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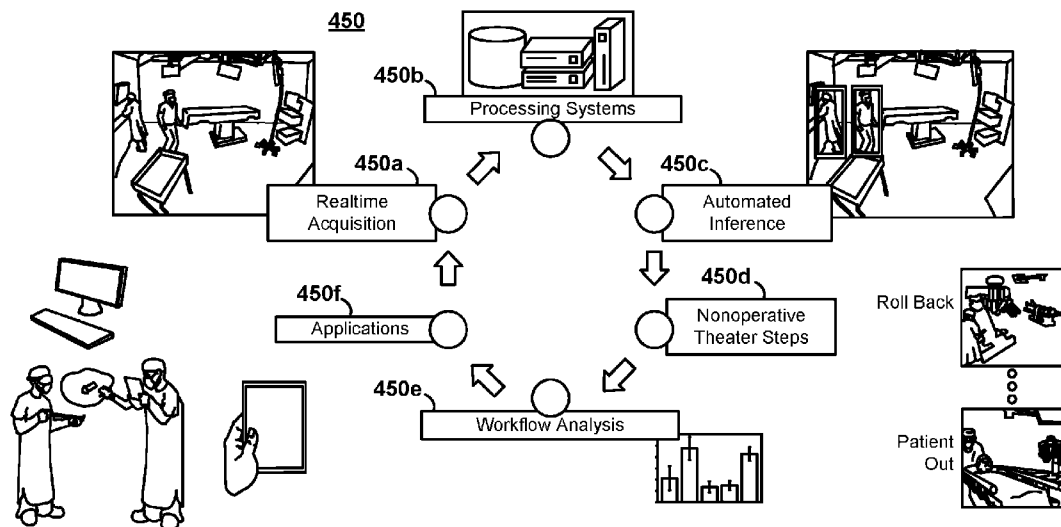


FIG. 4

(57) Abstract: Various of the disclosed embodiments provide systems and methods for assessing surgical team performance during nonoperative periods within the surgical theater. Particularly, one or more sensors placed throughout the surgical theater may acquire data during the nonoperative period, and in some embodiments, over the course of several procedures and nonoperative periods within the theater. Disclosed embodiments segment and analyze this data to infer undesirable or inefficient behavior, as well as progress in improving behaviors, during the periods between surgical procedures. A plurality of topologies and metrics for assessing nonoperative periods are also disclosed, as well as systems and methods for monitoring and providing feedback.



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SURGICAL THEATER NONOPERATIVE PERIOD ANALYSIS AND OPTIMIZATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of, and priority to, United States Provisional Application No. 63/526,966, filed upon July 14, 2023, entitled “SURGICAL THEATER NONOPERATIVE PERIOD ANALYSIS AND OPTIMIZATION”, and which is incorporated by reference herein in its entirety for all purposes.

TECHNICAL FIELD

[0002] Various of the disclosed embodiments relate to systems and methods for assessing surgical team member performance within a surgical theater during nonoperative periods, as well as providing meaningful feedback.

BACKGROUND

[0003] Surgical theaters present unique challenges and operating conditions, which require team members to quickly and efficiently adapt to a variety of rapidly changing technologies and circumstances. Failure of one or more team members to perform efficiently under these challenging conditions may precipitate errors and inefficiencies, which may cause a cascade of downstream delays, imposing undesirable costs and potential risks to patient health. Neither is the potential for such direct and indirect harm limited to inefficiencies occurring during the surgical operations themselves, but also actions taken before, between, and after such procedures. During these “nonoperative” periods, team members must reset the theater from past surgeries and configure the theater for upcoming procedures. Though frequently overlooked, poor performance during these nonoperative periods can itself result in a variety of costly, and potentially harmful, downstream adverse events. Failure to timely sort and store equipment, dilatory transport of patients to and from the theater, excessive and unnecessary motion when working near the patient, and similar nonoperative period inefficiencies can directly cause harm to the patient, impose costs, or may indirectly invite harm or costs via their effects upon downstream tasks.

[0004] Unfortunately, identifying, let alone remediating, such nonoperative inefficiencies can be so difficult as to often be intractable. Team members are themselves so focused upon patient care and the performance of their current tasks that opportunities to reflect upon their actions, to recognize the consequences of their actions upon other team members and downstream activities, and to appreciate inefficiencies in the team's collective dynamic as whole, rarely, if ever, occur. While third parties may observe the team's performance within the theater, or subsequently via in-theater sensor data, these observers are themselves subject to reviewer fatigue, reviewer subjectivity, and their presence imposes an undesirable temporal and financial constraint upon performance assessment. Indeed, such reviewers must be expertly trained and can review only a small number of procedures at a time. Furthermore, such human-in-the-loop coaching complicates verification that team members have adhered to any provided feedback, as there is regular turnover among reviewers and team members regularly transition between teams monitored by different reviewers.

[0005] While automated data acquisition via in-theater sensors may increase the number of nonoperative periods that can be reviewed, nonoperative periods present unique data management difficulties, as the same data or type of data available during operative periods may no longer be available. For example, reviewers may be able to review handheld instrument kinematics data or robotic surgical system events data captured during a surgery, whereas these datasets will be unavailable during nonoperative periods (when such equipment is typically inactive or absent). As inefficiencies in the nonoperative preparation may precipitate changes in the downstream operating period instrument kinematics data, discerning such causal relationships by manual inspection of the disparate datasets in isolation can be very difficult.

[0006] Accordingly, there exists a need for systems and methods to overcome challenges and difficulties such as those described above. For example, there exists a need for systems and methods to process disparate forms of surgical theater data acquired during nonoperative periods so as to facilitate reviewer analysis and feedback generation based upon team member inefficiencies identified therein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Various of the embodiments introduced herein may be better understood by referring to the following Detailed Description in conjunction with the accompanying drawings, in which like reference numerals indicate identical or functionally similar elements:

[0008] FIG. 1A is a schematic view of various elements appearing in a surgical theater during a surgical operation, as may occur in relation to some embodiments;

[0009] FIG. 1B is a schematic view of various elements appearing in a surgical theater during a surgical operation employing a robotic surgical system, as may occur in relation to some embodiments;

[0010] FIG. 2A is a schematic depth map rendering from an example theater-wide sensor perspective, as may be used in some embodiments;

[0011] FIG. 2B is a schematic top-down view of objects in the theater of FIG. 2A, with corresponding sensor locations;

[0012] FIG. 2C is a pair of images depicting a grid-like pattern of orthogonal rows and columns in perspective, as captured from a theater-wide visual image sensor having a rectilinear view and a theater-wide visual image sensor having a fisheye view, each of which may be used in connection with some embodiments;

[0013] FIG. 3 is a schematic representation of a series of surgical procedures within a surgical theater, their intervening nonoperative periods, and corresponding theater-wide sensor datasets for one such nonoperative period, as may occur in connection with some embodiments;

[0014] FIG. 4 is a schematic block diagram illustrating an example deployment topology for a nonoperative periods analysis system, as may be implemented in some embodiments;

[0015] FIG. 5A is a schematic representation of a collection of metrics intervals, as may be used to assess nonoperative team performance in some embodiments;

[0016] FIG. 5B is a schematic processing diagram indicating full-day relations of various intervals, including intervals from FIG. 5A, as may be applied in some embodiments;

[0017] FIG. 5C is a schematic block diagram indicating possible activity analysis class groupings, as may be used in connection with some embodiments;

[0018] FIG. 6 is a table of example task action temporal definitions, as may be used in some embodiments;

[0019] FIG. 7 is a table of additional example task action temporal definitions, as may be used in some embodiments;

[0020] FIG. 8 is a schematic block diagram illustrating various metrics and their relation in constructing a composite score (referred to as an operating room analysis “ORA” score), as may be used in some embodiments;

[0021] FIG. 9A is a schematic block diagram depicting a general nonoperative analysis system processing flow, as may be implemented in some embodiments;

[0022] FIG. 9B is a schematic block diagram depicting elements in a more detailed example nonoperative analysis system processing flow than the flow depicted in FIG. 9A, as may be implemented in some embodiments;

[0023] FIG. 9C is a flow diagram illustrating various operations in an example overall process for analyzing theater-wide sensor data during nonoperative periods, as may be implemented in some embodiments;

[0024] FIG. 10 is a flow diagram illustrating various operations in an example nonoperative segment detection process, as may be performed in some embodiments;

[0025] FIG. 11A is a schematic block diagram illustrating an example information processing flow for performing object detection, as may be used in connection with some embodiments;

[0026] FIG. 11B is a flow diagram illustrating various operations in an example process for performing object detection, as may be used in some embodiments;

[0027] FIG. 12A is schematic block diagram illustrating an example object tracking information processing flow, as may be used in connection with some embodiments;

[0028] FIG. 12B is flow diagram illustrating various operations in an example process for performing object tracking, as may be used in connection with some embodiments;

[0029] FIG. 13A is a schematic visual image and depth frame theater-wide data pair, from theater-wide data video, with an indication of the optical-flow derived correspondence, as may be used in some embodiments;

[0030] FIG. 13B is a schematic top-down view of the scene depicted in FIG. 13A;

[0031] FIG. 13C is a schematic pair of visual images showing team member motion distant from and near to an imaging sensor;

[0032] FIG. 13D is a schematic top-down view depicting the team member motion presented in the visual images of Fig. 13C;

[0033] FIG. 14 is a flow diagram illustrating various operations in an example process for performing motion analysis of nonoperative periods from theater-wide data, as may be used in connection with some embodiments;

[0034] FIG. 15 is flow diagram illustrating various operations in an example process for performing clustering and outlier determination analysis based upon metric values, such as those disclosed herein, as may be performed in some embodiments;

[0035] FIG. 16 is flow diagram illustrating various operations in an example process for providing coaching feedback based upon determined metric values, as may be performed in some embodiments;

[0036] FIG. 17 is a schematic representation of graphical user interface (GUI) elements in an example dashboard interface layout for nonoperative metrics quick review, as may be implemented in some embodiments;

[0037] FIG. 18A is a schematic representation of a GUI element in an example global nonoperative metrics quick review dashboard, as may be implemented in some embodiments;

[0038] FIG. 18B is a schematic representation of arrow graphical elements, as may be used in, e.g., the element of FIG. 18A in some embodiments;

[0039] FIG. 18C is a schematic representation of an example global nonoperative metrics quick review dashboard layout, as may be implemented in some embodiments;

[0040] FIG. 19A is a plot of example interval metric values acquired in connection with an example prototype implementation of an embodiment;

[0041] FIG. 19B is a plot of example interval metric values as acquired in connection with an example prototype implementation of an embodiment;

[0042] FIG. 20A is a plot of example interval metric values as acquired in connection with an example prototype implementation of an embodiment;

[0043] FIG. 20B is a plot of example interval metric values as acquired in connection with an example prototype implementation of an embodiment;

[0044] FIG. 21A is a plot of example metric values as acquired in connection with an example prototype implementation of an embodiment;

[0045] FIG. 21B is a plot of example metric values as acquired in connection with an example prototype implementation of an embodiment;

[0046] FIG. 21C is a plot of example metric values as acquired in connection with an example prototype implementation of an embodiment;

[0047] FIG. 22 is a schematic representation of example GUI elements for providing metrics-derived feedback, as may be used in some embodiments; and

[0048] FIG. 23 is a block diagram of an example computer system as may be used in conjunction with some of the embodiments.

