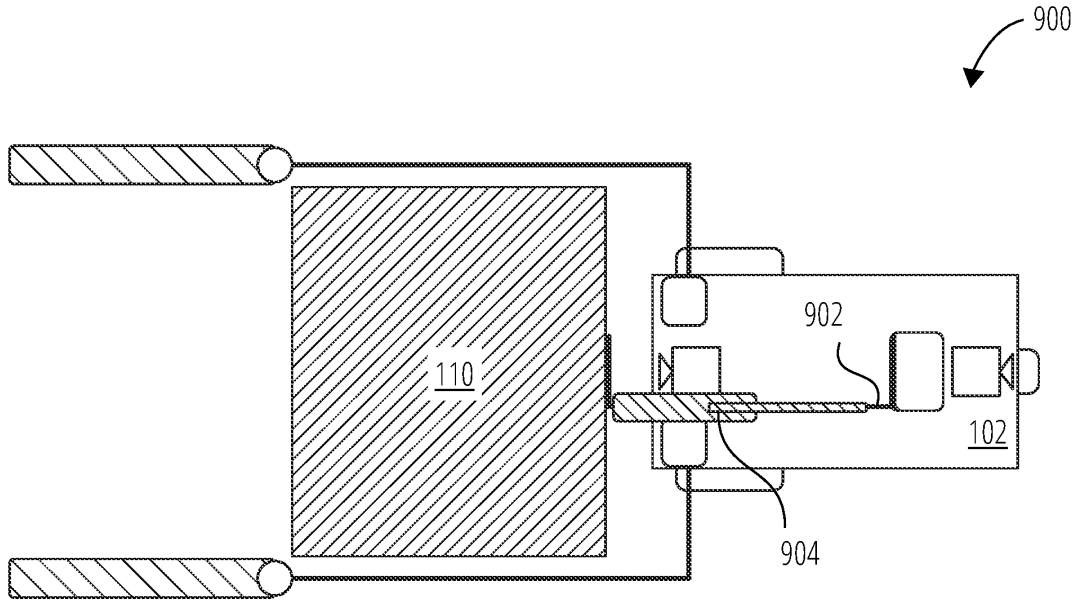


FIG. 9

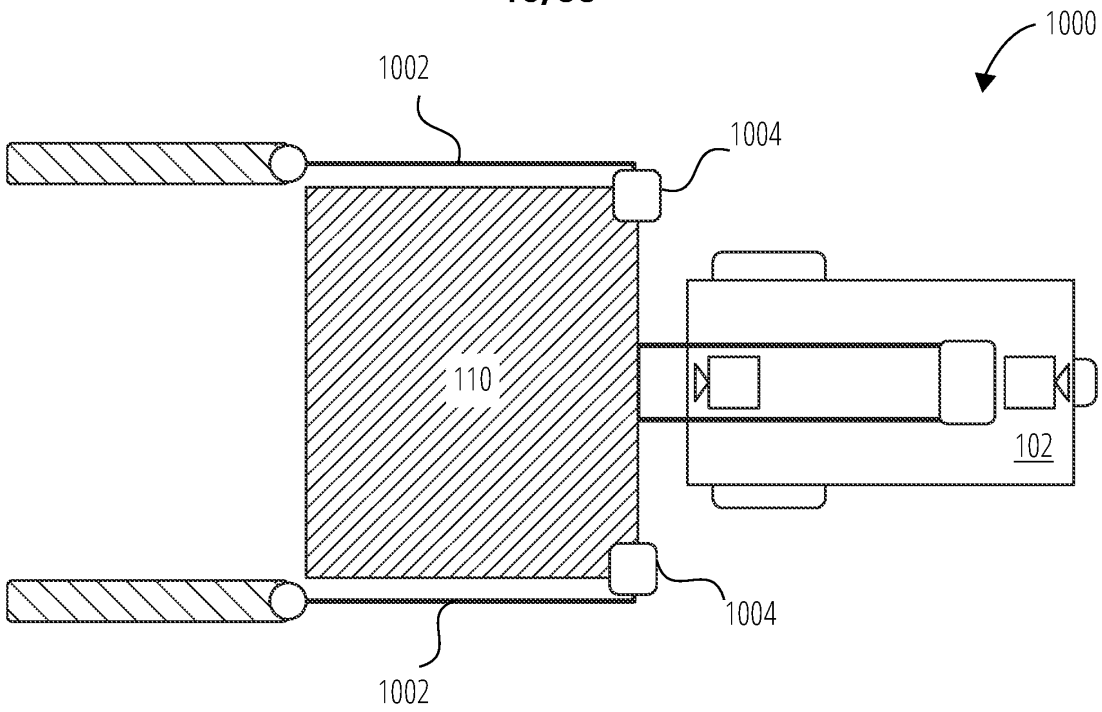


FIG. 10

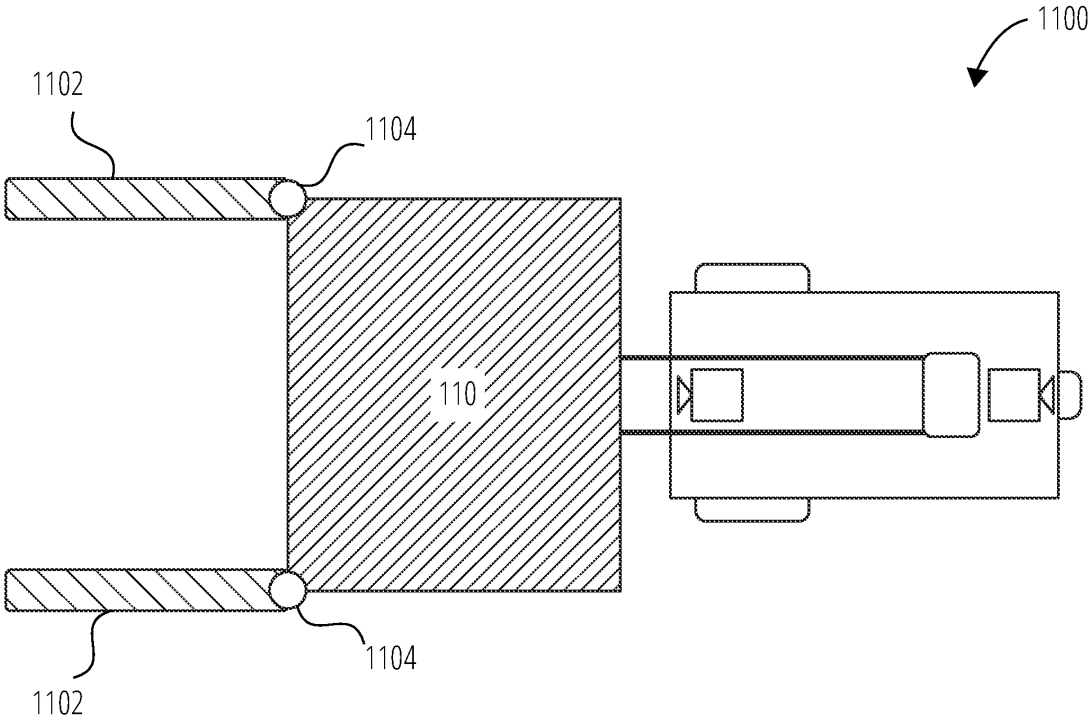


FIG. 11

FIG. 12

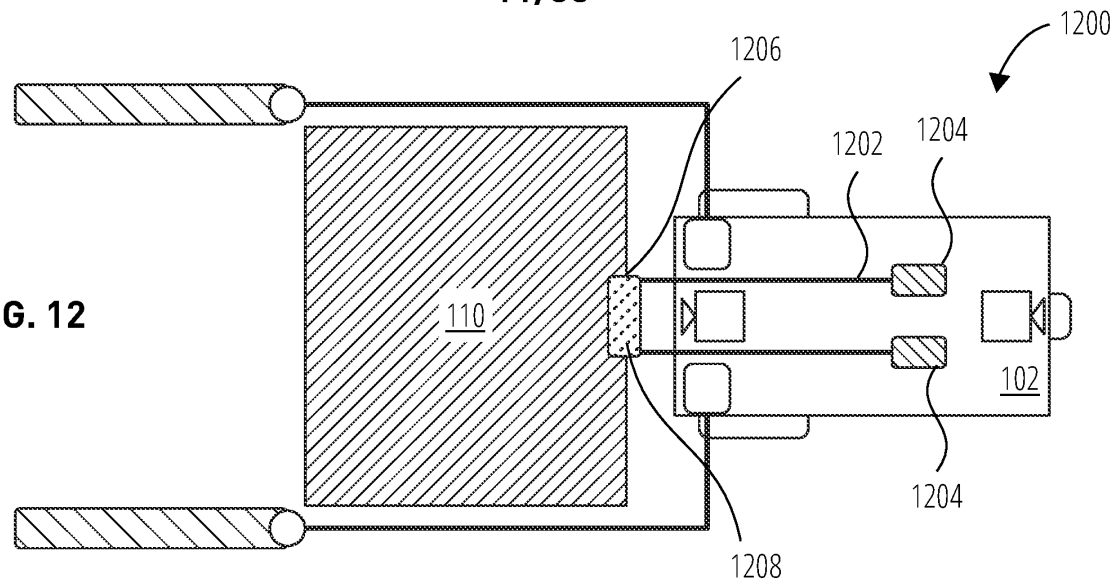


FIG. 13

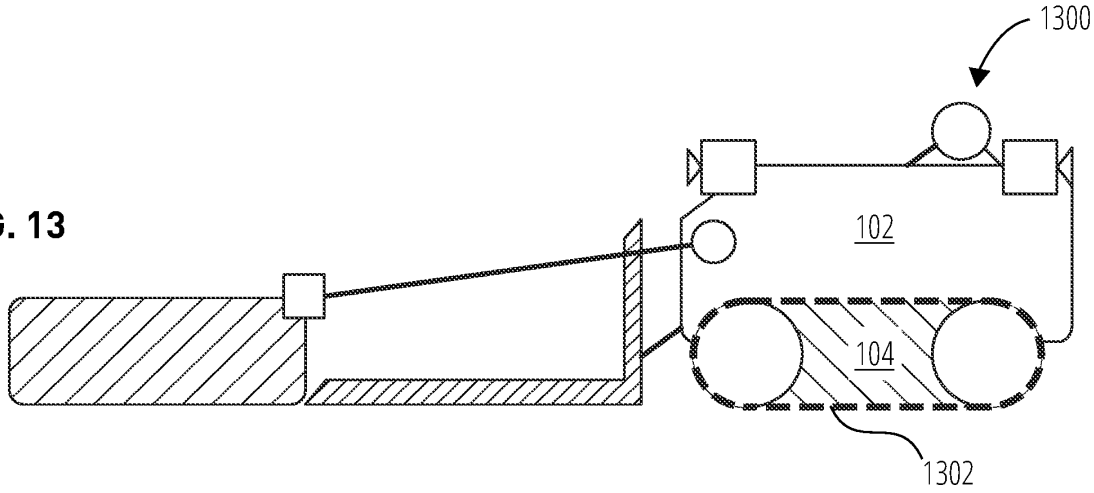
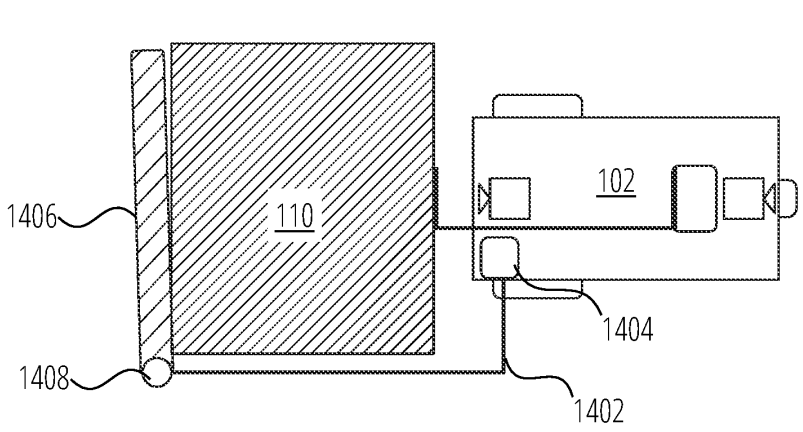