[0049] The specific examples depicted in the drawings have been selected to facilitate understanding. Consequently, the disclosed embodiments should not be restricted to the specific details in the drawings or the corresponding disclosure. For example, the drawings may not be drawn to scale, the dimensions of some elements in the figures may have been adjusted to facilitate understanding, and the operations of the embodiments associated with the flow diagrams may encompass additional, alternative, or fewer operations than those depicted here. Thus, some components and/or operations may be separated into different blocks or combined into a single block in a manner other

than as depicted. The embodiments are intended to cover all modifications, equivalents, and alternatives falling within the scope of the disclosed examples, rather than limit the embodiments to the particular examples described or depicted.

DETAILED DESCRIPTION

Example Surgical Theaters Overview

[0050] FIG. 1A is a schematic view of various elements appearing in a surgical theater **100a** during a surgical operation as may occur in relation to some embodiments. Particularly, FIG. 1A depicts a non-robotic surgical theater **100a**, wherein a patient-side surgeon **105a** performs an operation upon a patient **120** with the assistance of one or more assisting members **105b**, who may themselves be surgeons, physician's assistants, nurses, technicians, etc. The surgeon **105a** may perform the operation using a variety of tools, e.g., a visualization tool **110b** such as a laparoscopic ultrasound, visual image acquiring endoscope, etc., and a mechanical instrument **110a** such as scissors, retractors, a dissector, etc.

[0051] The visualization tool **110b** provides the surgeon **105a** with an interior view of the patient **120**, e.g., by displaying visualization output from an imaging device mechanically and electrically coupled with the visualization tool **110b**. The surgeon may view the visualization output, e.g., through an eyepiece coupled with visualization tool **110b** or upon a display **125** configured to receive the visualization output. For example, where the visualization tool **110b** is a visual image acquiring endoscope, the visualization output may be a color or grayscale image. Display **125** may allow assisting member **105b** to monitor surgeon **105a**'s progress during the surgery. The visualization output from visualization tool **110b** may be recorded and stored for future review, e.g., using hardware or software on the visualization tool **110b** itself, capturing the visualization output in parallel as it is provided to display **125**, or capturing the output from display **125** once it appears on-screen, etc. While two-dimensional video capture with visualization tool **110b** may be discussed extensively herein, as when visualization tool **110b** is a visual image endoscope, one will appreciate that, in some embodiments, visualization tool **110b** may capture depth data instead of, or in addition to, two-dimensional image data (e.g., with a laser rangefinder, stereoscopy, etc.).

[0052] A single surgery may include the performance of several groups of actions, each group of actions forming a discrete unit referred to herein as a task. For example, locating a tumor may constitute a first task, excising the tumor a second task, and closing the surgery site a third task. Each task may include multiple actions, e.g., a tumor excision task may require several cutting actions and several cauterization actions. While some surgeries require that tasks assume a specific order (e.g., excision occurs before closure), the order and presence of some tasks in some surgeries may be allowed to vary (e.g., the elimination of a precautionary task or a reordering of excision tasks where the order has no effect). Transitioning between tasks may require the surgeon **105a** to remove tools from the patient, replace tools with different tools, or introduce new tools. Some tasks may require that the visualization tool **110b** be removed and repositioned relative to its position in a previous task. While some assisting members **105b** may assist with surgery-related tasks, such as administering anesthesia **115** to the patient **120**, assisting members **105b** may also assist with these task transitions, e.g., anticipating the need for a new tool **110c**.

[0053] Advances in technology have enabled procedures such as that depicted in FIG. 1A to also be performed with robotic systems, as well as the performance of procedures unable to be performed in non-robotic surgical theater **100a**. Specifically, FIG. 1B is a schematic view of various elements appearing in a surgical theater **100b** during a surgical operation employing a robotic surgical system, such as a da Vinci™ surgical system, as may occur in relation to some embodiments. Here, patient side cart **130** having tools **140a**, **140b**, **140c**, and **140d** attached to each of a plurality of arms **135a**, **135b**, **135c**, and **135d**, respectively, may take the position of patient-side surgeon **105a**. As before, one or more of tools **140a**, **140b**, **140c**, and **140d** may include a visualization tool (here visualization tool **140d**), such as a visual image endoscope, laparoscopic ultrasound, etc. An operator **105c**, who may be a surgeon, may view the output of visualization tool **140d** through a display **160a** upon a surgeon console **155**. By manipulating a hand-held input mechanism **160b** and pedals **160c**, the operator **105c** may remotely communicate with tools **140a-d** on patient side cart **130** so as to perform the surgical procedure on patient **120**. Indeed, the operator **105c** may or may not be in the same physical location as patient side cart **130** and patient **120** since the

communication between surgeon console **155** and patient side cart **130** may occur across a telecommunication network in some embodiments. An electronics/control console **145** may also include a display **150** depicting patient vitals and/or the output of visualization tool **140d**.

[0054] Similar to the task transitions of non-robotic surgical theater **100a**, the surgical operation of theater **100b** may require that tools **140a-d**, including the visualization tool **140d**, be removed or replaced for various tasks as well as new tools, e.g., new tool **165**, be introduced. As before, one or more assisting members **105d** may now anticipate such changes, working with operator **105c** to make any necessary adjustments as the surgery progresses.

[0055] Also similar to the non-robotic surgical theater **100a**, the output from the visualization tool **140d** may here be recorded, e.g., at patient side cart **130**, surgeon console **155**, from display **150**, etc. While some tools **110a**, **110b**, **110c** in non-robotic surgical theater **100a** may record additional data, such as temperature, motion, conductivity, energy levels, etc., the presence of surgeon console **155** and patient side cart **130** in theater **100b** may facilitate the recordation of considerably more data than is only output from the visualization tool **140d**. For example, operator **105c**'s manipulation of hand-held input mechanism **160b**, activation of pedals **160c**, eye movement with respect to display **160a**, etc., may all be recorded. Similarly, patient side cart **130** may record tool activations (e.g., the application of radiative energy, closing of scissors, etc.), movement of instruments, etc., throughout the surgery. In some embodiments, the data may have been recorded using an in-theater recording device, which may capture and store sensor data locally or at a networked location (e.g., software, firmware, or hardware configured to record surgeon kinematics data, console kinematics data, instrument kinematics data, system events data, patient state data, etc., during the surgery).

[0056] Within each of theaters **100a**, **100b**, or in network communication with the theaters from an external location, may be computer systems **190a** and **190b**, respectively (in some embodiments, computer system **190b** may be integrated with the robotic surgical system, rather than serving as a standalone workstation). As will be

discussed in greater detail herein, the computer systems **190a** and **190b** may facilitate, e.g., data collection, data processing, etc.

[0057] Similarly, many of theaters **100a**, **100b** may include sensors placed around the theater, such as sensors **170a** and **170c**, respectively, configured to record activity within the surgical theater from the perspectives of their respective fields of view **170b** and **170d**. Sensors **170a** and **170c** may be, e.g., visual image sensors (e.g., color or grayscale image sensors), depth-acquiring sensors (e.g., via stereoscopically acquired visual image pairs, via time-of-flight with a laser rangefinder, structural light, etc.), or a combination of visual image and depth-acquiring sensors (e.g., red green blue depth RGB-D sensors). In some embodiments, sensors **170a** and **170c** may also include audio acquisition sensors or sensors specifically dedicated to audio acquisition may be placed around the theater. A plurality of such sensors may be placed within theaters **100a**, **100b**, possibly with overlapping fields of view and sensing range, to achieve a more holistic assessment of the surgery. For example, depth-acquiring sensors may be strategically placed around the theater so that their resulting depth frames at each moment may be consolidated into a single three-dimensional virtual element model depicting objects in the surgical theater. Similarly, sensors may be strategically placed in the theater to focus upon regions of interest. For example, sensors may be attached to display **125**, display **150**, or patient side cart **130** with fields of view focusing upon the patient **120**'s surgical site, attached to the walls or ceiling, etc. Similarly, sensors may be placed upon console **155** to monitor the operator **105c**. Sensors may likewise be placed upon movable platforms specifically designed to facilitate orienting of the sensors in various poses within the theater.

[0058] For clarity, as used herein, a "pose" refers to the translational position and rotational orientation of a body. For example, in a three-dimensional space, one may represent a pose with six total degrees of freedom. One will readily appreciate that poses may be represented using a variety of data structures, e.g., with matrices, with quaternions, with vectors, with combinations thereof, etc. Thus, in some situations, when there is no rotation, a pose may comprise only a translational component. Conversely, when there is no translation, a pose may comprise only a rotational component.

[0059] Similarly, for clarity, “theater-wide” sensor data refers herein to data acquired from one or more sensors configured to monitor a specific region of the theater (the region encompassing all, or a portion, of the theater) exterior to the patient, to personnel, to equipment, or to any other objects in the theater, such that the sensor can perceive the presence within, or passage through, at least a portion of the region of the patient, personnel, equipment, or other objects, throughout the surgery. Sensors so configured to collect such “theater-wide” data are referred to herein as “theater-wide sensors.” For clarity, one will appreciate that the specific region need not be rigidly fixed throughout the procedure, as, e.g., some sensors may cyclically pan their field of view so as to augment the size of the specific region, even though this may result in temporal lacunae for portions of the region in the sensor’s data (lacunae which may be remedied by the coordinated panning or fields of view of other nearby sensors). Similarly, in some cases, personnel or robotics systems may be able to relocate theater-wide sensors, changing the specific region, throughout the procedure, e.g., to better capture different tasks. Accordingly, sensors **170a** and **170c** are theater-wide sensors configured to produce theater-wide data. “Visualization data” refers herein to visual image or depth image data captured from a sensor. Thus, visualization data may or may not be theater-wide data. For example, visualization data captured at sensors **170a** and **170c** is theater-wide data, whereas visualization data captured via visualization tool **140d** would not be theater-wide data (for at least the reason that the data is not exterior to the patient).

Example Theater-Wide Sensor Topologies

[0060] For further clarity regarding theater-wide sensor deployment, FIG. 2A is a schematic depth map rendering from an example theater-wide sensor perspective **205** as may be used in some embodiments. Specifically, this example depicts depth values corresponding to an electronics/control console **205a** (e.g., the electronics/control console **145**) and a nearby tray **205b**, and cabinet **205c**. Also within the field of view are depth values associated with a first technician **205d**, presently adjusting a robotic arm (associated with depth values **205f**) upon a robotic surgical system (associated with depth values **205e**). Team members, with corresponding depth values **205g**, **205h**, and **205i**, likewise appear in the field of view, as does a portion of the surgical table **205j**. Depth

values **205l** corresponding to a movable dolly and a boom with a lighting system's depth values **205k** also appear within the field of view.