FIG. 14



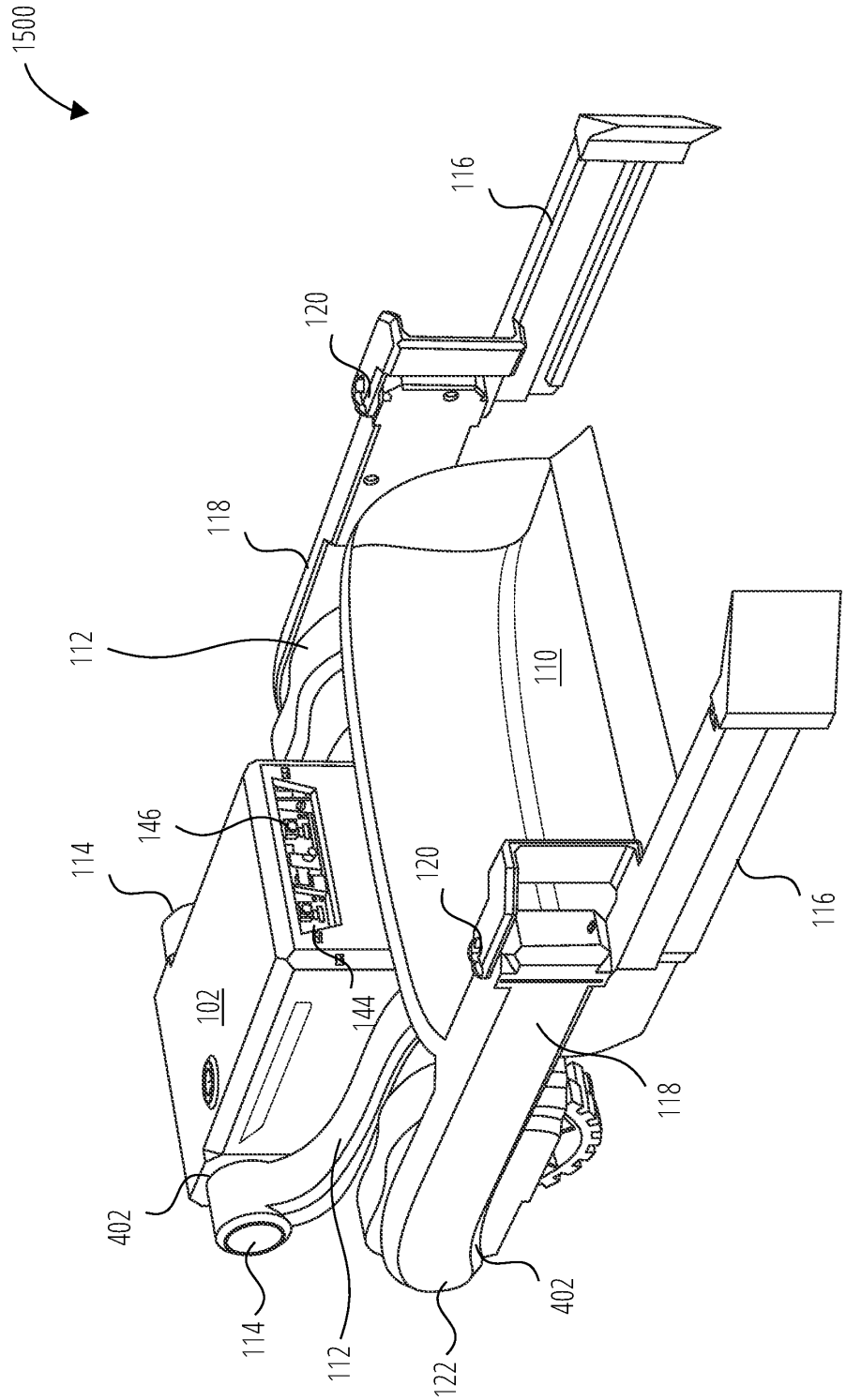

1500
116
120
118
112
110
146
114
120
116
102
144
118
402
114
112
122
402

FIG. 15

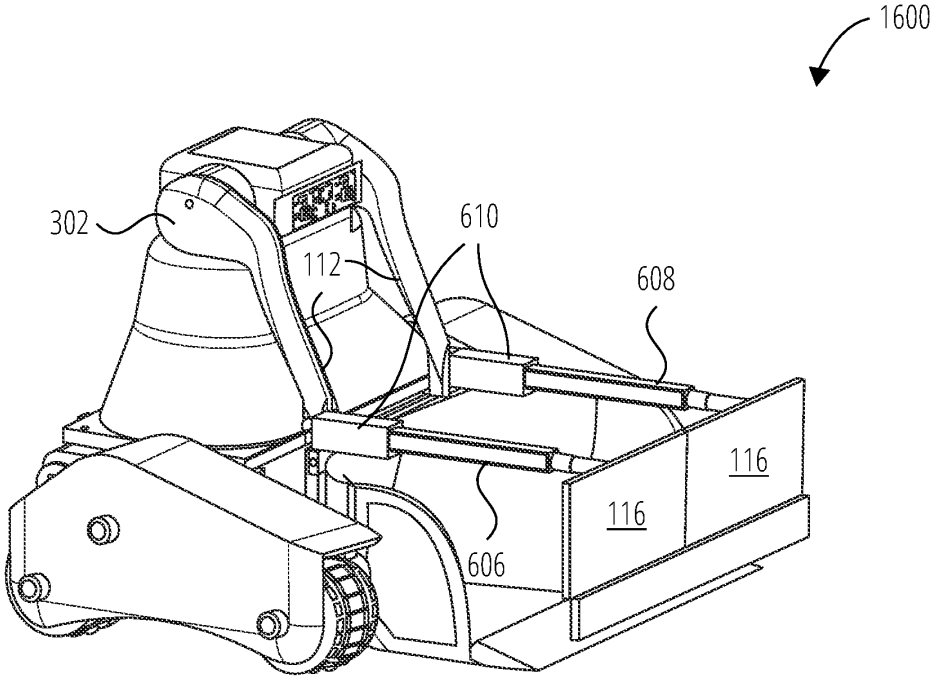


FIG. 16

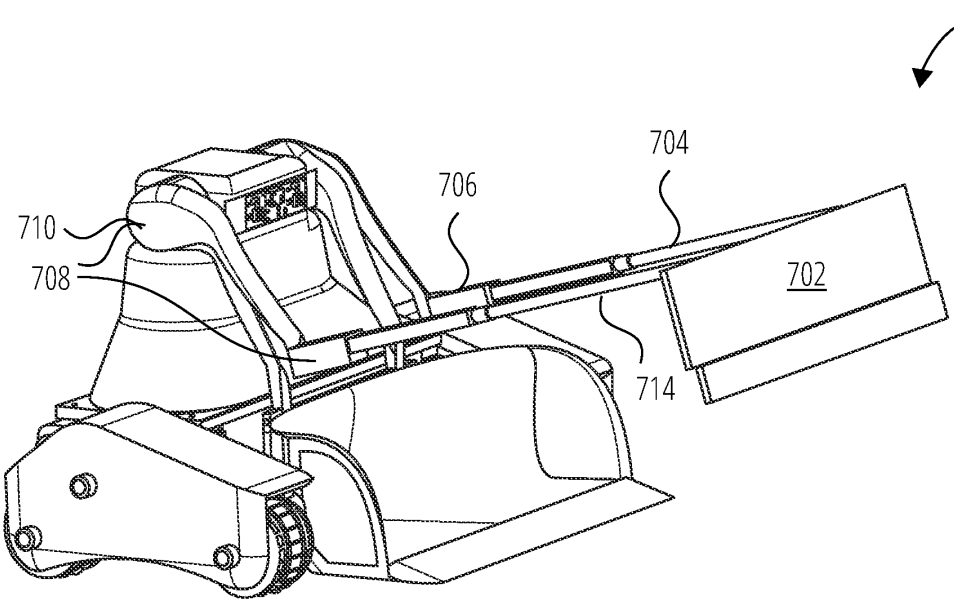


FIG. 17

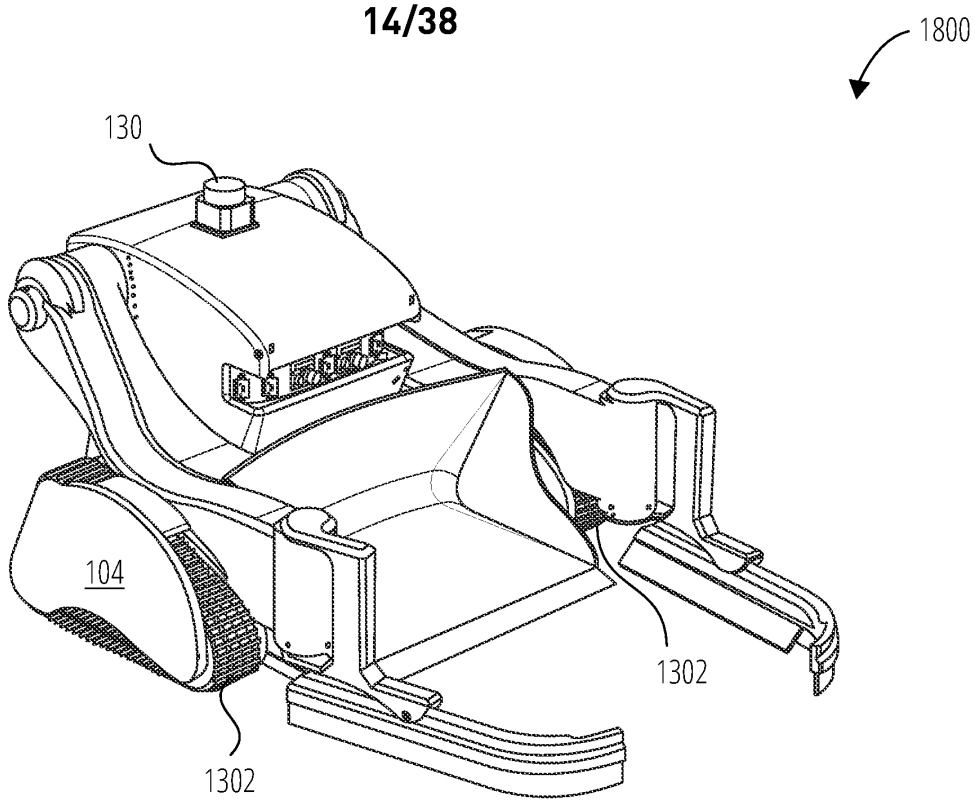


FIG. 18A

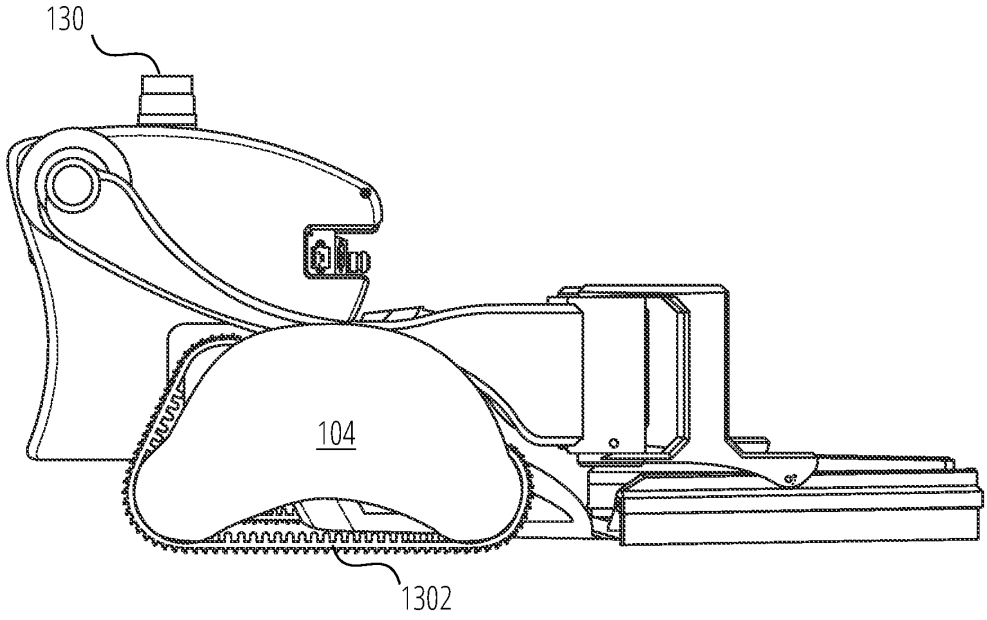


FIG. 18B

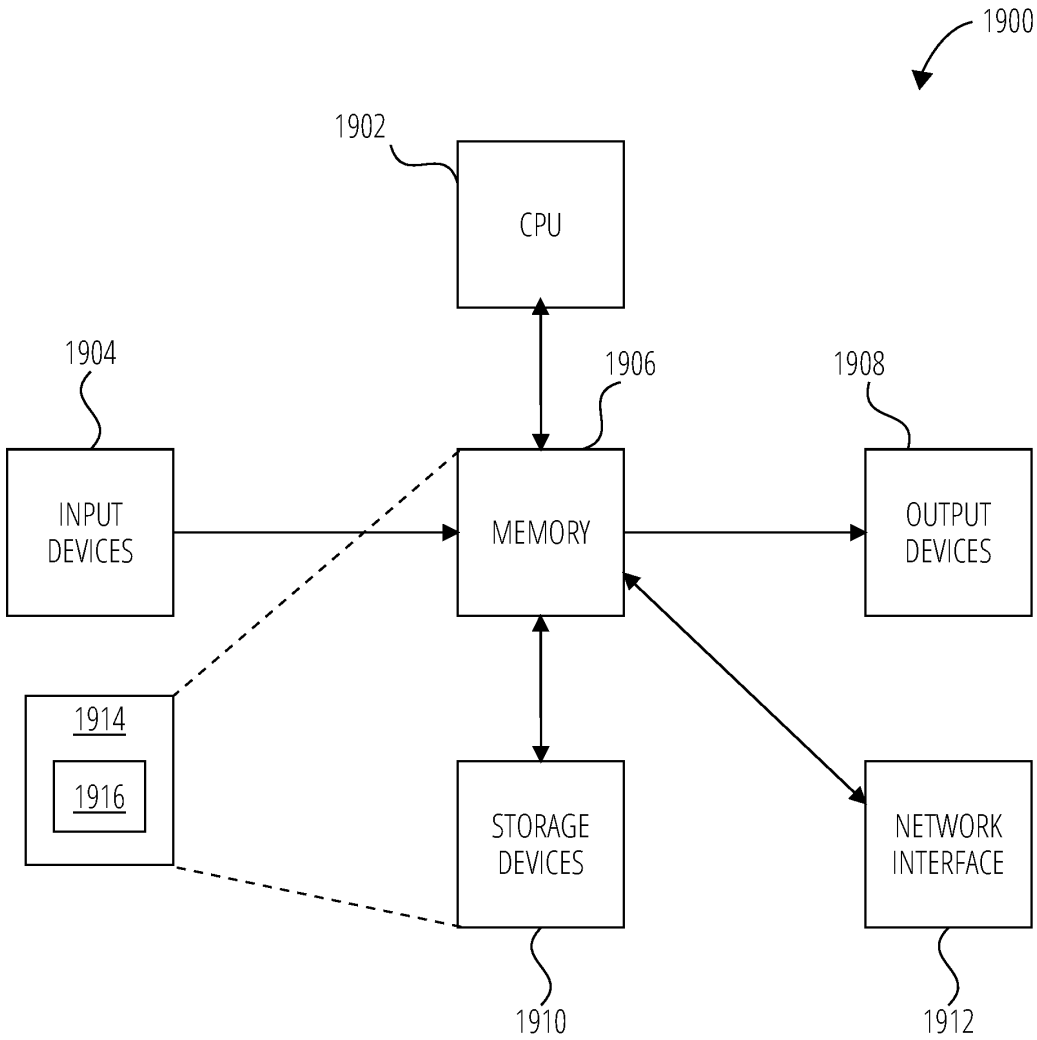

1900
1902
CPU
1904
1906
1908
INPUT DEVICES
MEMORY
OUTPUT DEVICES
1914
1916
STORAGE DEVICES
NETWORK INTERFACE
1910
1912

FIG. 19

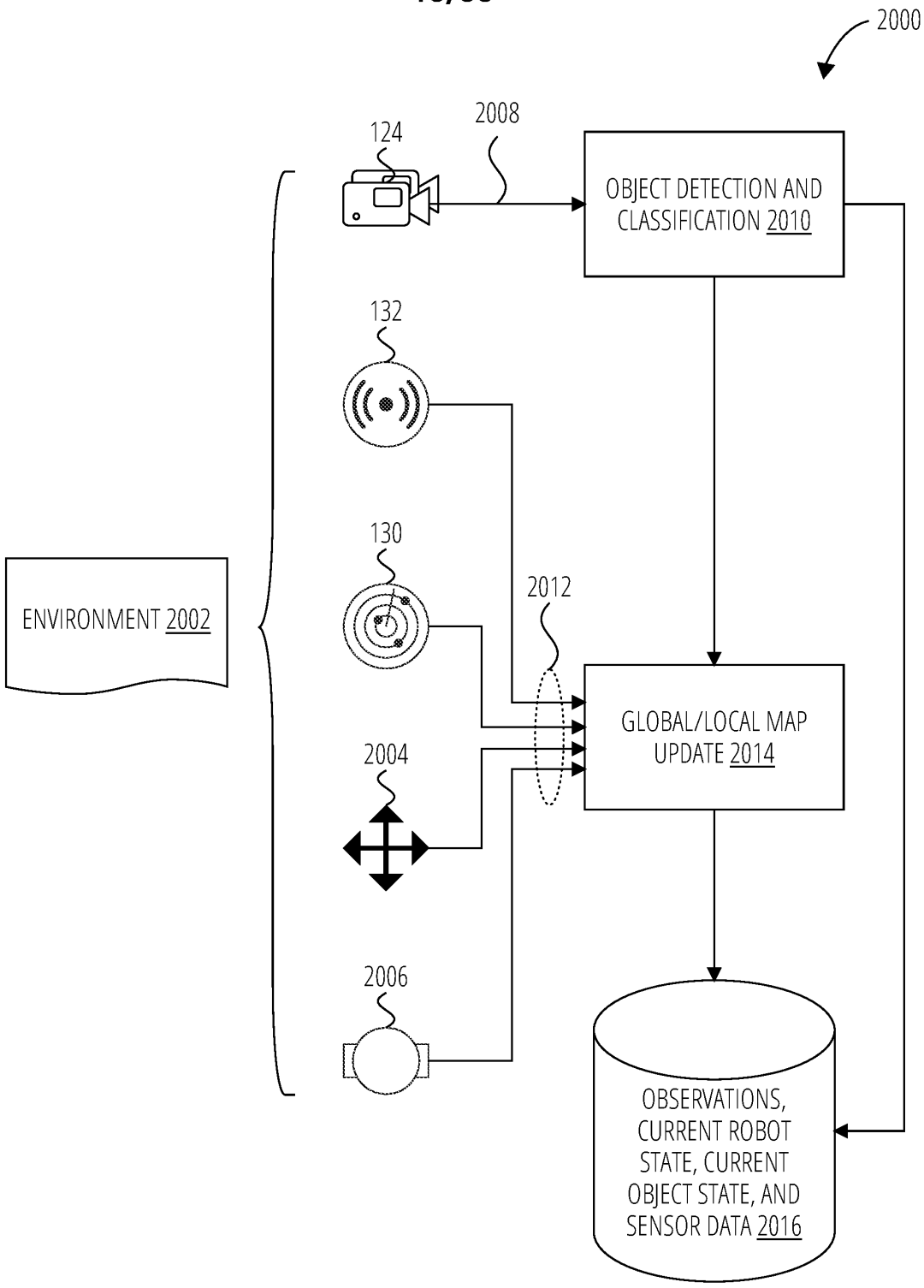

2000
124
2008
OBJECT DETECTION AND CLASSIFICATION 2010
132
130
2012
ENVIRONMENT 2002
GLOBAL/LOCAL MAP UPDATE 2014
2004
2006
OBSERVATIONS, CURRENT ROBOT STATE, CURRENT OBJECT STATE, AND SENSOR DATA 2016