[0061] The theater-wide sensor capturing the perspective **205** may be only one of several sensors placed throughout the theater. For example, FIG. 2B is a schematic top-down view of objects in the theater at a given moment during the surgical operation. Specifically, the perspective **205** may have been captured via a theater-wide sensor **220a** with corresponding field of view **225a**. Thus, for clarity, cabinet depth values **205c** may correspond to cabinet **210c**, electronics/control console depth values **205a** may correspond to electronics/control console **210a**, and tray depth values **205b** may correspond to tray **210b**. Robotic system **210e** may correspond to depth values **205e**, and each of the individual team members **210d**, **210g**, **210h**, and **210i** may correspond to depth values **205d**, **205g**, **205h**, and **205i**, respectively. Similarly, dolly **210l** may correspond to depth values **205l**. Depth values **205j** may correspond to table **210j** (with an outline of a patient shown here for clarity, though the patient has not yet been placed upon the table corresponding to depth values **205j** in the example perspective **205**). A top-down representation of the boom corresponding to depth values **205k** is not shown for clarity, though one will appreciate that the boom may likewise be considered in various embodiments.

[0062] As indicated, each of the sensors **220a**, **220b**, **220c** is associated with different fields of view **225a**, **225b**, and **225c**, respectively. The fields of view **225a-c** may sometimes have complementary characters, providing different perspectives of the same object, or providing a view of an object from one perspective when it is outside, or occluded within, another perspective. Complementarity between the perspectives may be dynamic both spatially and temporally. Such dynamic character may result from movement of an object being tracked, but also from movement of intervening occluding objects (and, in some cases, movement of the sensors themselves). For example, at the moment depicted in FIGs. 2A and 2B, the field of view **225a** has only a limited view of the table **210j**, as the electronics/control console **210a** substantially occludes that portion of the field of view **225a**. Consequently, in the depicted moment, the field of view **225b** is better able to view the surgical table **210j**. However, neither field of view **225b** nor **225a** has an adequate view of the operator **210n** in console **210k**. To observe the operator

210n (e.g., when they remove their head in accordance with “head out” events), field of view **225c** may be more suitable. However, over the course of the data capture, these complementary relationships may change. For example, before the procedure begins, electronics/control console **210a** may be removed and the robotic system **210e** moved into the position **210m**. In this configuration, field of view **225a** may instead be much better suited for viewing the patient table **210j** than the field of view **225b**. As another example, movement of the console **210k** to the presently depicted pose of electronics/control console **210a** may render field of view **225a** more suitable for viewing operator **210n**, than field of view **225c**. Suitability of a field of view may thus depend upon the number and duration of occlusions, quality of the field of view (e.g., how close the object of interest is to the sensor), and movement of the object of interest within the theater. Such changes may be transitory and short in duration, as when a team member moving in the theater briefly occludes a sensor, or they may be chronic or sustained, as when equipment is moved into a fixed position throughout the duration of the procedure.

[0063] As mentioned, the theater-wide sensors may take a variety of forms and may, e.g., be configured to acquire visual image data, depth data, both visual and depth data, etc. One will appreciate that visual and depth image captures may likewise take on a variety of forms, e.g., to afford increased visibility of different portions of the theater. For example, FIG. 2C is a pair of images **250b**, **255b** depicting a grid-like pattern of orthogonal rows and columns in perspective, as captured from a theater-wide sensor having a rectilinear view and a theater-wide sensor having a fisheye view, respectively. More specifically, some theater-wide sensors may capture rectilinear visual images or rectilinear depth frames, e.g., via appropriate lenses, post-processing, combinations of lenses and post-processing, etc. while other theater-wide sensors may instead, e.g., acquire fisheye or distorted visual images or rectilinear depth frames, via appropriate lenses, post-processing, combinations of lenses and post-processing, etc. For clarity, image **250b** depicts a checkboard pattern in perspective from a rectilinear theater wide sensor. Accordingly, the orthogonal rows and columns **250a** shown here in perspective, retain linear relations with their vanishing points. In contrast, image **255b** depicts the same checkboard pattern in the same perspective, but from a fish-eye theater-wise sensor perspective. Accordingly, the orthogonal rows and columns **255a**, while in reality

retaining a linear relationship with their vanishing points (as they appear in image **250b**) appear here from the sensor data as having curved relations with their vanishing points. Thus, each type of sensor, and other sensor types, may be used alone, or in some instances, in combination, in connection with various embodiments.

[0064] Similarly, one will appreciate that not all sensors may acquire perfectly rectilinear, fisheye, or other desired mappings. Accordingly, checkered patterns, or other calibration fiducials (such as known shapes for depth systems), may facilitate determination of a given theater-wide sensor's intrinsic parameters. For example, the focal point of the fisheye lens, and other details of the theater-wide sensor (principal points, distortion coefficients, etc.), may vary between devices and even across the same device over time. Thus, it may be necessary to recalibrate various processing methods for the particular device at issue, anticipating the device variation when training and configuring a system for machine learning tasks. Additionally, one will appreciate that the rectilinear view may be achieved by undistorting the fisheye view once the intrinsic parameters of the camera are known (which may be useful, e.g., to normalize disparate sensor systems to a similar form recognized by a machine learning architecture). Thus, while a fisheye view may allow the system and users to more readily perceive a wider field of view than in the case of the rectilinear perspective, when a processing system is considering data from some sensors acquiring undistorted perspectives and other sensors acquiring distorted perspectives, the differing perspectives may be normalized to a common perspective form (e.g., mapping all the rectilinear data to a fisheye representation or vice versa).

Example Surgical Theater Nonoperative Data

[0065] As discussed above, granular and meaningful assessment of team member actions and performance during nonoperative periods in a theater may reveal opportunities to improve efficiency and to avoid inefficient behavior having the potential to affect downstream operative and nonoperative periods. For context, FIG. 3 depicts a state of a single operating room over time **305**, e.g., over the course of a day. In this example, during an initial pre-surgical period **310a**, the team may prepare the operating room for the day's procedures, collecting appropriate equipment, reviewing scheduled

tasks, etc. After performing the day's first surgery **315a**, a nonoperative inter-surgical period **310b** will follow wherein the team performs the turnover from the operating room configuration for performing the surgery **315a** to the configuration for performing the surgery **315b**. Such alternating nonoperative and operative periods may continue throughout the day, e.g., nonoperative inter-surgical period **310c** here follows the second surgery **315b**, etc. After the final procedure **315c** is performed for the day, the team may perform any final maintenance operations, may secure and put away equipment, deactivate devices, upload data, etc., during the post-operative period **310d**. Ellipsis **310e** indicates the possibility of additional intervening operative and nonoperative states (though, naturally, in some theaters there may instead be only one surgery during the day). Because of the theater operations' sequential character, an error in an upstream period can cause errors and delays to cascade through downstream periods. For example, improper alignment of equipment during pre-surgical period **310a** may result in a delay during surgery **315a**. This delay may itself require nonoperative period **310b** to be shortened, providing a team member insufficient time to perform proper cleaning procedures, thereby placing the patient of surgery **315b**'s health at risk. Thus, inefficiencies early in the day may result in the delay, poor execution, or rescheduling of downstream actions. Conversely, efficiencies early in the day may provide tolerance downstream for unexpected events, facilitating more predictable operation outcomes and other benefits.

[0066] Each of the theater states, including both the operative periods **315a**, **315b**, etc. and nonoperative periods **310a**, **310b**, **310c**, **310d**, etc. may be divided into a collection of tasks. For example, the nonoperative period **310c** may be divided into the tasks **320a**, **320b**, **320c**, **320d**, and **320e** (with intervening tasks represented by ellipsis **320f**). In this example, at least three theater-wide sensors were present in the operating room, each sensor capturing at least visual image data (though one will appreciate that there may be fewer than three streams, or more, as indicated by ellipses **370q**). Specifically, a first theater-wide sensor captured a collection of visual images **325a** (e.g., visual image video) during the first nonoperative task **320a**, a collection of visual images **325b** during the second nonoperative task **320b**, a collection of visual images **325c** during the third nonoperative task **320c**, a collection of visual images **325d** during the fourth

nonoperative task **320d**, and the collection of visual images **325e** during the last nonoperative task **320e** (again, intervening groups of frames may have been acquired for other tasks as indicated by ellipsis **325f**).

[0067] Contemporaneously during each of the tasks of the second nonoperative period **310c**, the second theater-wide sensor may acquire the data collections **330a-e** (ellipsis **330f** depicting possible intervening collections), and the third theater-wide sensor may acquire the collections of **335a-e** (ellipsis **335f** depicting possible intervening collections). Thus, one will appreciate, e.g., that the data in sets **325a**, **330a**, and **335a** may be acquired contemporaneously by the three theater-wide sensors during the task **320a** (and, similarly, each of the other columns of collected data associated with each respective nonoperative task). Again, though visual images are shown in this example, one will appreciate that other data, such as depth frames, may alternatively, or additionally, be likewise acquired in each collection.

[0068] Thus, in task **320a**, which may be an initial “cleaning” task following the surgery **315b**, the sensor associated with collections **325a-e** depicts a team member and the patient in a first perspective. In contrast, the sensor capturing collections **335a-e** is located on the opposite side of the theater and provides a fisheye view from a different perspective. Consequently, the second sensor’s perception of the patient is more limited. The sensor associated with collections **330a-e** is focused upon the patient, however, this sensor’s perspective doesn’t depict the team member very well in the collection **330a**, whereas the collection **325a** does provide a clear view of the team member.

[0069] Similarly, in task **320b**, which may be a “roll-back” task, moving the robotic system away from the patient, the theater-wide sensor associated with collections **330a-e** depicts that the patient is no longer subject to anesthesia, but does not depict the state of the team member relocating the robotic system. Rather, the collections **325b** and **335b** each depict the team member and the new pose of the robotic system at a point distant from the patient and operating table (though the sensor associated with the stream collections **335a-e** is better positioned to observe the robot in its post-rollback pose).

[0070] In task **320c**, which may be a “turnover” or “patient out” task, a team member escorts the patient out of the operating room. While the theater-wide sensor associated

with collection **325c** has a clear view of the departing patient, the theater-wide sensor associated with the collection **335c** may be too far away to observe the departure in detail. Similarly, the collection **330c** only indicates that the patient is no longer on the operating table.

[0071] In task **320d**, which may be a “setup” task, a team member positions equipment which will be used in the next operative period (e.g., the final surgery **315c** if there are no intervening periods in the ellipsis **310e**).

[0072] Finally, in task **320e**, which may be a “sterile prep” task before the initial port placements and beginning of the next surgery (again, e.g., surgery **315c**), the theater-wide sensor associated with collection **330e** is able to perceive the pose of the robotic system and its arms, as well as the state of the new patient. Conversely, collections **325e** and **335e** may provide wider contextual information regarding the state of the theater.