FIG. 20

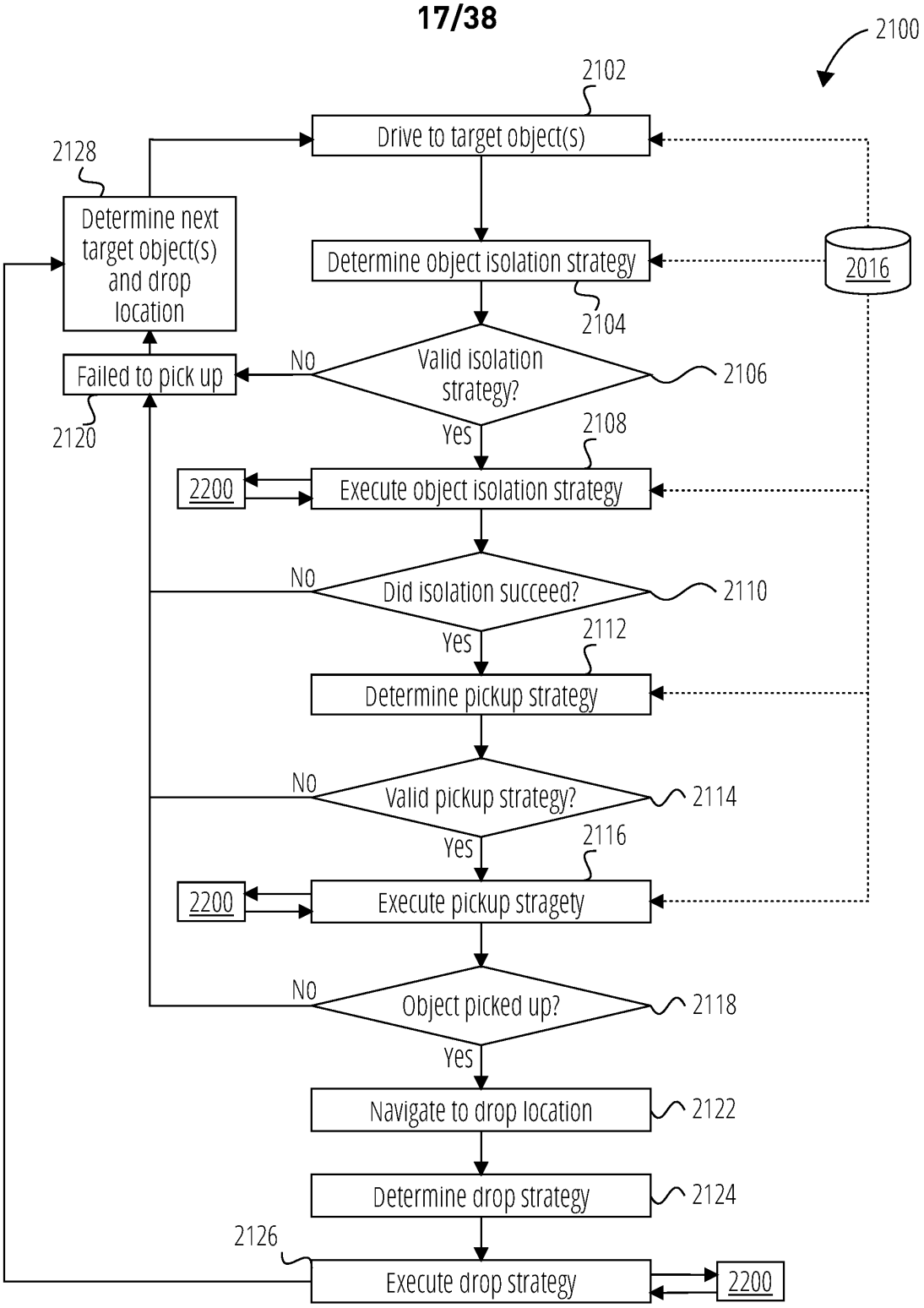

2100
2102
Drive to target object(s)
2128
Determine next target object(s) and drop location
Determine object isolation strategy
2016
2104
Failed to pick up
No
Valid isolation strategy?
2106
2120
Yes
2108
2200
Execute object isolation strategy
No
Did isolation succeed?
2110
Yes
2112
Determine pickup strategy
No
Valid pickup strategy?
2114
Yes
2116
2200
Execute pickup stragety
No
Object picked up?
2118
Yes
Navigate to drop location
2122
Determine drop strategy
2124
2126
Execute drop strategy
2200

FIG. 21

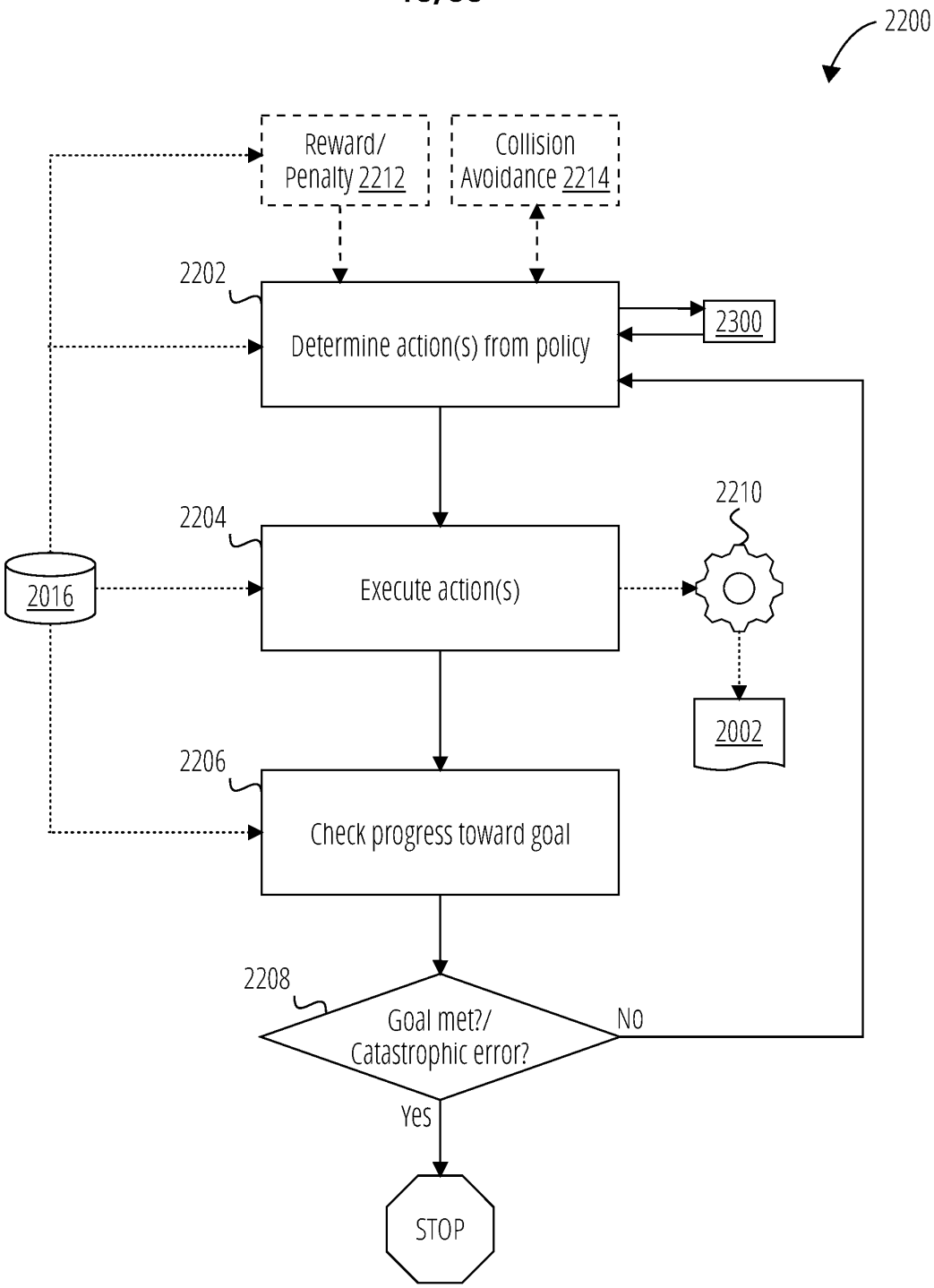

2200
Reward/ Penalty 2212
Collision Avoidance 2214
2202
Determine action(s) from policy
2300
2210
2204
Execute action(s)
2016
2002
2206
Check progress toward goal
2208
Goal met?/ Catastrophic error?
No
Yes
STOP

FIG. 22

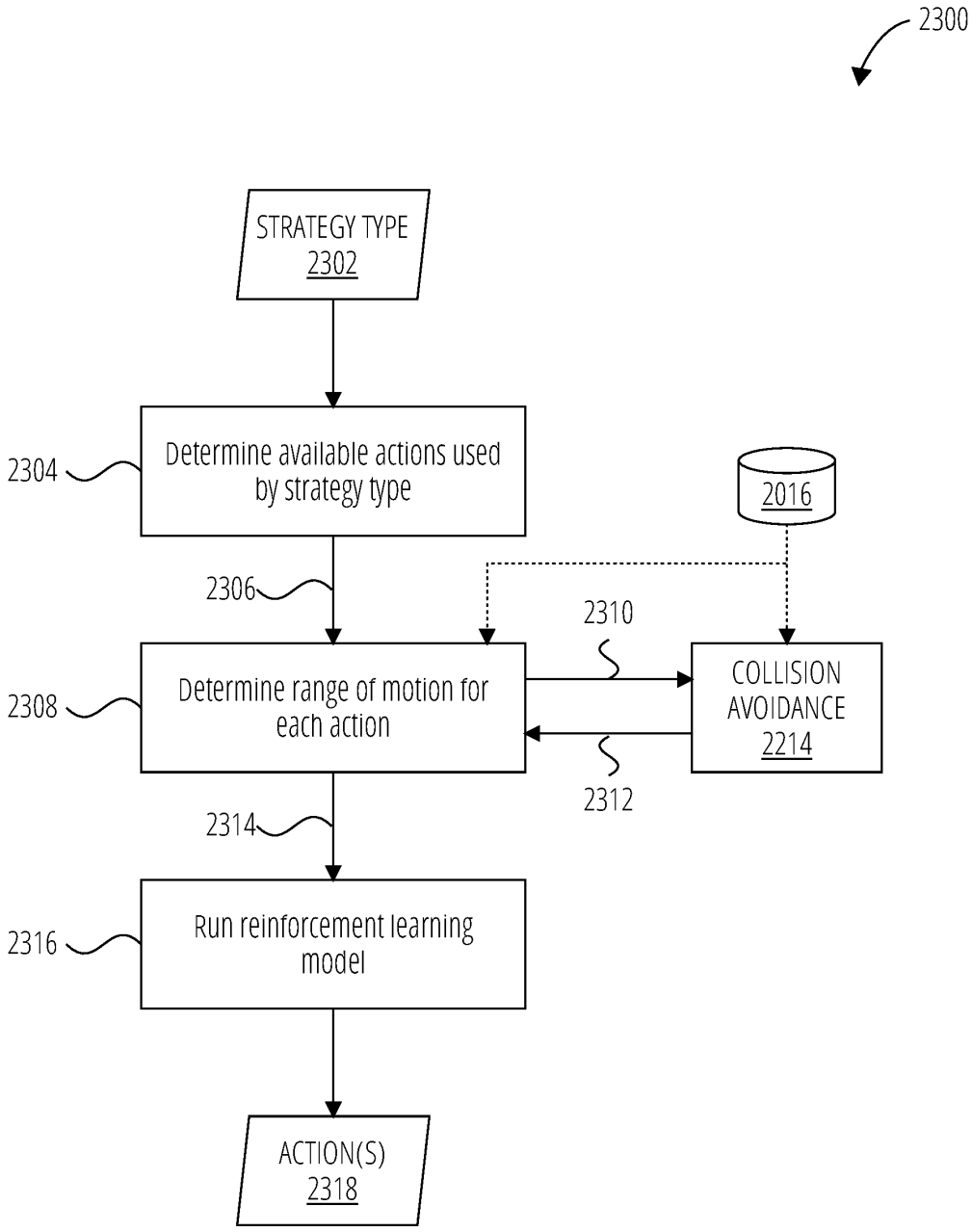

2300
STRATEGY TYPE
2302
2304
Determine available actions used by strategy type
2016
2306
2310
2308
Determine range of motion for each action
COLLISION AVOIDANCE
2214
2312
2314
2316
Run reinforcement learning model
ACTION(S)
2318

FIG. 23

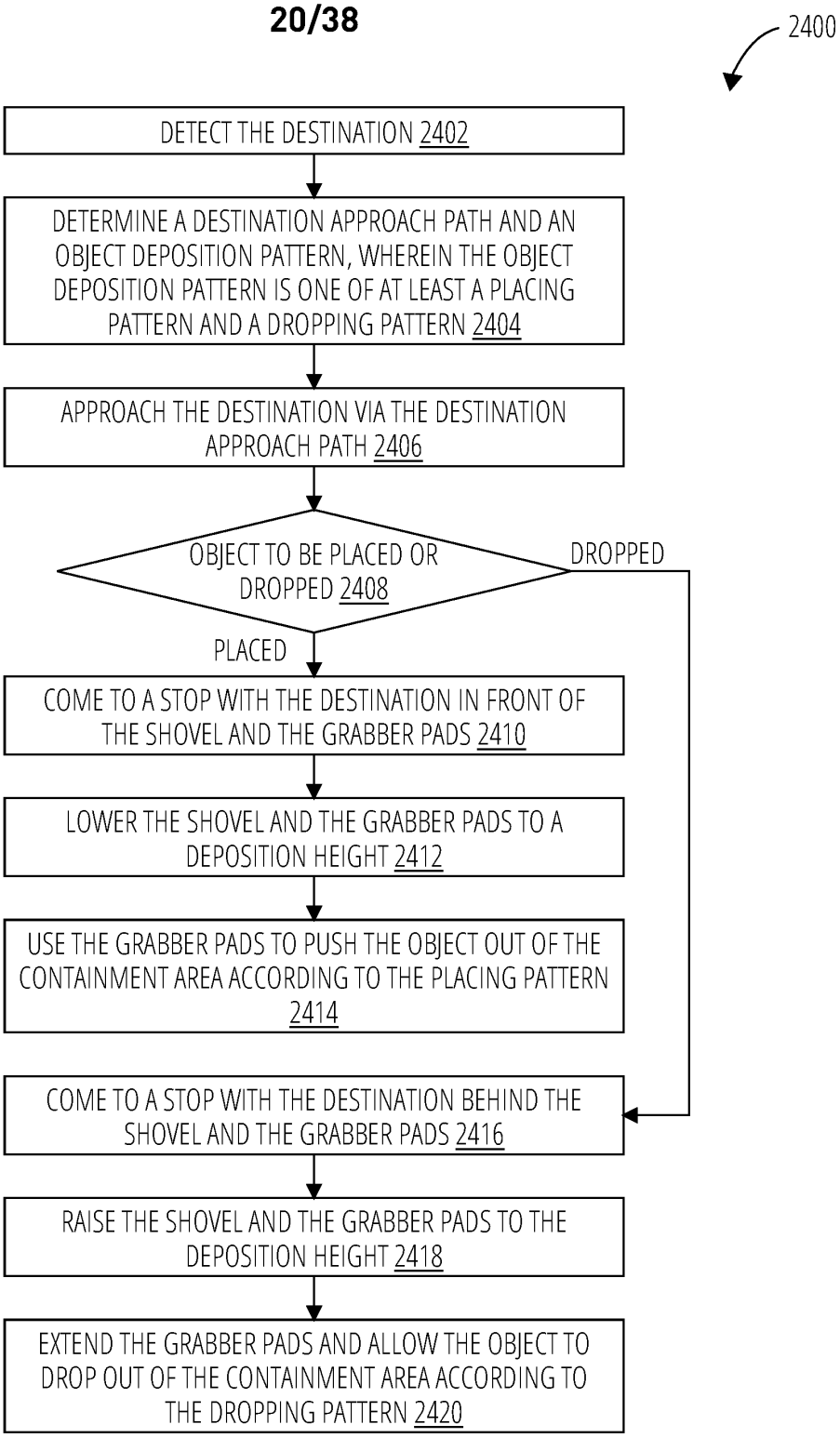

2400
DETECT THE DESTINATION 2402
DETERMINE A DESTINATION APPROACH PATH AND AN OBJECT DEPOSITION PATTERN, WHEREIN THE OBJECT DEPOSITION PATTERN IS ONE OF AT LEAST A PLACING PATTERN AND A DROPPING PATTERN 2404
APPROACH THE DESTINATION VIA THE DESTINATION APPROACH PATH 2406
OBJECT TO BE PLACED OR DROPPED 2408
DROPPED
PLACED
COME TO A STOP WITH THE DESTINATION IN FRONT OF THE SHOVEL AND THE GRABBER PADS 2410
LOWER THE SHOVEL AND THE GRABBER PADS TO A DEPOSITION HEIGHT 2412
USE THE GRABBER PADS TO PUSH THE OBJECT OUT OF THE CONTAINMENT AREA ACCORDING TO THE PLACING PATTERN 2414
COME TO A STOP WITH THE DESTINATION BEHIND THE SHOVEL AND THE GRABBER PADS 2416
RAISE THE SHOVEL AND THE GRABBER PADS TO THE DEPOSITION HEIGHT 2418
EXTEND THE GRABBER PADS AND ALLOW THE OBJECT TO DROP OUT OF THE CONTAINMENT AREA ACCORDING TO THE DROPPING PATTERN 2420