[0073] Thus, one can appreciate the holistic benefit of multiple sensor perspectives, as the combined views of the streams **325a-e**, **330a-e**, and **335a-e** may provide overlapping situational awareness. Again, as mentioned, not all of the sensors may acquire data in exactly the same manner. For example the sensor associated with collections **335a-e** may acquire data from a fisheye perspective, whereas the sensors associated with collections **325a-e** and **330a-e** may acquire rectilinear data. Similarly, there may be fewer or more theater-wide sensors and streams than are depicted here. Generally, because each collection is timestamped, it will be possible for a reviewing system to correlate respective streams’ representations, even when they are of disparate forms. Thus, data directed to different theater regions may be reconciled and reviewed. Unfortunately, as mentioned, unlike periods **315a-c**, surgical instruments, robotic systems, etc., may no longer be capturing data during the nonoperative periods (e.g., periods **310a-d**). Accordingly, systems and reviewers regularly accustomed to analyzing the copious datasets available from periods **315a-c** may find it especially difficult to review the more sparse data of periods **310a-d** as they may need to rely only upon the disparate theater-wide streams **325a-e**, **330a-e**, and **335a-e**. Even as the reader may have perceived in considering this figure, manually reconciling disparate, but

contemporaneously captured perspectives, may be cognitively taxing upon a human reviewer.

Example Nonoperative Activity Data Processing Overview

[0074] Various embodiments employ a processing pipeline facilitating analysis of nonoperative periods, and may include methods to facilitate iterative improvement of the surgical team's performance during these periods. Particularly, some embodiments include computer systems configured to automatically measure and analyze nonoperative activities in surgical operating rooms and recommend customized actionable feedback to operating room staff or hospital management based upon historical dataset patterns so as, e.g., to improve workflow efficiency. Such systems can also help hospital management assess the impact of new personnel, equipment, facilities, etc., as well as scale their review to a larger number, and more disparate types, of surgical theaters and surgeries, consequently driving down workflow variability. As discussed, various embodiments may be applied to surgical theaters having more than one modality, e.g., robotic, non-robotic laparoscopic, non-robotic open. Neither are various of the disclosed approaches limited to nonoperative periods associated with specific types of surgical procedures (e.g., prostatectomy, cholecystectomy, etc.).

[0075] FIG. 4 is a schematic block diagram illustrating an example deployment topology **450** for a nonoperative periods analysis system of certain embodiments. As described herein, during real-time acquisition **450a**, data may be collected from one or more theater-wide sensors in one or more perspectives. Multimodal (e.g., visual image and depth) sensor suites within a surgical theater (whether robotic or non-robotic) produce a wide variety of data. Consolidating this data into elemental and composite OR metrics, as described herein, may more readily facilitate analysis. To determine these metrics, the data may be provided to a processing systems **450b**, described in greater detail herein, to perform automated inference **450c**, including the detection of objects in the theater, such as personnel and equipment, as well as to segment the theater-wide data into distinct steps **450d** (which may, e.g., correspond to the groupings and their respective actions discussed herein with respect to FIGs. 5A-C). The discretization of the theater-wide data into the steps **450d** may facilitate more meaningful and granular

determinations of metrics from the theater-wide data via various workflow analytics **450e**, e.g., to ascertain surgical theater efficiency, to provide actionable coaching recommendations, etc.

[0076] Following the generation of such metrics during workflow analysis **450e**, embodiments also disclose software and algorithms for presentation of the metric values to users and for outlier detection within the metric values relative to historical patterns. These analytics results may then be used to provide coaching and feedback via various applications **450f**. Software applications **450f** may present various metrics and derived analysis disclosed herein in various interfaces as part of the actionable feedback, a more rigorous and comprehensive solution than the prior use of human reviewers alone. One will appreciate that such applications may be provided upon any suitable computer system, including desktop applications, tablets, augmented reality devices, etc. This feedback may result in the adjustment of the theater operation such that subsequent application of the steps **450a-f** identify new or more subtle inefficiencies in the team's workflow. Thus, the cycle may continue again, such that the iterative, automated OR workflow analytics facilitate gradual improvement in the team's performance, allowing the team to adapt contextually based on upon the respective adjustments. Such iterative application may also help reviewers to better track the impact of the feedback to the team, analyze the effect of changes to the theater composition and scheduling, as well as for the system to consider historical patterns in future assessments and metrics generation.

Example Nonoperative Interval Divisions

[0077] FIG. 5A is a schematic representation of a collection of metrics intervals as may be used to assess nonoperative team performance in some embodiments. One will appreciate that the intervals may be applied cyclically in accordance with the alternating character of the operative and nonoperative periods in the theater described above in FIG. 3. For example, initially, the surgical operation **315b** may correspond to the interval **550e**. Following the operation **315b**'s completion, actions and corresponding data in the theater may be allocated to consecutive intervals **550a-d** during the subsequent nonoperative period **310c**. Data and actions in the next surgery (e.g., surgery **315c**, if there are no intervening periods in ellipsis **310e**), may then be ascribed again to a second

instance of the interval **550e**, and so forth (consequently, data from each of the nonoperative periods **310b**, **310b** will be allocated to instances of intervals **550a-d**). Intervals may also be grouped into larger intervals, as is the case here with the “wheels out to wheels in” interval **550f**, which groups the intervals **550b** and **550c**, sharing the start time of interval **550b** and the end time of interval **550c**. Consolidating theater-wide data into this taxonomy, in conjunction with various other operations disclosed herein, may more readily facilitate analysis in a manner amenable to larger efficiency review, as described in greater detail herein. For example, organizing data in this manner may facilitate comparisons with different days of the week over the course of the month across theaters, surgery configurations (both robotic and non-robotic), and teams, with specific emphasis upon particular of these intervals **550a-d** appearing in the corresponding nonoperative periods. Though not part of the nonoperative period, in some embodiments, it may still be useful to determine the duration of the surgery in interval **550e**, as the duration may inform the efficiency or inefficiency of the preceding or succeeding nonoperative period. Accordingly, in some embodiments, some of the disclosed metrics may consider events and actions in this interval **550e**, even when seeking ultimately to assess the efficiency of a nonoperative period.

[0078] For further clarity in the reader’s understanding, FIG. 5B is a schematic block diagram indicating full-day relations of the elements from FIG. 5A. Specifically, as discussed above, instances of the intervals of FIG. 5A may be created cyclically in accordance with the alternating operative and nonoperative periods of FIG. 3. In some embodiments, when considering full day data (e.g., data including the nonoperative pre-operative period **310a**, nonoperative post-operative period **310d**, and all intervening periods), the system may accordingly anticipate a preliminary interval “day start to patient in” **555a** to account for actions within the pre-operative period **310a**. This interval may, e.g., begin when the first personnel enters the theater for the day and may end when the patient enters the theater for the first surgery. Accordingly, as shown by the arrow **555c**, this may result in a transition to the first instance of the “patient in to skin cut” interval **550d**. From there, as indicated by the circular relation, the data may be cyclically grouped into instances of the intervals **550a-e**, e.g., in accordance with the alternating periods **315a**, **310b**, **315b**, **310c**. etc. until the period **315c**.

[0079] At the conclusion of the final surgery for the day (e.g., surgery **315c**), and following the last instance of the interval **550a** after that surgery, then rather than continue with additional cyclical data allocations among instances of the intervals **550a-e**, the system may instead transition to a final “patient out to day end” interval **555b**, as shown by the arrow **555d** (which may be used to assess nonoperative post-operative period **310d**). The “patient out to day end” interval **555b** may end when the last team member leaves the theater or the data acquisition concludes. One will appreciate that various of the disclosed computer systems may be trained to distinguish actions in the interval **555b** from the corresponding data of interval **550b** (naturally, conclusion of the data stream may also be used in some embodiments to infer the presence of interval **555b**). Though concluding the day’s actions, analysis of interval **555b** may still be appropriate in some embodiments, as actions taken at the end of one day may affect the following day’s performance.

Example Task to Interval Assignments and Action Temporal Intervals

[0080] In some embodiments, the durations of each of intervals **550a-e** may be determined based upon respective start and end times of various tasks or actions within the theater. Naturally, when the intervals **550a-e** are used consecutively, the end time for a preceding interval (e.g., the end of interval **550c**) may be the start time of the succeeding interval (e.g., the beginning of interval **550d**). When coupled with a task action grouping ontology, theater-wide data may be readily grouped into meaningful divisions for downstream analysis. This may facilitate, e.g., consistency in verifying that team members have been adhering to proposed feedback, as well as computer-based verification of the same, across disparate theaters, team configurations, etc. As will be explained, some task actions may occur over a period of time (e.g., cleaning), while others may occur at a specific moment (e.g., entrance of a team member).

[0081] Specifically, FIG. 5C depicts four high-level task action classes: post-surgery **520**, turnover **525**, pre-surgery **510**, and surgery **515**. Surgery **515** may include the tasks or actions **515a-i**. As will be discussed, FIGs. 6 and 7 provide various example temporal definitions for the actions, though for the reader’s appreciation, brief summaries will be provided here. Specifically, the task “first cut” **515a**, may correspond to a time when the

first incision upon the patient occurs (consider, e.g., the duration **605a**). The task “port placement” **515b**, may correspond to a duration between the time when a first port is placed into the patient and the time when the last port is placed (consider, e.g., the duration **605b**). The task “rollup” **515c**, may correspond to the duration in which a team member begins moving a robotic system to a time when the robotic system assumes the pose it will use during at least an initial portion of the surgical procedure (consider, e.g., the duration **605c**). The task “room prep” **515d**, may correspond to a duration beginning with the first surgery preparation action specific to the surgery being performed and may conclude with the last preparation action specific to the surgery being performed (consider, e.g., the duration **605d**). The task “docking” **515e**, may correspond to a duration starting when a team member begins docking a robotic system and concludes when the robotic system is docked (consider, e.g., the duration **605e**). The task “surgery” **515f**, may correspond with a duration starting with the first incision and ending with the final closure of the patient (consider, e.g., the durations **705a-c** for respective contemplated surgeries, specifically the robotic surgery **705a** and non-robotic surgeries **705b** and **705c**). Naturally, in many taxonomies, these action blocks may be further broken down into considerably more action and task divisions in accordance with the analyst’s desired focus (e.g., if the action “port placement” **515b** were associated with an inefficiency, a supplemental taxonomy wherein each port’s placement were a distinct action, with its own measured duration, may be appropriate for refining the analysis). Here, however, as nonoperative period actions are the subject of review, the general task “surgery” **515f** (e.g., one of durations **705a-c**) may suffice, despite surgery’s encompassing many constituent actions. The task “undocking” **515g**, may correspond to a duration beginning when a team member starts to undock a robotic system and concludes when the robotic system is undocked (consider, e.g., the duration **705d**). The task “rollback” **515h**, may correspond to a duration when a team member begins moving a robotic system away from a patient and concludes when the robotic system assumes a pose it will retain until turnover begins (consider, e.g., the duration **705e**). The task “patient close” **515a**, may correspond to a duration (e.g., duration **705f**) when the surgeon observes the patient during rollback (e.g., one will appreciate by this example that some action durations may overlap and proceed in parallel).

[0082] Within the post-surgical class grouping **520**, the task “robot undraping” **520a** may correspond to a duration when a team member first begins undraping a robotic system and ends when the robotic system is undraped (consider, e.g., the duration **705g**). The task “patient out” **520b**, may correspond to a time, or duration, during which the patient leaves the theater (consider, e.g., the duration **705h**). The task “patient undraping” **520c**, may correspond to a duration beginning when a team member begins undraping the patient and ends when the patient is undraped (consider, e.g., the duration **705i**).

[0083] Within the turnover class grouping **525**, the task “clean” **525a**, may correspond to a duration starting when the first team member begins cleaning equipment in the theater and concludes when the last team member (which may be the same team member) completes the last cleaning of any equipment (consider, e.g., the duration **705j**). The task “idle” **525b**, may correspond to a duration that starts when team members are not performing any other task and concludes when they begin performing another task (consider, e.g., the duration **705k**). The task “turnover” **505a** may correspond to a duration that starts when the first team member begins resetting the theater from the last procedure and concludes when the last team member (which may be the same team member) finishes the reset (consider, e.g., the duration **615a**). The task “setup” **505b** may correspond to a duration that starts when the first team member begins changing the pose of equipment to be used in a surgery, and concludes when the last team member (which may be the same team member) finishes the last equipment pose adjustment (consider, e.g., the duration **615a**). The task “sterile prep” **505c**, may correspond to a duration that starts when the first team member begins cleaning the surgical area and concludes when the last team member (which may be the same team member) finishes cleaning the surgical area (consider, e.g., the duration **615c**). Again, while shown here in linear sequences, one will appreciate that task actions within the classes may proceed in orders other than that shown or, in some instances, may refer to temporal periods which may overlap and may proceed in parallel (e.g., when performed by different team members).

[0084] Within pre-surgery class grouping **510**, the task “patient in” **510a** may correspond to a duration that starts and ends when the patient first enters the theater

(consider, e.g., the duration **620a**). The task “robot draping” **510b** may correspond to a duration that starts when the a member begins draping the robotic system and concludes when draping is complete (consider, e.g., the duration **620b**). The task “intubate” **510c** may correspond to a duration that starts when intubation of the patient begins and concludes when intubation is complete (consider, e.g., the duration **620c**). The task “patient prep” **510d** may correspond to a duration that starts when a team member begins preparing the patient for surgery and concludes when preparations are complete (consider, e.g., the duration **620d**). The task “patient draping” **510e** may correspond to a duration that starts when a team member begins draping the patient and concludes when the patient is draped (consider, e.g., the duration **620e**).

[0085] Though not discussed herein, as mentioned, one will appreciate the possibility of additional or different task actions. For example, the durations of “Imaging” **720a** and “Walk In” **720b**, though not part of the example taxonomy of FIG. 5C, may also be determined in some embodiments.

[0086] Thus, as indicated by the respective arrows in FIG. 5C, the intervals of FIG. 5A may be allocated as follows. “Skin-close to patient-out” **550a** may begin at the last closing operation **515j** of the previous surgery interval and concludes with the patient’s departure from the theater (e.g., from the end of the last suture at block **515i** until the patient has departed at block **520b**). Similarly, the interval “Patient-out to case-open” **550b** may begin when the patient’s departure from the theater at block **520b** and concludes with the start of sterile prep at block **505c** for the next case.

[0087] The interval “case-open to patient-in” **550c**, may begin with the start of the sterile prep at block **505c** and conclude with the start of the new patient entering the theater at block **510a**. The interval “patient-in to skin cut” **550d** may begin when the new patient enters the theater at block **510a** and concludes at the start of the first cut at block **515**. The surgery itself may occur during the interval **550e** as shown.

[0088] As previously discussed, the “wheels out to wheels in” interval **550f** is the interval from the start of “Patient out to case open” **550b** and concludes with the end of “case open to patient in” **550c**.

Example Nonoperative Metric Generation and Scoring

[0089] After the nonoperative segments have been identified (e.g., using systems and methods discussed herein with respect to FIGs. 9A-C and FIG. 10), the number and location of objects (e.g., using systems and methods discussed herein with respect to FIGs. 9A-C and FIGs. 11A-B), such as personnel, within each segment, and their respective motions have been identified (e.g., using systems and methods discussed herein with respect to FIGs. 9A-C, 12A-B, 13A-D, and 14), the system may generate one or more metric values. As mentioned, the duration and relative times of the intervals, classes, and task actions of FIGs. 5A-C may themselves serve as metrics.

[0090] Various embodiments may also determine “composite” metric scores based upon various of the other determined metrics. These metrics assume the functional form of EQN. 1:

$$s = f(m) \quad (1)$$

where s refers to the composite metric score value, which may be confined to a range, e.g., from 0 to 1, from 0 to 100, etc., and $f(\cdot)$ represents the mapping from individual metrics to the composite score. For example, $\mathbf{m}$ may be a vector of metrics computed using various data streams and models as disclosed herein. In such composite scores, in some embodiments, the constituent metrics may fall within one of temporal workflow, scheduling, human resource, or other groupings disclosed herein.

[0091] Specifically, FIG. 8 is a schematic block diagram illustrating various metrics and their relations in constructing an “ORA score” as may be performed in some embodiments. Within the temporal grouping **805**, an “efficiency” scoring metric **805a** may combine the nonoperative metrics that measure temporal workflow efficiency in an operating room (OR), e.g., the duration of one or more of the six temporal interval metrics of FIG. 5A. More specifically, the nonoperative metrics, averaged, as a mean or median, over all cases collected from a team, theater, or hospital, may be compared to the top 20% teams, theaters, or hospitals (e.g., as manually indicated by reviewers or from historical patterns via iterations of topology **450**) in a database as a benchmark. A “consistency” metric **805b** may combine (e.g., sum or find the mean or median) the standard deviations of nonoperative metrics (e.g., the six temporal interval metrics of FIG. 5A) across all cases collected from a current team, theater, or hospital. An “adverse

event” metric **805c** may combine (e.g., sum) negative outliers, e.g., as detected in terms of the interval metrics of FIGs. 5A-B. Outliers may, e.g., be detected using statistical analysis algorithms (e.g., clustering, distribution analysis, regression, etc. as discussed herein with reference to FIGs. 15, 16, 19A-B, and 20A-B). Negative outliers may be identified as those for which at least one of the nonoperative interval metrics of FIGs. 5A-B metrics are outside a threshold, such as a standard deviation, from than the relevant team, theater, or hospital median or mean (e.g., based on a threshold specified by an expert reviewer or upon historical patterns from past iterations of topology **450**). Examples of such outliers are discussed herein, e.g., with respect to FIGs. 19A-B and FIGs. 20A-B.

[0092] Within the scheduling grouping **810**, a “case volume” scoring metric **810a** includes the mean or median number of cases operated per OR, per day, for a team, theater, or hospital, normalized by the expected case volume for a typical OR (e.g., again, as designated in a historical dataset benchmark, such as a mean or median). A “first case turnovers” scoring metric **810b** is the ratio of first cases in an operating day that were turned over compared to the total number of first cases captured from a team, theater, or hospital. Alternatively, a more general “case turnovers” metric is the ratio of all cases that were turned-over compared to the total number of cases as performed by a team, in a theater, or in hospital. A “delay” scoring metric **810c** is an mean or median positive (behind a scheduled start time of an action) or negative (before a scheduled start time of an action) departure from a scheduled time in minutes for each case, normalized by the acceptable delay (e.g., a historical mean or median benchmark). Naturally, the negative or positive definition may be reversed (e.g., wherein starting late is instead negative and starting early is instead positive) if other contextual parameters are likewise adjusted.

[0093] Within the human resource metrics grouping **815**, a “headcount to complete tasks” scoring metric **815a** combines the mean or median headcount (the largest number of detected personnel throughout the procedure in the OR at one time) over all cases collected for the team, theater, or hospital needed to complete each of the temporal nonoperative tasks for each case, normalized by the recommended headcount for each task (e.g., a historical benchmark median or mean). An “OR Traffic” scoring metric **815b**

measures the mean amount of motion in the OR during each case, averaged (itself as a median or mean) over all cases collected for the team, theater, or hospital, normalized by the recommended amount of traffic (e.g., based upon a historical benchmark as described above). For example, this metric may receive (two or three-dimensional) optical flow, and convert such raw data to a single numerical value, e.g., an entropy representation, a mean magnitude, a median magnitude, etc.

[0094] Within the “other” metrics grouping **815**, a “room layout” scoring metric **820a** includes a ratio of robotic cases with multi-part roll-ups or roll-backs, normalized by the total number of robotic cases for the team, theater, or hospital. That is, ideally, each roll up or back of the robotic system would comprise a single motion. When, instead, the team member moves the robotic system back and forth, such a “multi-part” roll implies an inefficiency, and so the number of such multi-part rolls relative to all the roll up and roll back events may provide an indication of the proportion of inefficient attempts. As indicated by this example, some metrics may be unique to robotic theaters, just as some metrics may be unique to nonrobotic theaters. In some embodiments, correspondences between metrics unique to each theater-type may be specified to facilitate their comparison. A “modality conversion” scoring metric **820b** includes a ratio of cases that have both robotic and non-robotic modalities normalized by the total number of cases for the team, theater, or hospital. For example, this metric may count the number of conversions, e.g., transitioning from a planned robotic configuration to a nonrobotic configuration, and vice versa, and then dividing the total number of such cases with such a conversion by the total cases. Whether occurring in an operative or nonoperative periods, such conversions may be reflective of inefficiencies in nonoperative periods (e.g., improper actions in a prior nonoperative period may have rendered the planned robotic procedure in the operative period impractical). Thus, this metric may capture inefficiencies in planning, in equipment, or in unexpected complications in the original surgical plan.

[0095] While each of the metrics **805a-c**, **810a-c**, **815a-c**, and **820a-b** may be considered individually to assess nonoperative period performances, or in combinations of the multiple of the metrics, as discussed above with respect to EQN. 1, some embodiments consider an “ORA score” **830** reflecting an integrated **825** representation

of all these metrics. When, e.g., presented in combination with data of the duration of one or more of the intervals in FIG. 5A-C, the ORA score may provide a readily discernible means for reviewers to quickly and intuitively assess the relative performance of surgical teams, surgical theaters, hospitals and hospital systems, etc. during nonoperative periods, across theaters, across teams, across types of surgical procedures (nonoperative periods before or after prostatectomies, hernia repair, etc.), types of surgical modalities (nonoperative periods preparing for, or resetting after, nonrobotic laparoscopic procedures, nonrobotic open procedures, robotic procedures, etc.), hospital systems, etc.

[0096] Accordingly, while some embodiments may employ more complicated relationships (e.g., employing any suitable mathematical functions and operations) between the metrics **805a-c**, **810a-c**, **815a-c**, and **820a-b** in forming the ORA score **830**, in this example, each of the metrics may be weighted by a corresponding weighting value **850a-j** such that the integrating **825** is a weighted sum of each of the metrics. The weights may be selected, e.g., by a hospital administrator or reviewers in accordance with which of the metrics are discerned to be more vital to current needs for efficiency improvement. For example, in a system where reviewers wish to assess whether reports that limited staff are affecting efficiency, then the weight **850g** may be upscaled relative to the other weights. Thus, when the ORA score **830** across procedures is compared in connection with the durations of one or more of the intervals in FIG. 5A-C for the groups of surgeries, the reviewer can more readily discern if there exists a relation between the head count and undesirable interval durations. Naturally, one will appreciate other choices and combinations of weight adjustment, as well as particular consideration of specific interval durations, to assess other performance characteristics.