FIG. 24

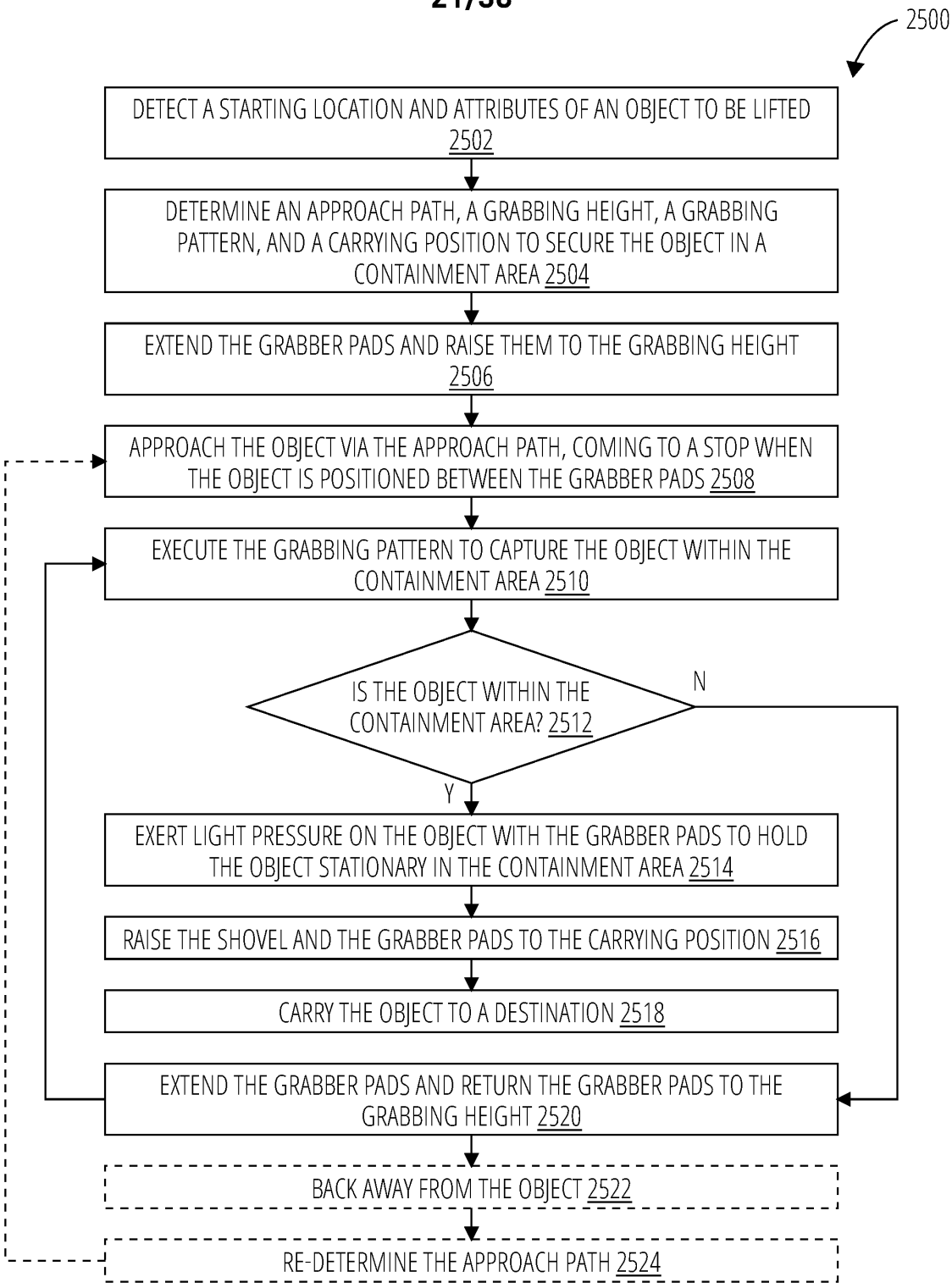

2500
DETECT A STARTING LOCATION AND ATTRIBUTES OF AN OBJECT TO BE LIFTED 2502
DETERMINE AN APPROACH PATH, A GRABBING HEIGHT, A GRABBING PATTERN, AND A CARRYING POSITION TO SECURE THE OBJECT IN A CONTAINMENT AREA 2504
EXTEND THE GRABBER PADS AND RAISE THEM TO THE GRABBING HEIGHT 2506
APPROACH THE OBJECT VIA THE APPROACH PATH, COMING TO A STOP WHEN THE OBJECT IS POSITIONED BETWEEN THE GRABBER PADS 2508
EXECUTE THE GRABBING PATTERN TO CAPTURE THE OBJECT WITHIN THE CONTAINMENT AREA 2510
IS THE OBJECT WITHIN THE CONTAINMENT AREA? 2512
N
Y
EXERT LIGHT PRESSURE ON THE OBJECT WITH THE GRABBER PADS TO HOLD THE OBJECT STATIONARY IN THE CONTAINMENT AREA 2514
RAISE THE SHOVEL AND THE GRABBER PADS TO THE CARRYING POSITION 2516
CARRY THE OBJECT TO A DESTINATION 2518
EXTEND THE GRABBER PADS AND RETURN THE GRABBER PADS TO THE GRABBING HEIGHT 2520
BACK AWAY FROM THE OBJECT 2522
RE-DETERMINE THE APPROACH PATH 2524

FIG. 25

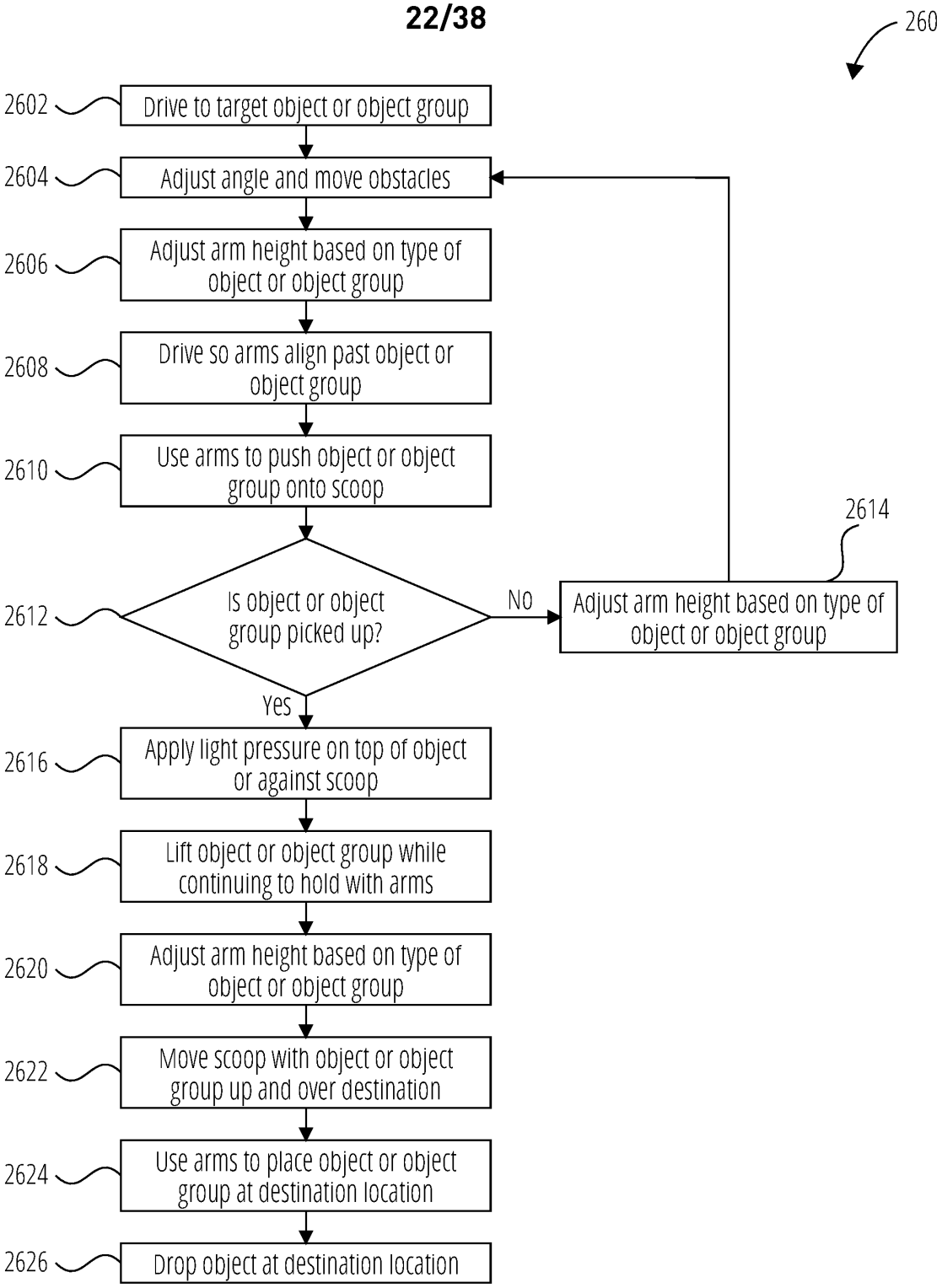

260
2602
Drive to target object or object group
2604
Adjust angle and move obstacles
2606
Adjust arm height based on type of object or object group
2608
Drive so arms align past object or object group
2610
Use arms to push object or object group onto scoop
2612
Is object or object group picked up?
No
2614
Adjust arm height based on type of object or object group
Yes
2616
Apply light pressure on top of object or against scoop
2618
Lift object or object group while continuing to hold with arms
2620
Adjust arm height based on type of object or object group
2622
Move scoop with object or object group up and over destination
2624
Use arms to place object or object group at destination location
2626
Drop object at destination location