Example Metric Scoring Methodologies – ORA Significance Assessment

[0097] Some higher ORA composite metrics scores may positively correlate with increased system utilization u and reduced OR minutes per case t for the hospitals in a database, e.g., as represented by EQN. 2:

$$p_{s,u} = \frac{cov(s,u)}{\sigma_s \sigma_u} \geq 0.75 \quad (2)$$

[0098] Thus, the ORA composite score may be used for a variety of analysis and feedback applications. For example, the ORA composite score may be used to detect negative trends and prioritize hospitals, theaters, teams, or team members, that need workflow optimizations. The ORA composite score may also be used to monitor workflow optimizations, e.g., to verify adherence to requested adjustments, as well as to verify that the desired improvements are, in fact, occurring. The ORA composite score may also be used to provide an objective measure of efficiency for when teams perform new types of surgeries for the first time.

Example Metric Scoring Methodologies – Additional Metrics

[0099] Additional metrics to assess workflow efficiency may be generated by compositing time, staff count, and motion metrics. For example, a composite score may consider scheduling efficiency (e.g., a composite formed from one or more of case volume **810a**, first case turnovers **810b**, and case delay **810c**) and one or both of modality conversion **820b** and the duration of an “idle time” metric, which is a mean or median of the idle time (for individual members or teams collectively) over a period (e.g., during action **525b**).

[0100] Though, for convenience, sometimes described as considering the behavior of one or more team members, one will appreciate that the metrics described herein may be used to compare the performances of individual members, teams, theaters (across varying teams and modalities), hospitals, hospital systems, etc. Similarly, metrics calculated at the individual, team, or hospital level may be aggregated for assessments of a higher level. For example, to compare hospital systems, metrics for team members within each of the systems, across the system’s hospitals, may be determined, and then averaged (e.g., a mean, median, sum weighted by characteristics of the team members, etc.) for a system-to-system comparison.

Example Nonoperative Data Processing Workflow

[0101] FIG. 9A is a schematic block diagram depicting a general processing flow as may be implemented in some embodiments. Specifically, this example flow employs various machine learning consolidation systems for producing elemental OR metrics (such as temporal interval durations, personnel presence, personnel motion, equipment

motion, etc., from which other metrics, e.g., as described in FIG. 8, may be generated) from the raw multimodal theater-wide sensor data.

[0102] In some embodiments (e.g., where the data has not been pre-processed), a nonoperative segment detection module **905a** may be used to detect nonoperative segments from full-day theater-wide data. A personnel count detection module **905b** may then be used to detect a number of people involved in each of the detected nonoperative segments/activities of the theater-wide data (e.g., a spatial-temporal machine learning algorithm employing a 3D convolutional network for handling visual image and depth data over time, e.g., as appearing in video). A motion assessment module **905c** may then be used to measure the amount of motion (e.g., people, equipment, etc.) observed in each of the nonoperative segment/activities (e.g., using optical flow methods, a machine learning tracking system, etc.). A metrics generation component **905d** may then be used to generate metrics, e.g., as disclosed herein (e.g., determining as metrics the temporal durations of each of the intervals and actions of FIGs. 5A-C and the metrics as discussed in FIG. 8). While metrics results may be presented directly to the reviewer in some embodiments, as described herein, some embodiments may instead provide some initial analytical assessment of the metric values, determining standard deviations relative to historical values, prioritizing greater tolerance departures for prioritized presentation to the reviewer, determining if metric values (e.g., motion) indicate that it would be desirable to perform a more refined analysis of the data (e.g., determining team member movement paths, object collision event detections, etc.), etc. Accordingly, a metrics analysis component **905e** may then analyze the generated metrics, e.g., to determine outliers relative to historical patterns.

[0103] FIG. 9B is a schematic block diagram depicting elements in a more detailed example processing flow than the flow depicted in FIG. 9A, as may be implemented in some embodiments. One will appreciate that each depicted component may be logic or may be one or more machine learning systems, as discussed in greater detail herein. The computer system **910b** may receive the theater wide sensor data **910a** and first perform the nonoperative period detection **910c** (e.g., identifying the periods **310a**, **310b**, **310c**, **310d**, though some systems may be configured to only detect nonoperative periods of the character of periods **310b**, and **310c**). Once the portions of the theater-wide data

corresponding to the nonoperative periods have been detected, the data may then be further segmented into corresponding action tasks or intervals (e.g., the intervals **550a-d** and/or groupings **510**, **515**, **520**, **525** and respective action tasks) at block **910d**.

[0104] Using object detection (and in some embodiments, tracking) machine learning systems **910e**, the system may perform object detection using machine learning methods, such as of equipment **910f** or personnel **910h** (ellipsis **910g** indicating the possibility of other machine learning systems). In some embodiments, only personnel detection **910h** is performed, as only the number of personnel and their motion are needed for the desired metrics. Motion detection component **910i** may then analyze the objects detected at block **910e** to determine their respective motions, e.g., using various machine learning methods, optical flow, combinations thereof, etc. disclosed herein.

[0105] Using the number of objects, detected motion, and determined interval durations, a metric generation system **910j** may generate metrics (e.g., the interval durations may themselves serve as metrics, the values of FIG. 8 may be calculated, etc.). The metric values may then be analyzed via component **910k** to determine, e.g., outliers and other deviations from historical data (e.g., previous iterations of the topology **450**). The system may consider **915a**, **915c** historical sensor data **915e** and historical metrics data **915f** when performing the historical comparison at block **910k** (e.g., clustering historical metric values around efficient and inefficient nodes, then assessing the newly arrived data's distance to these nodes). In this manner, the system may infer that entire teams, groups of members, or individual members performed subpar compared to historical metrics data for similar roles, team member compositions, or individual team members. Conversely, the processed and raw theater-wide sensor data may be provided **915b** to the historical data storage **915e** for use in future analysis. Similarly, the metrics results and outlier determinations may be recorded **915d** in the historical metrics database **915f** for future reference.

[0106] The results of the analysis may then be presented via component **910l** (e.g., sent over a network to one or more of applications **550f**) for presentation to the reviewer. For example, application algorithms may consume the determined metrics and nonoperative data and propose customized actionable coaching for each individual in the

team, as well as the team as a whole, based upon metrics analysis results (though such coaching or feedback may first be determined on the computer system **910b** in some embodiments). Example recommendations include, e.g.: changes in the OR layout at various points in time, changes in OR scheduling, changes in communication systems between team members, changes in numbers of staff involved in various tasks, etc. In some embodiments, such coaching and feedback may be generated by comparing the metric values to a finite corpus of known inefficient patterns (or conversely, known efficient patterns) and corresponding remediations to be proposed (e.g., slow port placement and excess headcount may be correlated with an inefficiency resolved by reducing head count for that task).

[0107] For further clarity, FIG. 9C is a flow diagram illustrating various operations in an example overall process **920** for analyzing theater-wide data. At block **920a**, the computer system may receive the theater-wide sensor data for the theater to be examined. At block **920b**, the system may perform pre-processing on the data, e.g., reconciling theaterwide data to a common format, as when fisheye and rectilinear sensor data are both to be processed.

[0108] At block **920c**, the system may perform operative and nonoperative period recognitions, e.g., identifying each of the segments **310a-d** and **315a-c** from the raw theater wide sensor data. In some embodiments, such divisions may be recognized, or verified, via ancillary data, e.g., console data, instrument kinematics data, etc. (which may, e.g., be active only during operative periods).

[0109] The system may then iterate over the detected nonoperative periods (e.g., periods **310a**, **310b**) at blocks **920d** and **925a**. In some embodiments, operative periods may also be included in the iteration, e.g., to determine metric values that may inform the analysis of the nonoperative segments, though many embodiments will consider only the nonoperative periods. For each period, the system may identify the relevant tasks and intervals at block **925b**, e.g., the intervals, groups, and actions of FIGs. 5A-C.

[0110] At blocks **925c** and **925e**, the system may iterate over the corresponding portions of the theater data for the respectively identified tasks and intervals, performing object detections at block **925f**, motion detection at block **925g**, and corresponding

metrics generation at block **925h**. In some embodiments, at block **925f**, only a number of personnel in the theater may be determined, without determining their roles or identities. Again, the metrics may thus be generated at the action task level, as well as at the other intervals described in FIGs. 5A-C. In alternative embodiments, the metrics may simply be determined for the nonoperative period (e.g., where the duration of the intervals **550a-e** are the only metrics to be determined).

[0111] After all the relevant tasks and intervals have been considered for the current period at block **925c**, then the system may create any additional metric values (e.g., metrics including the values determined at block **925h** across multiple tasks as their component values) at block **925d**. Once all the periods have been considered at block **920d** the system may perform holistic metrics generation at block **930a** (e.g., metrics whose component values depend upon the period metrics of block **925d** and block **925h**, such as certain composite metrics described herein).

[0112] At block **930b**, the system may analyze the metrics generated at blocks **930a**, **925d**, and at block **925h**. As discussed, many metrics (possibly at each of blocks **930a**, **925h**, and **925d**) will consider historical values, e.g., to normalize the specific values here, in their generation. Similarly, at block **930b** the system may determine outliers as described in greater detail herein, by considering the metrics results in connection with historical values. Finally, at block **930c**, the system may publish its analysis for use, e.g., in applications **450f**.

Example Nonoperative Theater-Wide Data Processing – Nonoperative Data Recognition

[0113] One will appreciate a number of systems and methods sufficient for performing the operative / nonoperative period detection of components **905a** or **910c** and activity / task / interval segmentation of block **910d** (e.g., identifying the actions, tasks, or intervals of FIGs. 5A-C). Indeed, as mentioned, in some embodiments, alternative signals than the theater-wide data or monitoring of gross-signals in the theater-wide data may suffice for distinguishing periods **310a-d** from periods **315a-d**. For example, in some embodiments, a team member may provide explicit notification. Similarly, the absence of kinematics and system events data from robotic surgical systemics consoles or instruments may indicate a prolonged separation between the surgeon and patient or

between a robotic platform and the patient, which may suffice to indicate that an inter-surgical nonoperative period has begun (or provide verification of a machine learning system's parallel determination).

[0114] However, some embodiments consider instead, or in addition, employing machine learning systems for performing the nonoperative period detection. For example, some embodiments employ spatiotemporal model architectures, e.g., like a transformer architecture such as that described in Bertasius, Gedas, Heng Wang, and Lorenzo Torresani. "Is Space-Time Attention All You Need for Video Understanding?" *arXivTM preprint arXivTM:2102.05095* (2021). Such approaches may also be especially useful for automatic activity detection from long sequences of theater-wide sensor data. The spatial segment transformer architecture may be designed to learn features from frames of theater-wide data (e.g., visual image video data, depth frame video data, visual image and depth frame video data, etc.). The temporal segment may be based upon a gated recurrent unit (GRU) method and designed to learn the sequence of actions in a long video and may, e.g., be trained in a fully supervised manner (again, where data labelling may be assisted by the activation of surgical instrument data). For example, OR theater-wide data may be first annotated by a human expert to create ground truth labels and then fed to the model for supervised training.

[0115] Some embodiments may employ a two-stage model training strategy: first training the back-bone transformer model to extract features and then training the temporal model to learn a sequence. Input to the model training may be long sequences of theater-wide data (e.g., many hours of visual image video) with output time-stamps for each segment (e.g., the nonoperative segments) or activity (e.g., intervals and tasks of FIGs. 5A-C) of interest. One will appreciate that some models may operate on individual visual images, individual depth frames, groups of image frames (e.g., segments of video), groups of depth frames (e.g., segments of depth frame video), combinations of visual video and depth video, etc.

[0116] As another example, FIG. 10 is a flow diagram illustrating various operations in an example process **1005** for performing nonoperative period detection in some embodiments. Specifically, as the number of theater-wide sensors may change across

theaters, or across time in the same theater, it may be undesirable to invest in training a machine learning system configured to receive only a specific number of theater-wide data inputs. Thus, in these embodiments, where the classifier is not configured to consider the theater-wide sensor data from all the available streams at once, the system may instead consider the streams individually, or in smaller groups, and then analyze the collective results, e.g., in combination with smoothing operations, so as to assign a categorization to the segment under consideration.

[0117] For example, after receiving the theater-wide data at block **1005a** (e.g., all of three streams **325a-e**, **330a-e**, and **335a-e**) the system may iterate over the data in intervals at blocks **1005b** and **1005c**. For example, the system may consider the streams in successive segments (e.g., 30 second, one, or two minute intervals), though the data therein may be down sampled depending upon the framerate of its acquisition. For each interval of data, the system may iterate over the portion of the interval data associated with the respective sensor's streams at blocks **1010a** and **1010b** (e.g., each of streams **325a-e**, **330a-e**, and **335a-e** or groups thereof, possibly considering the same stream more than once in different groupings). For each stream, the system may determine the classification results at block **1010c** as pertaining to an operative or nonoperative interval. After all the streams have been considered, at block **1010d**, the system may consider the final classification of the interval. For example, the system may take a majority vote of the individual stream classifications of block **1010c**, resolving ties and smoothing the results based upon continuity with previous (and possibly subsequently determined) classifications.

[0118] After all the theater-wide data has been considered at block **1005b**, then at block **1015a** the system may consolidate the classification results (e.g., performing smoothing and continuity harmonization for all the data, analogous to that discussed with respect to block **1010d**, but here for larger smoothing windows, e.g., one to two hours). At block **1015b**, the system may perform any supplemental data verification before publishing the results. For example, if supplemental data indicates time intervals with known classifications, the classification assignments may be hardcoded for these true positives and the smoothing rerun.

Example Nonoperative Theater-Wide Data Processing – Object Recognition

[0119] Like nonoperative and operative theater-wide data segmentation, one will likewise appreciate a number of ways for performing object detection (e.g., at block **905b** or component **910e**). Again, in some embodiments, object detection includes merely a number of personnel count, and so a You Only Look Once (YOLO) style network (e.g., as described in Redmon, Joseph, et al. "You Only Look Once: Unified, Real-Time Object Detection." *arXivTM preprint arXivTM:1506.02640* (2015)), perhaps applied iteratively, may suffice. However, some embodiments consider using groups of visual images or depth frames. For example, some embodiments employ a transformer based spatial model to process frames of the theater-wide data, detecting all humans present and reporting the number. An example of such architecture is described in Carion, Nicolas, et al. "End-to-End Object Detection with Transformers." *arXivTM preprint arXivTM:2005.12872* (2020).

[0120] To clarify this specific approach, FIG. 11A is a schematic block diagram illustrating an example information processing flow as may be used for performing object detection in connection with some embodiments. Given a visual or depth frame image **1105f**, the system may present the image's raw pixel or depth values to a convolutional network **1105a** trained to produce image features **1105b**. These features may in turn be provided to a transformer encoder-decoder **1105c** and the bipartite matching loss **1105d** used to make predictions **1105e** for the location and number of objects (e.g., personnel or equipment) in the image, reflected here by bounding boxes within the augmented image **1105g** (one will appreciate that an actual augmented image may not be produced by the system, but rather, only indications of the object locations and, in some embodiments, of the type of object found therein).

[0121] FIG. 11B is a flow diagram illustrating various operations in an example process **1100** for performing object detection as may be used in connection with some embodiments. At block **1110a**, the system may receive the theater-wide data (visual image data, depth data, etc.). At blocks **1110b**, and **1110c**, as in the process **1005**, the system may iterate over the nonoperative periods, considering the data in discrete, successive intervals (as mentioned, in some embodiments the operative periods may be

considered as well, e.g., to verify continuity with the object detections and recognitions at the beginnings or ends of the nonoperative periods).

[0122] At blocks **1110d** and **1115a** the system may consider groups of theater-wide data. For example, some embodiments may consider every moment of data capture, whereas other embodiments may consider every other capture or captures at intervals, since some theater sensors may employ high data acquisition rates (indeed, not all sensors in the theater may apply a same rate and so normalization may be applied so as to consolidate the data). For such high rates, it may not be reasonable to interpolate object locations between data captures if the data capture rate is sufficiently larger than the movement speeds of objects in the theater. Similarly, some theater sensor's data captures may not be perfectly synchronized, or may capture data at different rates, obligating the system to interpolate or to select data captures sufficiently corresponding in time so as to perform detection and metrics calculations.

[0123] At blocks **1115b** and **1115c**, the system may consider the data in the separate theater-wide sensor data streams and perform object detection at block **1115d**, e.g., as described above with respect to FIG. 11A, or using a YOLO network, etc. After object detection has been performed for each stream for the group under consideration, the system may perform post-processing at block **1115e**. For example, if the relative poses of the theater-wide sensors are known within the theater, then their respective object detections may be reconciled to better confirm the location of the object in a three-dimensional representation. Similarly, the relative data captures may be used to verify one another's determinations and to resolve occlusions based upon temporal continuity (e.g., as when a team member occludes one sensor's perspective, but not another sensor's).

[0124] After all of the temporal groups have been considered at block **1110d**, then at block **1110e**, additional verification may be performed, e.g., using temporal information from across the intervals of block **1110d** to reconcile occlusions and lacuna in the object detections of block **1115d**. Once all the nonoperative periods of interest have been considered at block **1110b**, at block **1120a**, the system may perform holistic post-processing and verification in-filling. For example, knowledge regarding object presence

between periods or based upon a type of theater or operation may inform the expected numbers and relative locations of objects to be recognized. To this end, even though some embodiments may be interested in analyzing nonoperative periods exclusively, the beginning and end of operative periods may help inform or verify the nonoperative period object detections, and may be considered. For example, if four personnel are consistently recognized throughout an operative period, then the system should expect to identify four personnel at the end of the preceding, and the beginning of the succeeding, nonoperative periods.

Example Nonoperative Theater-Wide Data Processing – Object Tracking

[0125] As with segmentation of the raw data into nonoperative periods (e.g., as performed by nonoperative period detection component **910c**), and the detection of objects, such as personnel, within those periods (e.g., via component **910e**), one will appreciate a number of ways to perform tracking and motion detection. For example, object detection, as described, e.g., in FIG. 11B, in combination with optical flow analysis (with complementary stream perspectives resolving ambiguities) may readily be used to recognize each particular object's movement throughout the theater. As another example, some embodiments may employ multi-object machine learning tracking algorithms, which involve detecting and tracking multiple objects within a sequence of theater-wide data. These approaches may identify and locate objects of interest in each frame and then associate those objects across frames to keep track of their movements over time. For example, some embodiments may use an implementation analogous to that described in Meinhardt, Tim, et al. "TrackFormer: Multi-Object Tracking with Transformers." *arXivTM preprint arXivTM:2101.02702* (2021).

[0126] As an example in accordance with the approach of Meinhardt, et al., FIG. 12A is schematic block diagram illustrating an example tracking information processing flow as may be used in connection with some embodiments. In a first visual image or depth frame **1205a**, the system may apply a tracking framework collection **1210a** of convolution neural network, transformer encoders and decoders, and initial object detection (e.g., with the assistance of the object detection method of FIG. 11A). Iterative application **1210b** and **1210c** of the tracking framework to subsequent images or frames

1205b and **1205c** may produce object detections, such as personnel, with a record of the positions across the frames **1205a**, **1205b**, **1205c** (ellipsis **1205d** reflect the presence of intervening frames and tracking recognitions).

[0127] FIG. 12B is flow diagram illustrating various operations in an example process **1215** for performing object tracking as may be used in connection with some embodiments. At block **1215a**, the system may receive the theater-wide data, e.g., following nonoperative period identification. At blocks **1215b** and **1215c** the system may iterate over the nonoperative periods and for each period, iterate over the contemplated detection and tracking methods at blocks **1220a** and **1220b**. For each method, the sensor data streams may be considered in turn at blocks **1220c** and **1220d**, performing the applicable detection and tracking method at block **1220e** (one will appreciate that alternatively, in some embodiments, the streams may be first integrated before applying the object detection and tracking systems, as when simultaneously acquired depth frames from multiple sensors are consolidated into a single virtual model). As mentioned, some methods may benefit from considering temporal and spatial continuity across the theater-wide sensors, and so reconciliation methods for the particular tracking application may be applied at block **1220f**.

[0128] Similarly, reconciliation between the tracking methods' findings across the period may be performed at block **1225a**. For example, determined locations for objects found by the various methods may be averaged. Similarly, the number of objects may be determined by taking a majority vote among the methods, possibly weighted by uncertainty or confidence values associated with the methods. Similarly, after all the nonoperative periods have been considered, the system may perform holistic reconciliation at block **1225b**, e.g., ensuring that the initial and final object counts and locations agree with those of neighboring periods or action groups.

[0129] As one will note when comparing FIG. 12B and FIG. 9C, object detection, tracking, or motion detection may be performed at the period level (and then associated with tasks / actions / intervals for metrics calculation if desired) or may be performed after the actions, tasks, or intervals have been identified, and upon corresponding data specifically.

Example Nonoperative Theater-Wide Data Processing – Motion Assessment

[0130] While some tracking systems may readily facilitate motion analysis at motion detection component **910i**, some embodiments may alternatively, or in parallel, perform motion detection and analysis using visual image and depth frame data. In some embodiments, simply the amount of motion (in magnitude, regardless of its direction component) within the theater in three-dimensional space of any objects, or of only objects of interest, may be useful for determining meaningful metrics during nonoperative periods. However, more refined motion analysis may facilitate more refined inquiries, such as team member path analysis, collision detection, etc.