FIG. 26

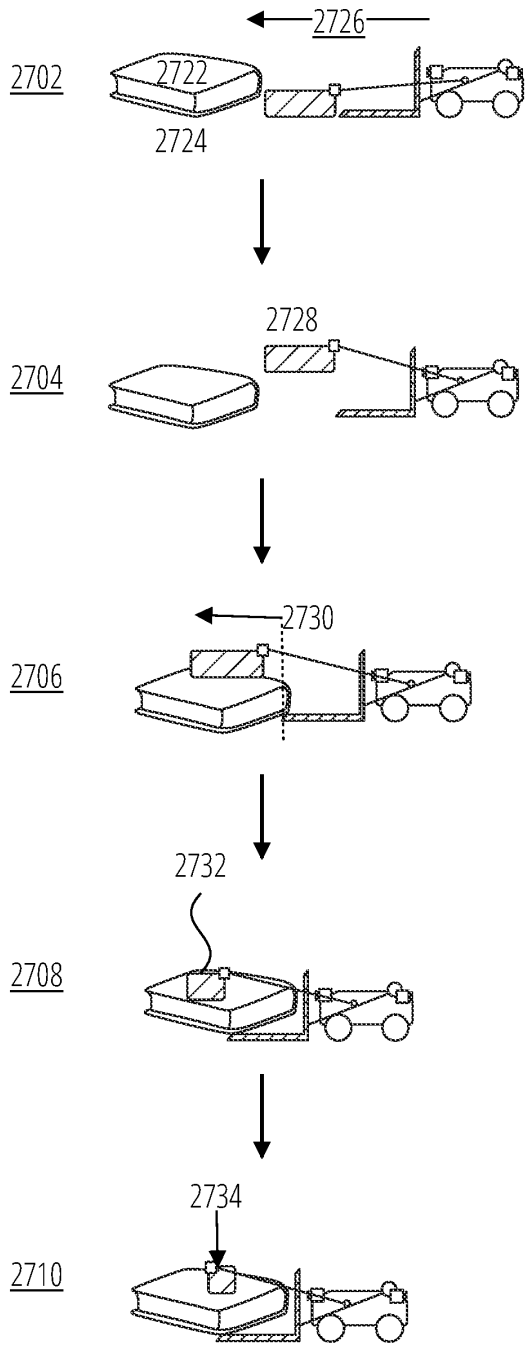


FIG. 27A

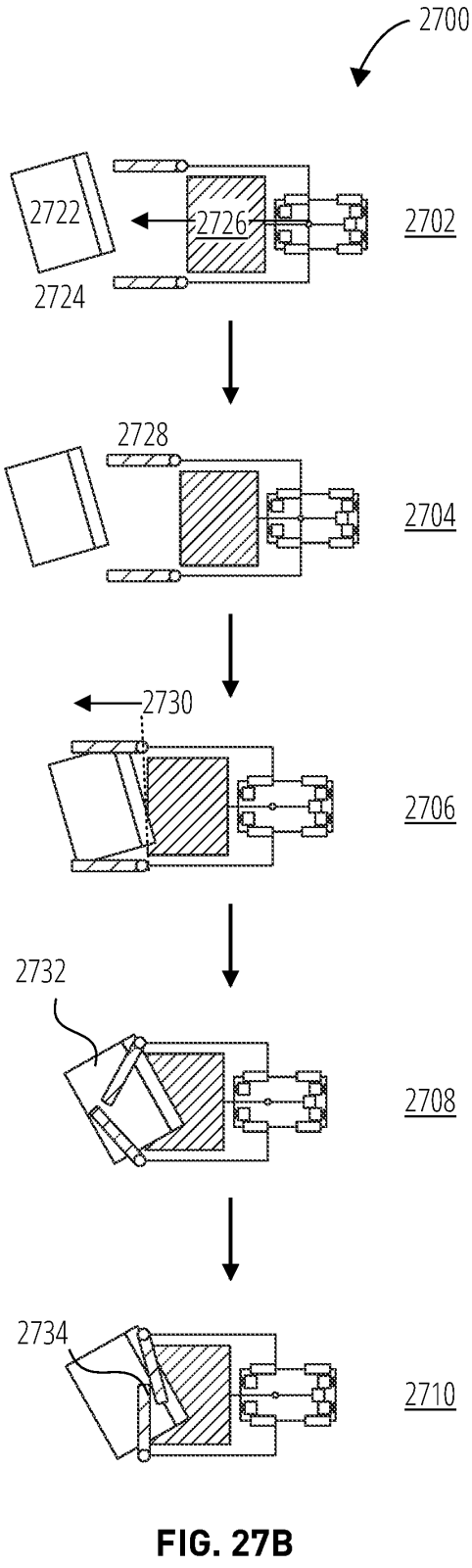


FIG. 27B

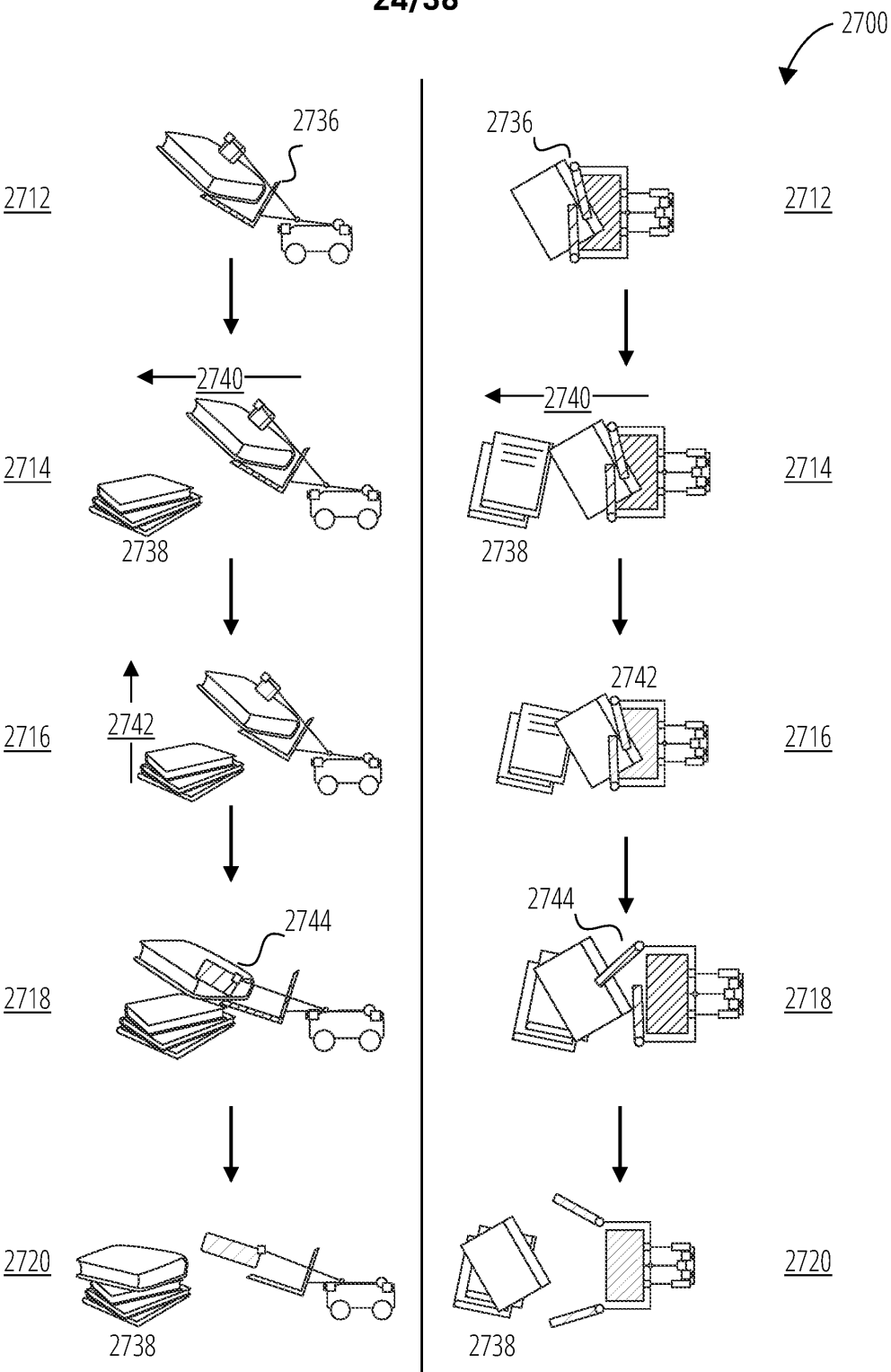


FIG. 27C

FIG. 27D

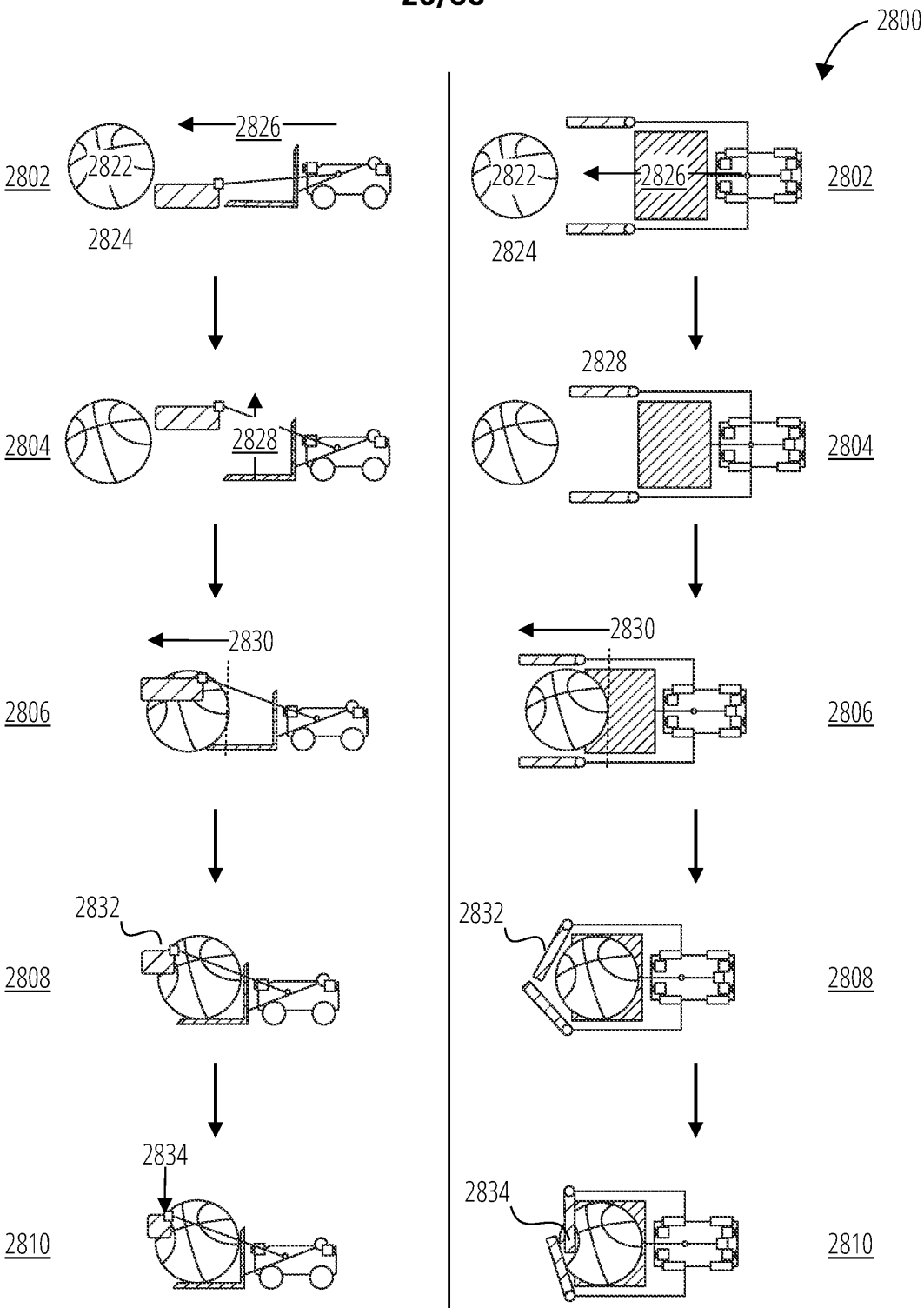


FIG. 28A

FIG. 28B

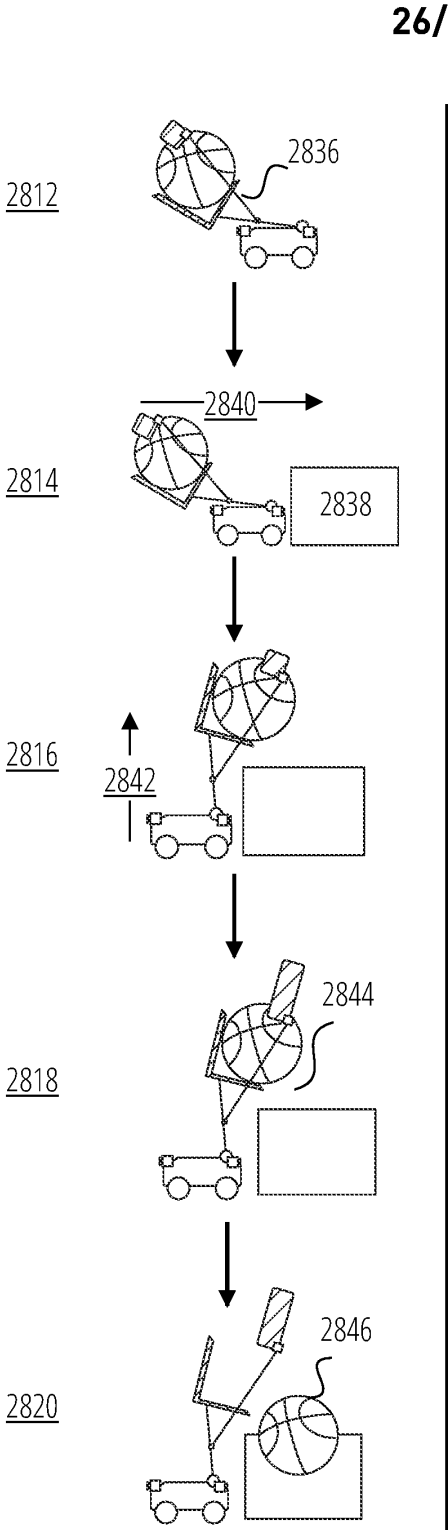


FIG. 28C

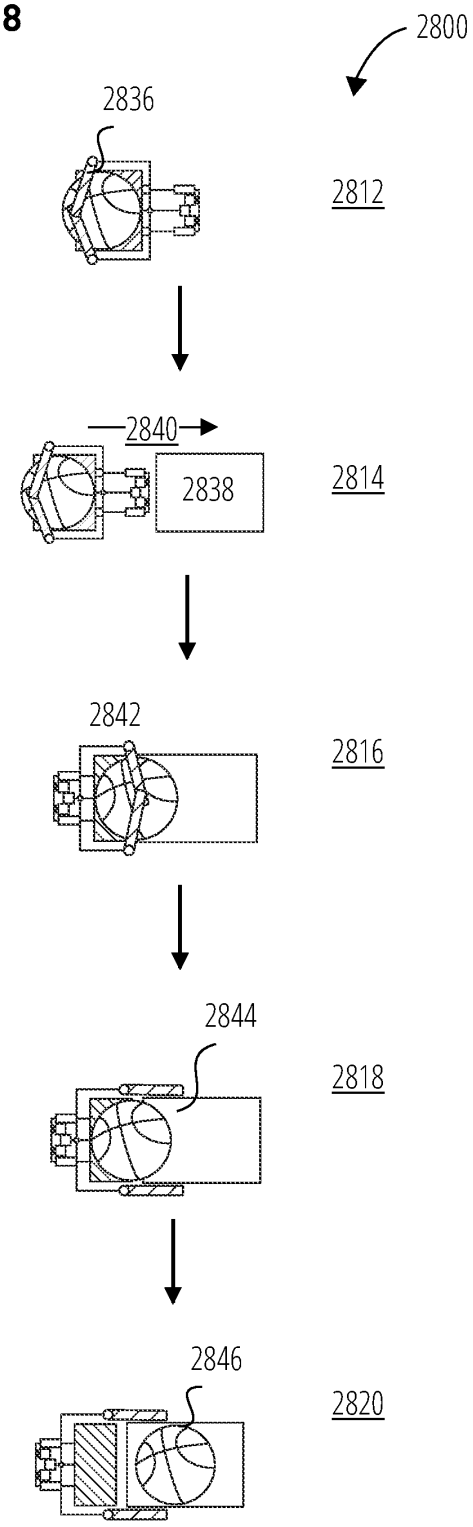


FIG. 28D

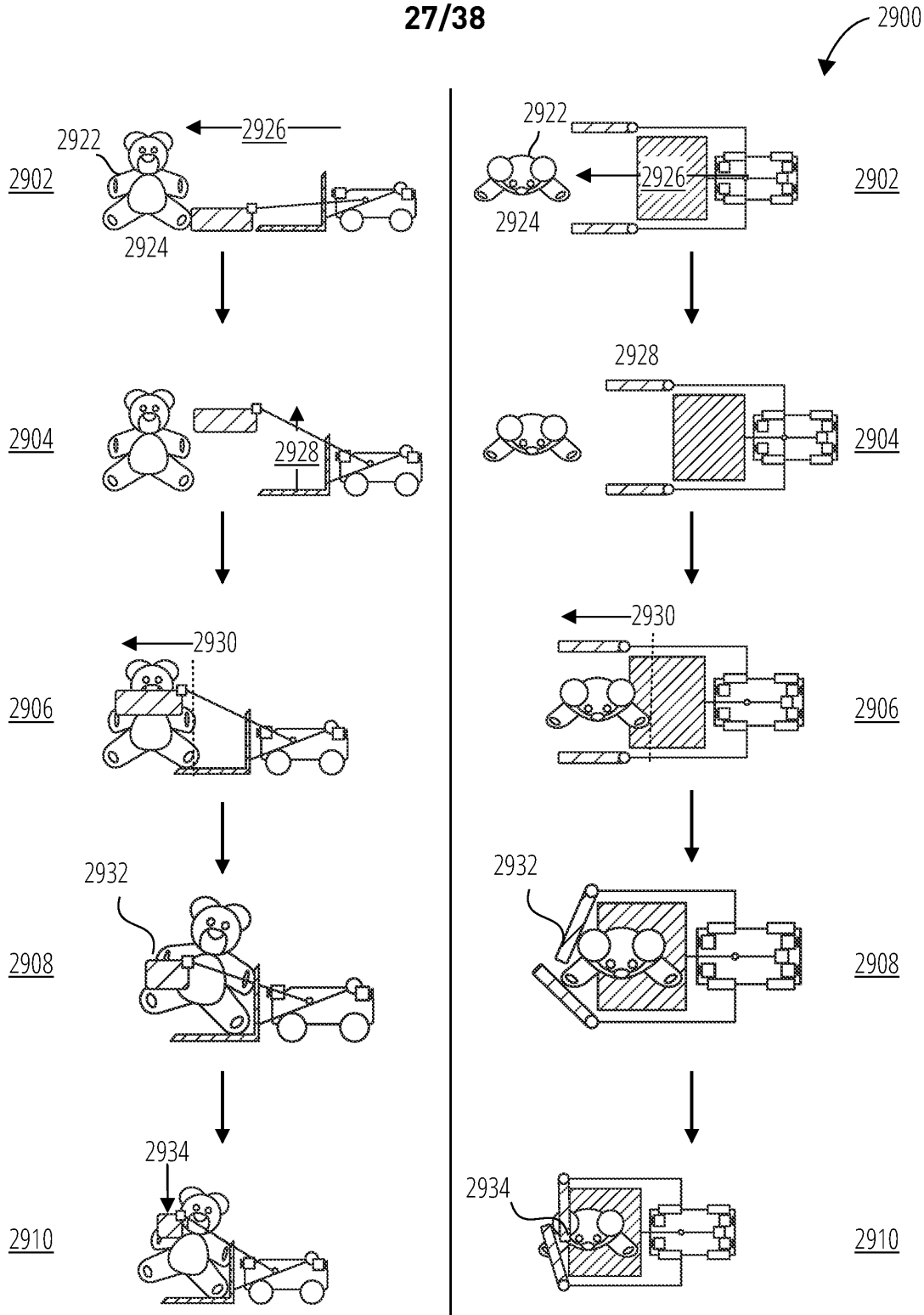


FIG. 29A

FIG. 29B

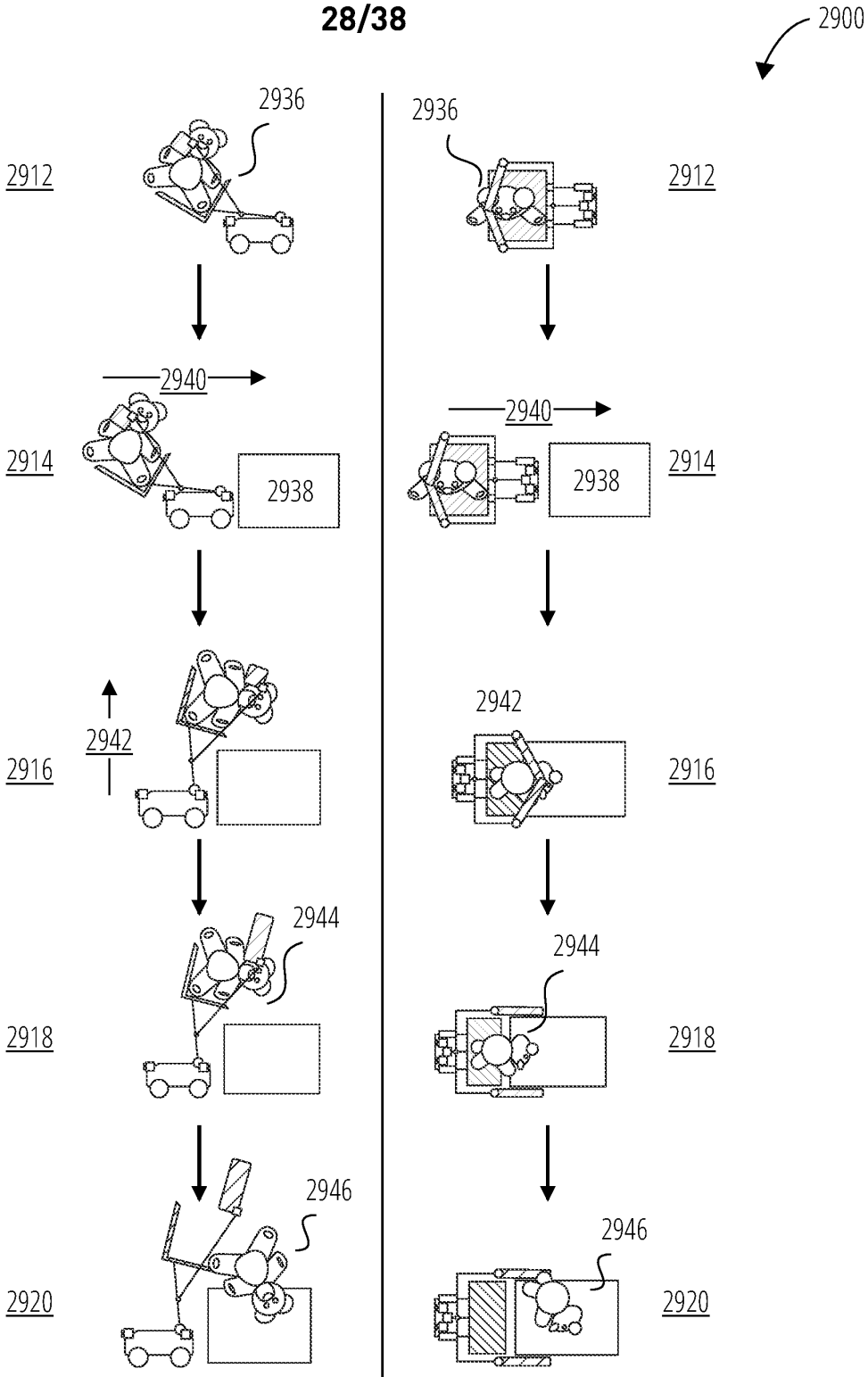


FIG. 29C

FIG. 29D

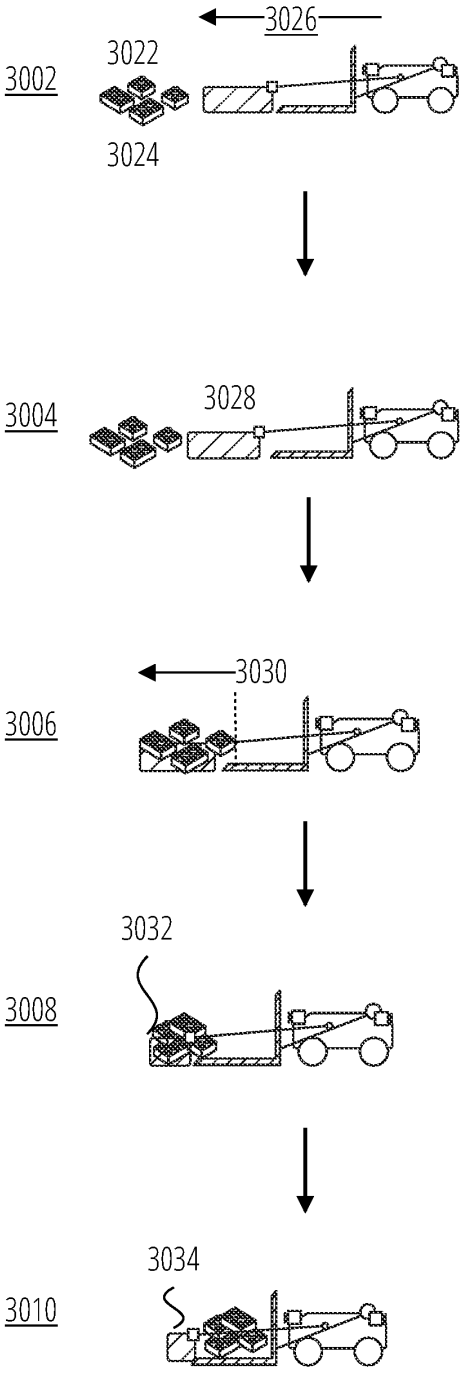


FIG. 30A

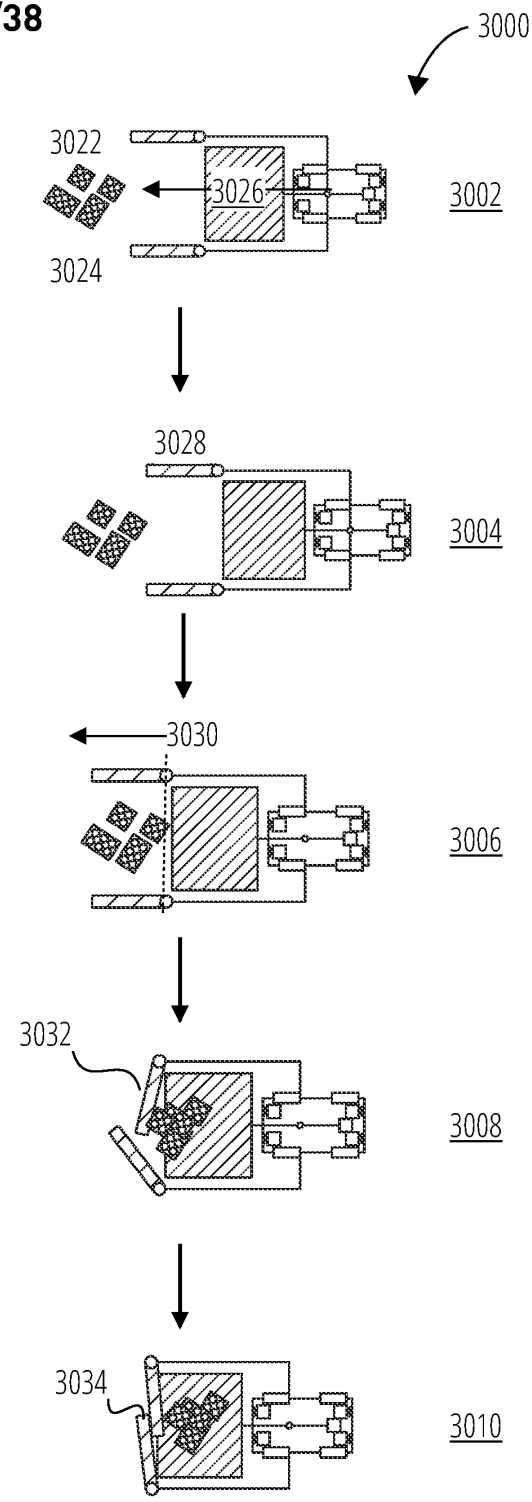


FIG. 30B

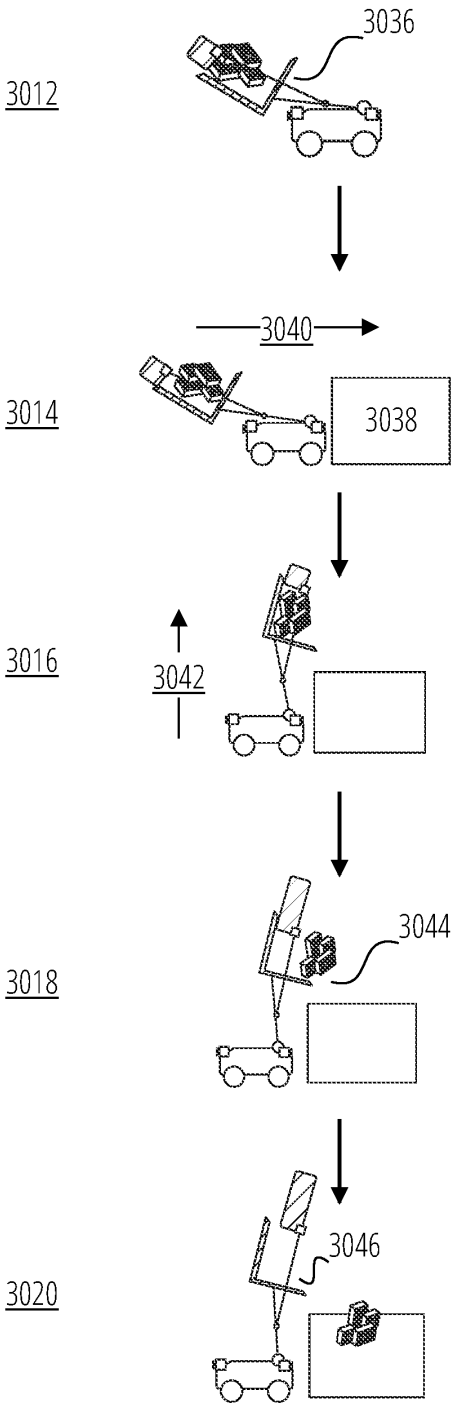


FIG. 30C

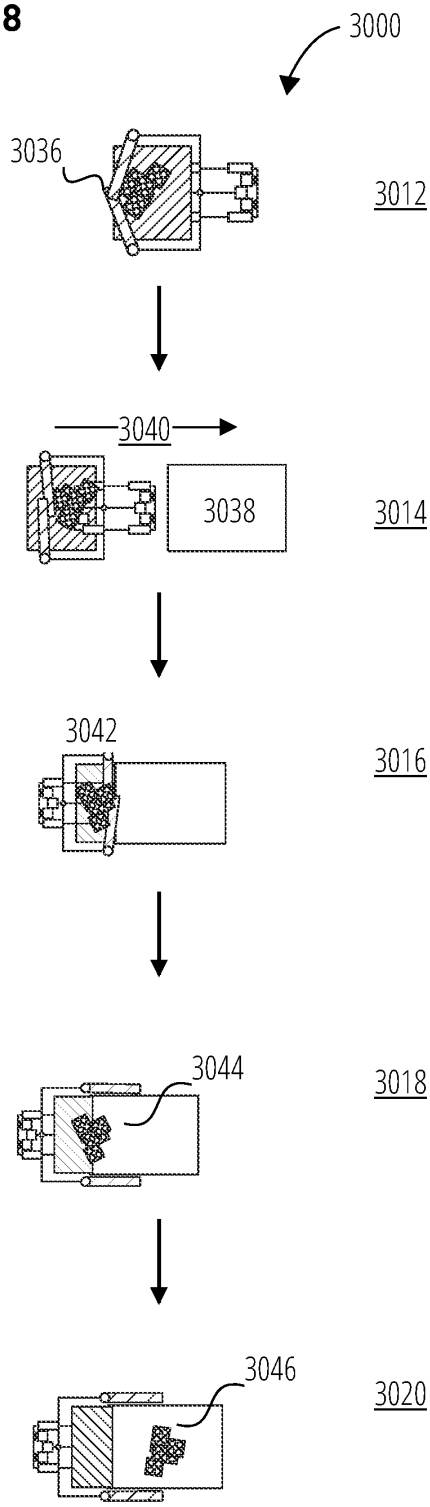


FIG. 30D

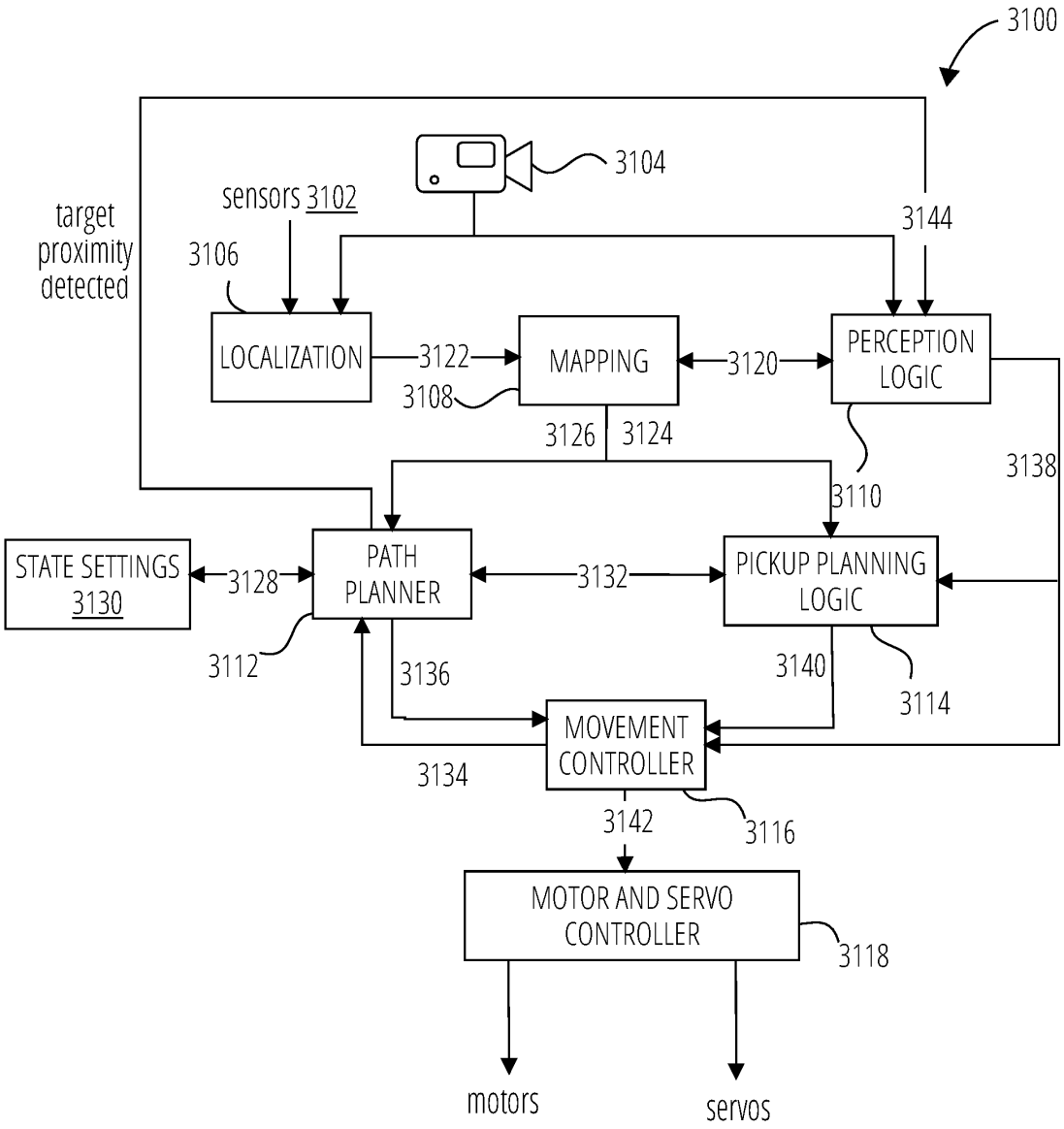

3100
3104
sensors 3102
target proximity detected
3106
3144
LOCALIZATION
3122
MAPPING
3120
PERCEPTION LOGIC
3108
3126
3124
3138
3110
STATE SETTINGS 3130
3128
PATH PLANNER
3132
PICKUP PLANNING LOGIC
3112
3136
3140
3114
MOVEMENT CONTROLLER
3134
3142
3116
MOTOR AND SERVO CONTROLLER
3118
motors
servos

FIG. 31

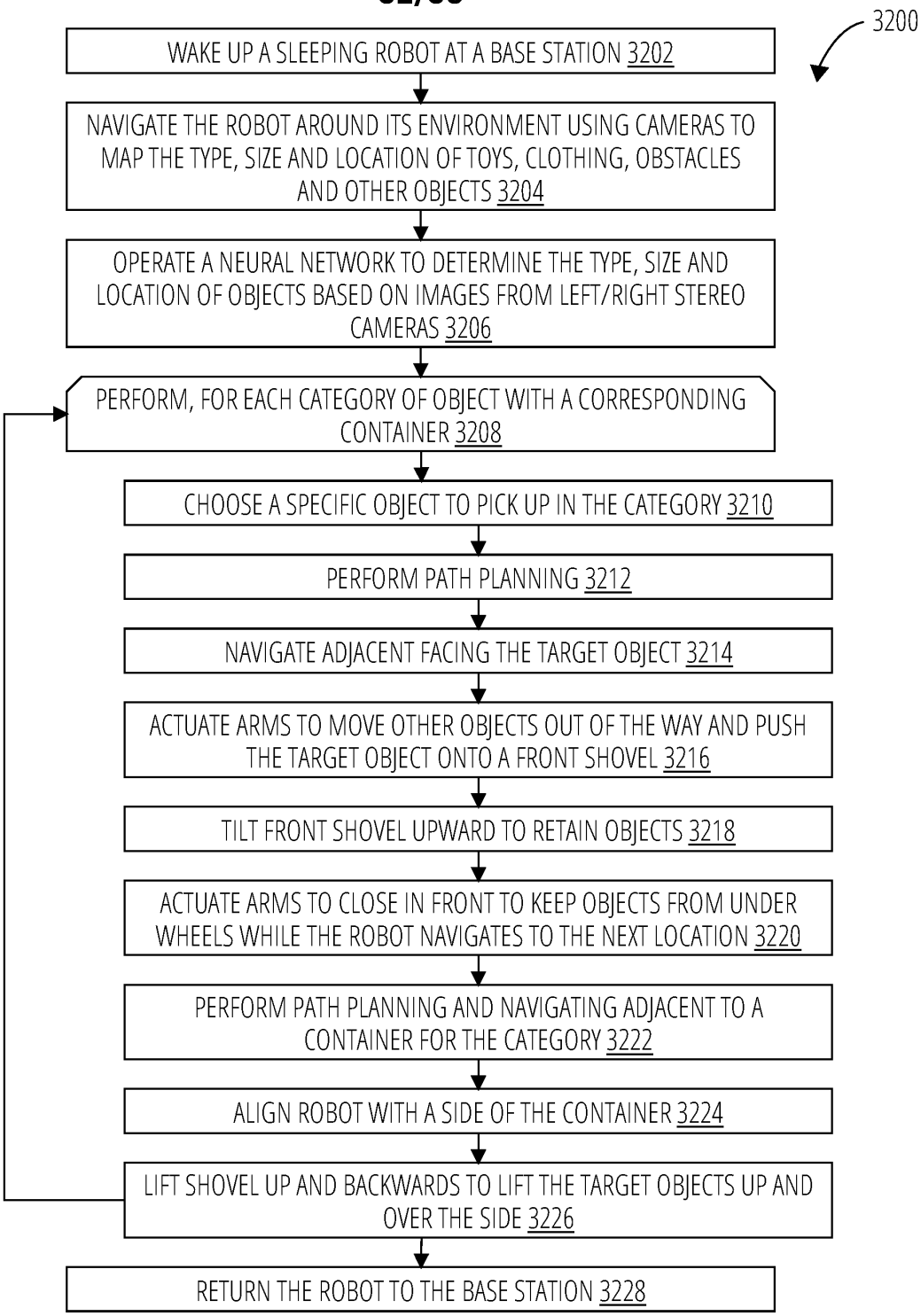

3200
WAKE UP A SLEEPING ROBOT AT A BASE STATION 3202
NAVIGATE THE ROBOT AROUND ITS ENVIRONMENT USING CAMERAS TO MAP THE TYPE, SIZE AND LOCATION OF TOYS, CLOTHING, OBSTACLES AND OTHER OBJECTS 3204
OPERATE A NEURAL NETWORK TO DETERMINE THE TYPE, SIZE AND LOCATION OF OBJECTS BASED ON IMAGES FROM LEFT/RIGHT STEREO CAMERAS 3206
PERFORM, FOR EACH CATEGORY OF OBJECT WITH A CORRESPONDING CONTAINER 3208
CHOOSE A SPECIFIC OBJECT TO PICK UP IN THE CATEGORY 3210
PERFORM PATH PLANNING 3212
NAVIGATE ADJACENT FACING THE TARGET OBJECT 3214
ACTUATE ARMS TO MOVE OTHER OBJECTS OUT OF THE WAY AND PUSH THE TARGET OBJECT ONTO A FRONT SHOVEL 3216
TILT FRONT SHOVEL UPWARD TO RETAIN OBJECTS 3218
ACTUATE ARMS TO CLOSE IN FRONT TO KEEP OBJECTS FROM UNDER WHEELS WHILE THE ROBOT NAVIGATES TO THE NEXT LOCATION 3220
PERFORM PATH PLANNING AND NAVIGATING ADJACENT TO A CONTAINER FOR THE CATEGORY 3222
ALIGN ROBOT WITH A SIDE OF THE CONTAINER 3224
LIFT SHOVEL UP AND BACKWARDS TO LIFT THE TARGET OBJECTS UP AND OVER THE SIDE 3226
RETURN THE ROBOT TO THE BASE STATION 3228

FIG. 32

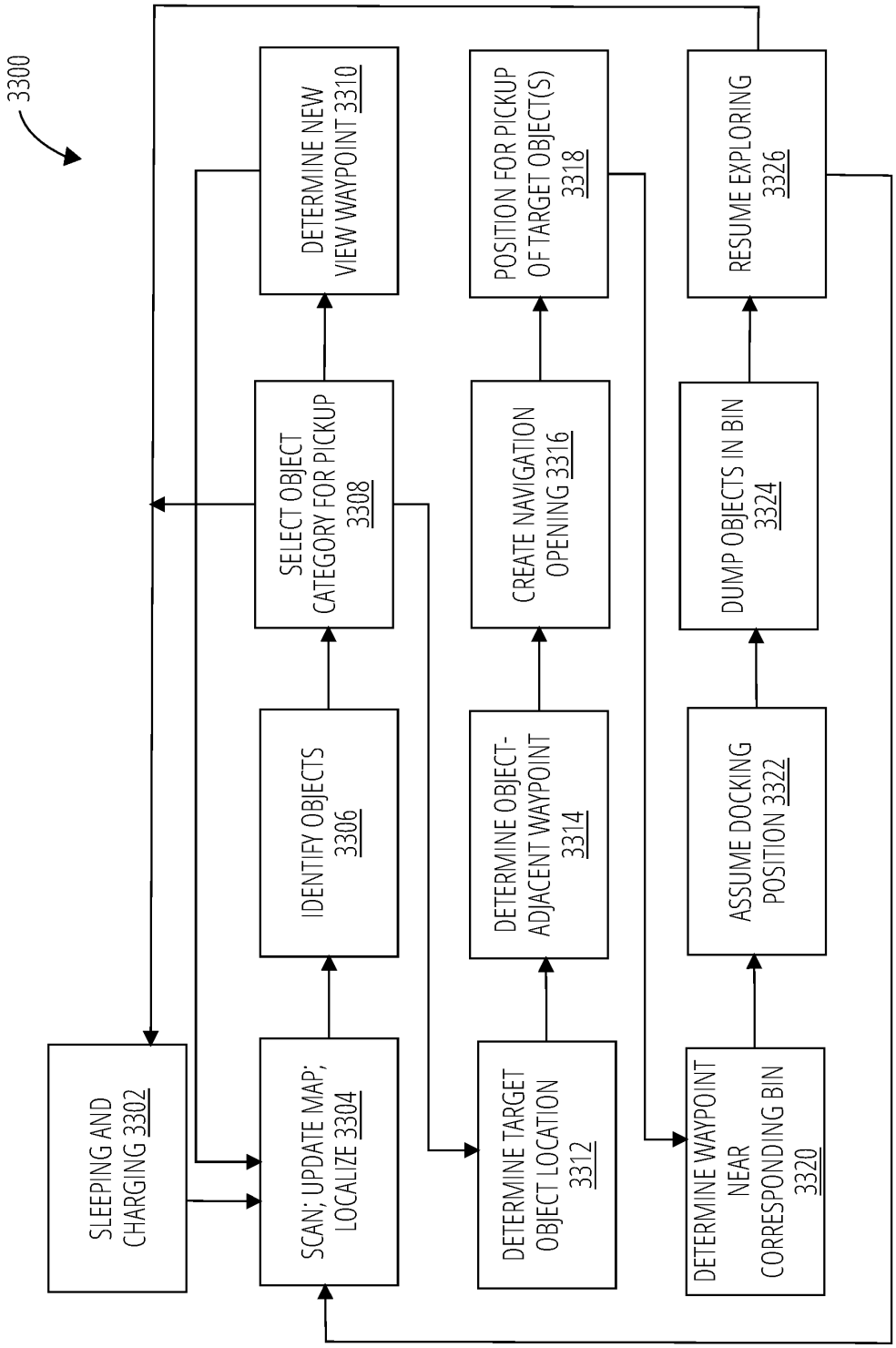

3300
SLEEPING AND CHARGING 3302
SCAN; UPDATE MAP; LOCALIZE 3304
IDENTIFY OBJECTS 3306
SELECT OBJECT CATEGORY FOR PICKUP 3308
DETERMINE NEW VIEW WAYPOINT 3310
DETERMINE TARGET OBJECT LOCATION 3312
DETERMINE OBJECT-ADJACENT WAYPOINT 3314
CREATE NAVIGATION OPENING 3316
POSITION FOR PICKUP OF TARGET OBJECT(S) 3318
DETERMINE WAYPOINT NEAR CORRESPONDING BIN 3320
ASSUME DOCKING POSITION 3322
DUMP OBJECTS IN BIN 3324
RESUME EXPLORING 3326

FIG. 33

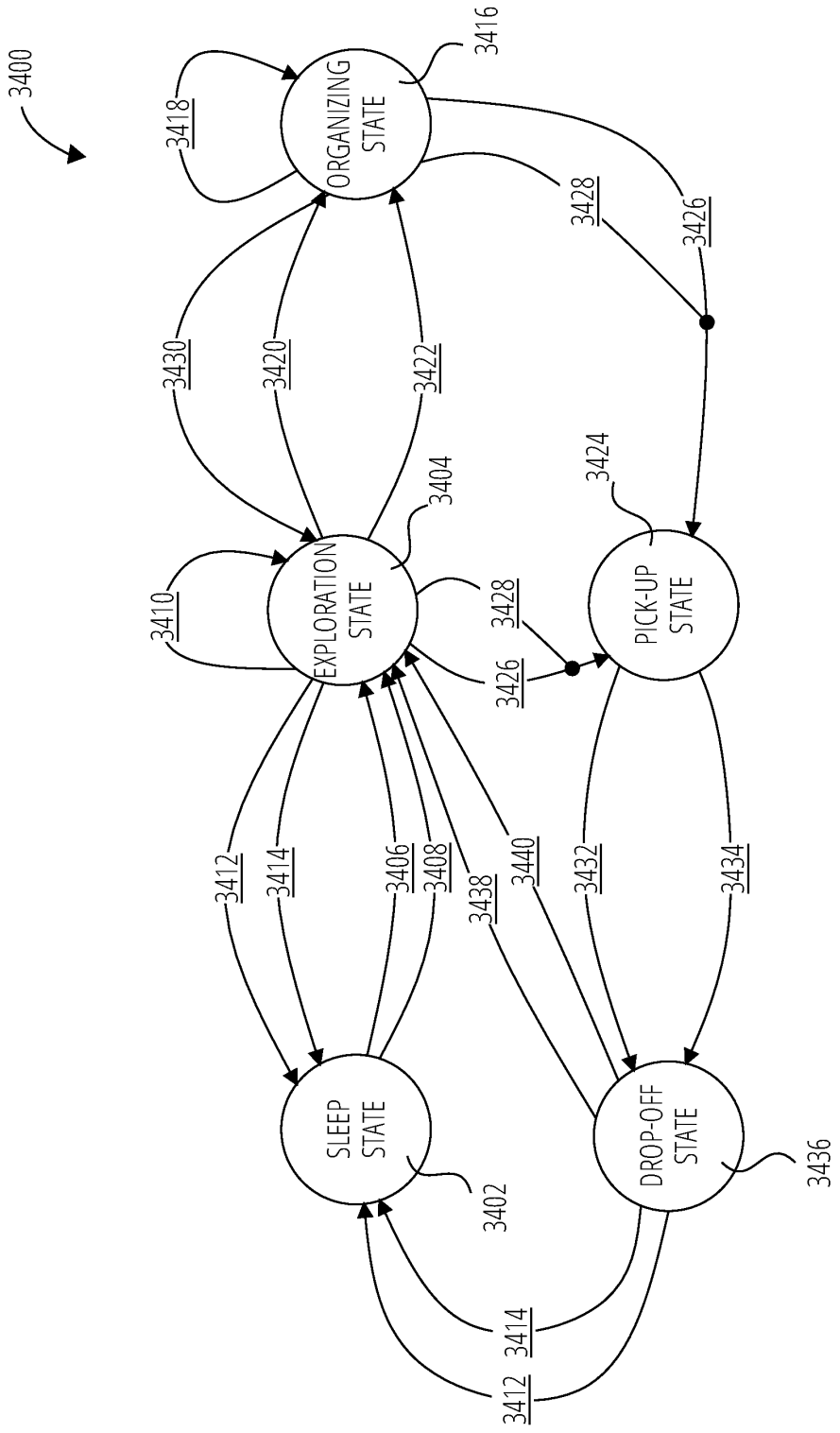

3400
ORGANIZING STATE
3416
3418
3428
3426
3430
3420
3422
EXPLORATION STATE
3404
3410
3428
3426
PICK-UP STATE
3424
3412
3414
3406
3408
3438
3440
3432
3434
SLEEP STATE
3402
DROP-OFF STATE
3436
3414
3412

FIG. 34

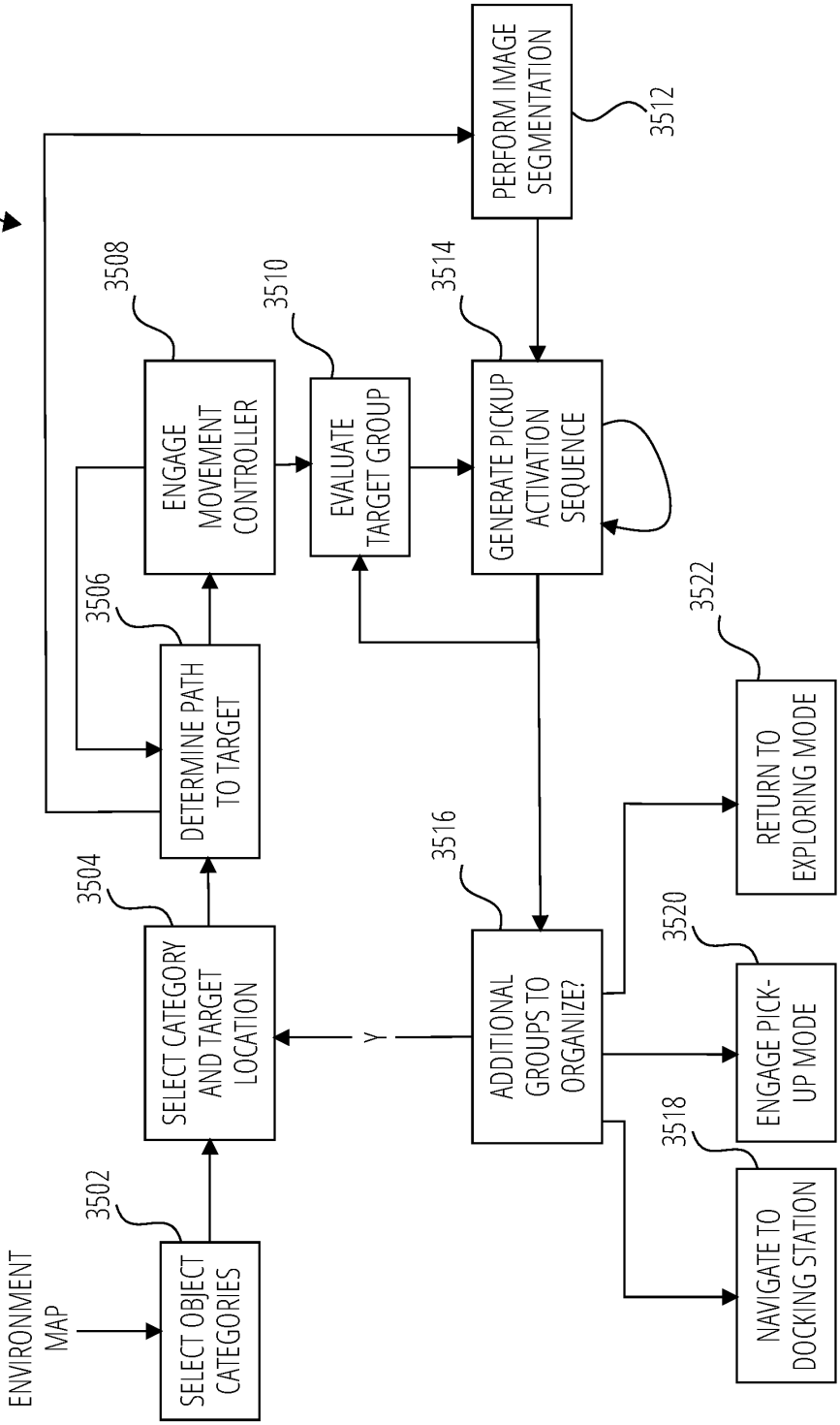

3500
PERFORM IMAGE SEGMENTATION
3512
3508
ENGAGE MOVEMENT CONTROLLER
3510
EVALUATE TARGET GROUP
3514
GENERATE PICKUP ACTIVATION SEQUENCE
3506
DETERMINE PATH TO TARGET
3522
RETURN TO EXPLORING MODE
3504
SELECT CATEGORY AND TARGET LOCATION
Y
3516
ADDITIONAL GROUPS TO ORGANIZE?
3520
ENGAGE PICK-UP MODE
3518
NAVIGATE TO DOCKING STATION
3502
SELECT OBJECT CATEGORIES
ENVIRONMENT MAP

FIG. 35

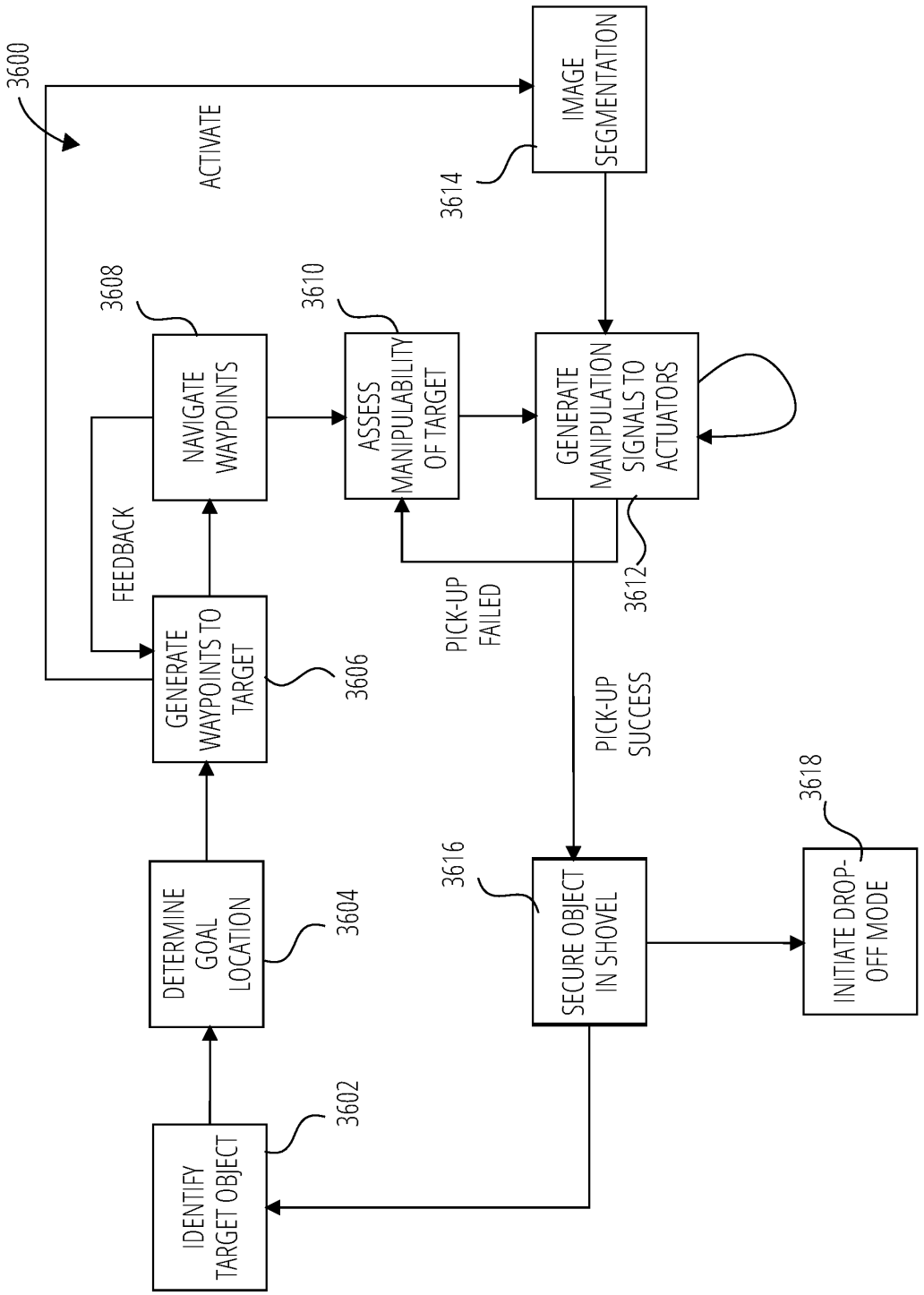

3600
ACTIVATE
IMAGE SEGMENTATION
3614
3608
NAVIGATE WAYPOINTS
3610
ASSESS MANIPULABILITY OF TARGET
GENERATE MANIPULATION SIGNALS TO ACTUATORS
FEEDBACK
PICK-UP FAILED
3612
GENERATE WAYPOINTS TO TARGET
3606
PICK-UP SUCCESS
3618
3616
DETERMINE GOAL LOCATION
3604
SECURE OBJECT IN SHOVEL
INITIATE DROP-OFF MODE
3602
IDENTIFY TARGET OBJECT

FIG. 36

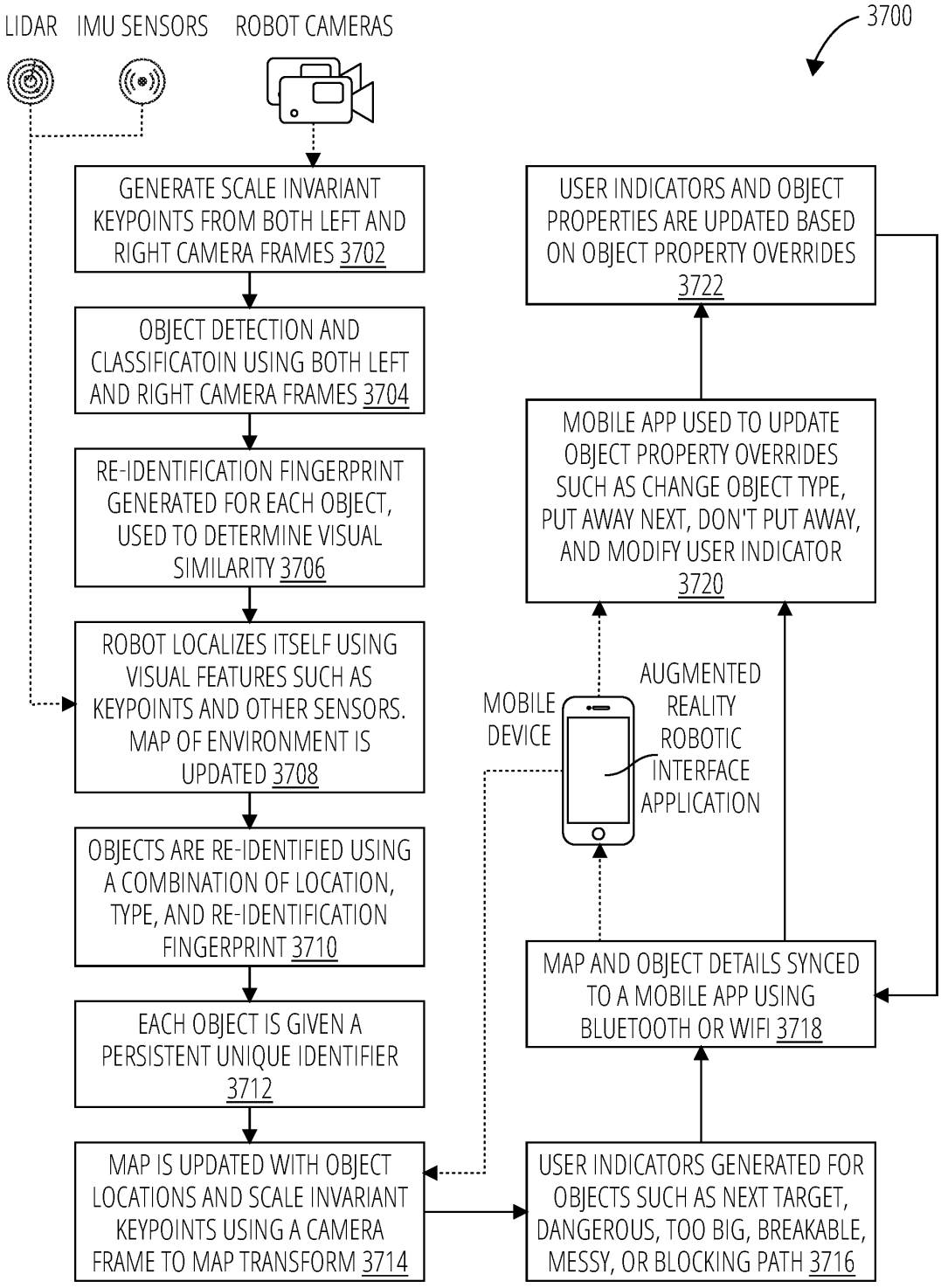

LIDAR
IMU SENSORS
ROBOT CAMERAS
3700
GENERATE SCALE INVARIANT KEYPOINTS FROM BOTH LEFT AND RIGHT CAMERA FRAMES 3702
OBJECT DETECTION AND CLASSIFICATOIN USING BOTH LEFT AND RIGHT CAMERA FRAMES 3704
RE-IDENTIFICATION FINGERPRINT GENERATED FOR EACH OBJECT, USED TO DETERMINE VISUAL SIMILARITY 3706
ROBOT LOCALIZES ITSELF USING VISUAL FEATURES SUCH AS KEYPOINTS AND OTHER SENSORS. MAP OF ENVIRONMENT IS UPDATED 3708
OBJECTS ARE RE-IDENTIFIED USING A COMBINATION OF LOCATION, TYPE, AND RE-IDENTIFICATION FINGERPRINT 3710
EACH OBJECT IS GIVEN A PERSISTENT UNIQUE IDENTIFIER 3712
MAP IS UPDATED WITH OBJECT LOCATIONS AND SCALE INVARIANT KEYPOINTS USING A CAMERA FRAME TO MAP TRANSFORM 3714
USER INDICATORS GENERATED FOR OBJECTS SUCH AS NEXT TARGET, DANGEROUS, TOO BIG, BREAKABLE, MESSY, OR BLOCKING PATH 3716
MAP AND OBJECT DETAILS SYNCED TO A MOBILE APP USING BLUETOOTH OR WIFI 3718
MOBILE DEVICE
AUGMENTED REALITY ROBOTIC INTERFACE APPLICATION
MOBILE APP USED TO UPDATE OBJECT PROPERTY OVERRIDES SUCH AS CHANGE OBJECT TYPE, PUT AWAY NEXT, DON'T PUT AWAY, AND MODIFY USER INDICATOR 3720
USER INDICATORS AND OBJECT PROPERTIES ARE UPDATED BASED ON OBJECT PROPERTY OVERRIDES 3722

FIG. 37

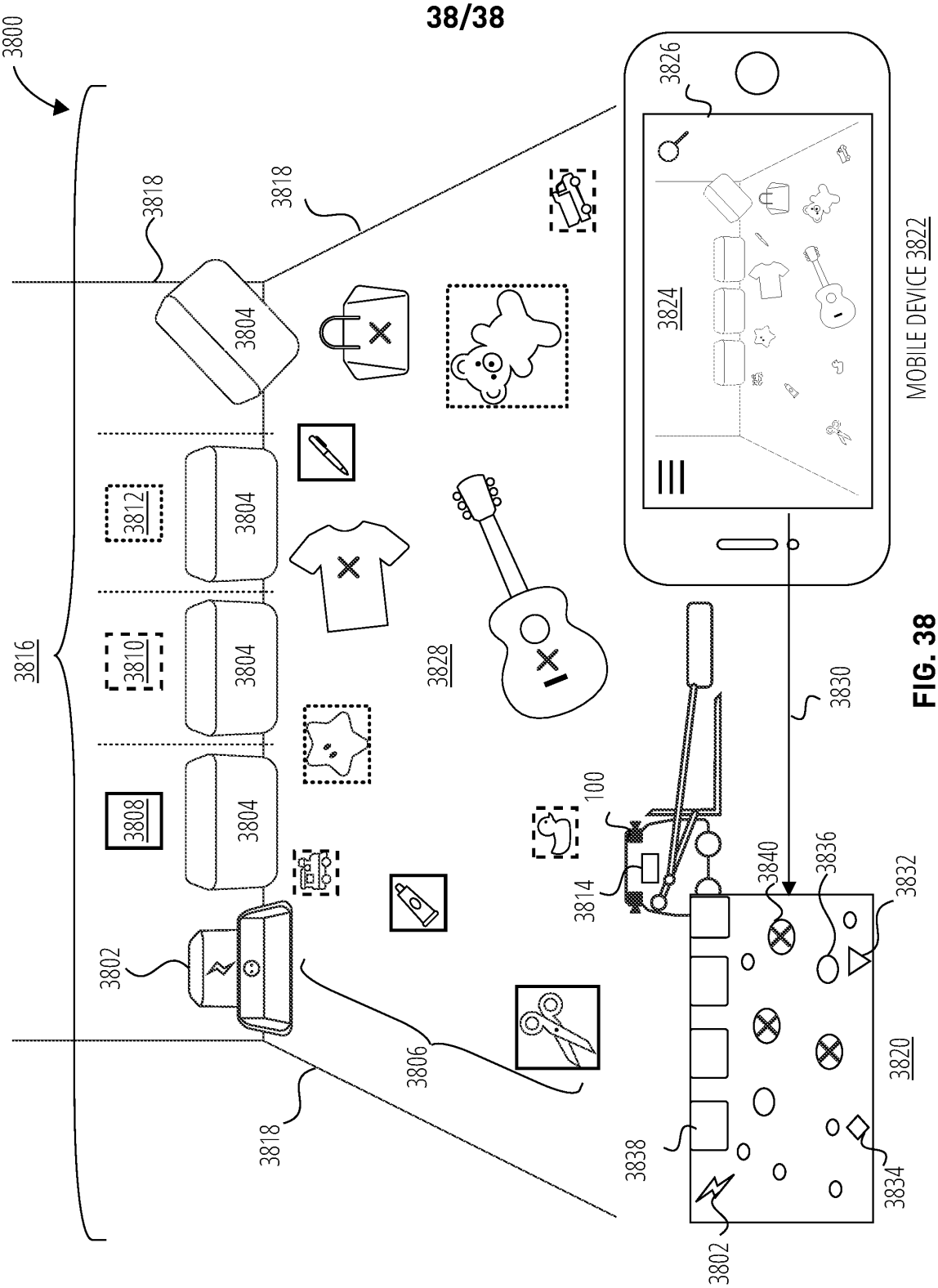

3800
3818
3818
3804
3804
3804
3804
3812
3810
3808
3816
3802
3806
3818
3828
3826
3824
MOBILE DEVICE 3822
3830
100
3814
3840
3836
3832
3820
3838
3834
3802

FIG. 38