[0131] As an example optical-flow based motion assessment, FIG. 13A is a schematic visual image **1305a** and depth frame **1305b** theater-wide data pair, with an indication of the optical-flow derived correspondence as may be used in some embodiments. Specifically, the data processing system may review sequences of visual image data to detect optical flow. Here, the system has detected that the team member **1310b** is moving from the right to the left of the image as indicated by arrow **1310a** and by the pixel border around the pixels having optical flow around team member **1310b**.

[0132] While some embodiments may consider motion based upon the optical flow from visual images alone, it may sometimes be desirable to “standardize” the motion. Specifically, turning to FIG. 13C, movement **1345a** far from the camera, as shown in image **1340a** may result in a smaller number of pixels (the pixels depicting the member **1350a**) being associated with the optical flow. Conversely, as shown in image **1340b**, when the team member **1350b** is very close to the sensor, their motion **1345b** may result in an optical flow affecting many more pixels.

[0133] Rather than allow the number of visual image pixels involved in the flow to affect the motion determination, some embodiments may standardize the motion associated with the optical flow to three-dimensional space. That is, with reference to FIG. 13D, the motions **1345a** and **1345b** may be the same in magnitude in three-dimensional space, as the team members move from locations **1355a**, **1360a** to locations **1355b**, **1360b**, respectively. While the locations **1360a-b** are a smaller distance **1370b** from the sensor **1365** than the distance **1370a** from the sensor **1365** to the locations

1355a-b, some embodiments may seek to identify the same amount of motion **1345a**, **1345b** in each instance. Specifically, downstream metrics may treat the speed of the motions **1345a**, **1345b** equally, regardless of their distance from the capturing sensor.

[0134] To accomplish this, returning to FIG. 13A, for each portion of the visual image **1305a** associated with the optical flow, the system may consider the corresponding portions of the simultaneously acquired depth image **1305b**, here, where the team member **1310b** and their motion, indicated by arrow **1315a**, will also be manifest. That is, in this example the pixels **1310c** associated with the optical flow may correspond **1320** to the depth values **1315c**. By considering these depth values **1320**, the system may infer the distance to the object precipitating the optical flow (e.g., one of distances **1370b** and **1370a**). That is, with reference to FIG. 13B, the system may be able to infer the “standardized” motion **1325c** in three-dimensional space for the object moving from position **1325a** to position **1325b**, once the distances **1330a** and **1330b** from the capturing sensor **1335** have been inferred from the depth data. In some embodiments, in lieu of first detecting optical flow in the two-dimensional visual image, optical flow in the three-dimensional depth data may instead be used and the standardized motion determined *mutatis mutandis*.

[0135] FIG. 14 is a flow diagram illustrating various operations in an example process **1400** for performing motion analysis from theater-wide data, as may be applied in some embodiments. At blocks **1405b** and **1405c**, the system may iterate over the theater-wide data received at block **1405a**. For example, theater-wide data may be down sampled and considered in discrete data sets of temporally successive visual image and depth frame pairs. Where one or more optical flow artifacts (contiguous regions with optical flow above a threshold are detected in either the visual images or the depth frames) are detected within the data set at block **1405d**, the system may iterate over the artifacts at blocks **1410a** and **1410b**. Many artifacts may not correspond to objects of interest for preparing metrics. For example, incidental motion of some equipment, adjustment of some lights, opening of some doors, etc., may not be relevant to the downstream analysis. Accordingly, at block **1410c**, the system may verify that the artifact is associated with one or more of the objects of interest (e.g., the personnel or equipment detected using the methods disclosed herein via the machine learning systems of

component **910e**, e.g., including the systems and methods of FIGs. 11A-B and 12A-B). for example, pixels corresponding to the optical flow may be compared with pixels identified in, e.g., a YOLO network object detection. In some cases, a single optical flow artifact may be associated with more than one object, e.g., when one moving object occludes another moving object. Assessment of the corresponding depth values may reveal the identities of the respective objects appearing in the artifact or at least their respective locations and trajectories.

[0136] Thus, where the artifact corresponds to an object of interest (e.g., team personnel), then at block **1415a**, the system may determine the corresponding depth values and may standardize the detected motion at block **1415b** to be in three-dimensional space (e.g., the same motion value regardless of the distance from the sensor) rather than in the two-dimensional plane of a visual image optical flow, e.g., using the techniques discussed herein with respect to FIGs. 13A-D. The resulting motion may then be recorded at block **1415c** for use in subsequent metrics calculation as discussed in greater detail herein.

Example Nonoperative Theater-Wide Metrics Analysis – Outlier Detection

[0137] Following metrics generation (e.g., at metric generation system **910j**) some embodiments may seek to recognize outlier behavior (e.g., at metric analysis system **910k**) to detect outliers in each team / operating room / hospital / etc. based upon the above metrics, including the durations of the actions and intervals in FIGs. 5A-C, the numbers of people involved in each theater and the amount of motion observed, etc. For example, FIG. 15 is flow diagram illustrating various operations in an example process **1500** for outlier analysis based upon the determined metric values, as may be implemented in some embodiments.

[0138] At block **1505a**, the system may acquire historical datasets, e.g., for use with metrics having component values (such as normalizations) based upon historical data. At block **1505b**, the system may determine metrics results for nonoperative period as a whole (e.g., cumulative motion within the period, regardless of whether it occurred in association with any particular task or interval). At block **1505c**, the system may determine metrics results for specific tasks and intervals within each of the nonoperative

segments (e.g., the durations of actions and intervals in FIGs. 5A-C). At block **1505d**, the system may then determine composite metric values from the previous of the determined metrics (e.g., the ORA score **830** discussed in FIG. 8).

[0139] At block **1505e**, clusters of metric values corresponding to patterns of inefficient or efficient nonoperative theater states, as well as clusters of metric values corresponding to patterns of efficient or positive nonoperative theater states, may be included in the historical data of block **1505a**. Such clusters may be used both to find metric scores, and patterns of metrics scores, distance from ideal clusters and distance from undesirable clusters (e.g., where the distance is the Euclidean distance and each metric of a group is considered as a separate dimension).

[0140] Thus, the system may the iterate over the metrics individually, or in groups, at blocks **1510a** and **1510b** to determine if the metrics or groups exceed a tolerance at block **1510c** relative to the historical data clusters (naturally, the nature of the tolerance may change with each expected grouping and may be based upon a historical benchmark, such as one or more standard deviations from a median or mean). Where such tolerance is exceeded (e.g., metric values or groups of metric values are either too close to inefficient clusters or too far from efficient clusters), the system may document the departure at block **1510d** for future use in coaching and feedback as described herein.

[0141] For clarity, as mentioned, the cluster may occur in an N dimensional space where there are N respective metrics considered in the group (though alternative spaces and surfaces for comparing metric values may also be used). Such an algorithm may be applied to detect outliers for each team / operating room / hospital based upon the above metrics. Cluster algorithms (e.g., based upon K-means, using machine learning classifiers, etc.) may both reveal groupings and identify outliers, the former for recognizing common inefficient / efficient patterns in the values, and the latter for recognizing, e.g., departures from ideal performances or acceptable avoidance of undesirable states.

[0142] Thus the system may determine whether the metrics individually, or in groups, are associated (e.g., within a threshold distance of, such as the cluster's standard deviation, larges principal component, etc.) with an inefficient, or efficient, cluster at block **1515a**, and if so, document the cluster for future coaching and feedback at block **1515b**.

For example, raw metric values, composite metric values, outliers, distances to or from clusters, correlated remediations, etc., may be presented in a GUI interface, e.g., as will be described herein with respect to FIGs. 17 or 18A-C.

Example Nonoperative Data Analysis – Coaching

[0143] Following outlier detection and clustering, in some embodiments, the system may also seek to consolidate the results into a form suitable for use by feedback and coaching (e.g., by the applications **550f**). For example, remediating actions may already be known for tolerance breaches (e.g., at block **1510c**) or nearness to adverse metrics clusters (e.g., at block **1515a**). Here, coaching may, e.g., simply include the known remediation when reporting the breach or clustering association.

[0144] Some embodiments may recognize higher level associations in the metric values, from which remediations may be proposed. For example, after considering a new dataset from a theater in a previously unconsidered hospital, various embodiments may determine that a specific surgical specialty (e.g., Urology) in that theater, possesses a large standard deviation in its nonoperative time metrics. Various algorithms disclosed herein may consume such large standard deviations, other data points, and historical data and suggest corrective action regarding with scheduling or staffing model. For example, a regression model may be used that employs historical data to infer potential solutions based upon the data distribution.

[0145] As another example, FIG. 16 is flow diagram illustrating various operations in an example process **1600** for providing coaching feedback based upon the determined metric values, as may be implemented in some embodiments. While focusing on relations between metric values and adverse / inefficient patterns in this example, one will appreciate variations that instead determine relations to desirable / efficient patterns (with corresponding remediations when the metrics depart too far from these preferred states). Similarly, in some embodiments, metrics and groups of metrics may be directly compared to known patterns without first identifying tolerance departures and cluster distances, as in the example process **1600**.

[0146] Here, at blocks **1615a** and **1615b**, the system may iterate over all the previously identified tolerance departures (e.g., as determined at block **1510c**) for the

groupings of one or more metric results and consider whether they correspond with a known inefficient pattern at block **1615c** (e.g., taking an inner product with the metric values with a known inefficient vector). For example, a protracted “case open to patient in” duration in combination with certain delay **810c** and case volume **810a** values, may, e.g., be indicative of a scheduling inefficiency where adjusting the scheduling regularly resolves the undesirable state. Note that the metric or metrics used for mapping to inefficient patterns for remediation may, or may not, be the same as the metric or metrics, which departed from the tolerance (e.g., at block **1615a**) or approached the undesirable clustering (e.g., at block **1620a**), e.g., the latter may instead indicate that the former may correspond to an inefficient pattern. For example, an outlier in one duration metric from FIG. 5A may imply an inefficient pattern derived from a combinations of metrics from FIG. 8.

[0147] Accordingly, the system may iterate through the possible inefficient patterns at blocks **1615c** and **1615d** to consider how the corresponding metric values resemble the inefficient pattern. For example, the Euclidean distance from the metrics to the pattern may be taken at block **1615e**. At block **1615f**, the system may record the similarity (e.g., the distance) between the inefficient pattern and the metrics group associated with the tolerance departure.

[0148] Similarly, following consideration of the tolerance departures, the system may consider metrics score combinations with clusters near adverse / inefficient events (e.g., as determined at block **1515a**) at blocks **1620a** and **1620b**. As was done previously, the system may iterate over the possible known inefficient patterns at blocks **1620c** and **1620d**, again determining the inefficient pattern correspondence to the respective metric values (which may or may not be the same group of metric values identified in the cluster association of block **1620a**) at block **1620e** (again, e.g., the Euclidean or other appropriate similarity metric) and recording the degree of correspondence at block **1620f**.

[0149] Based upon the distances and correspondences determined at blocks **1615e** and **1620e**, respectively, the system may determine a priority ordering for the detected inefficient patterns at block **1625a**. At block **1625b**, the system may return the most significant threshold number of inefficient pattern associations. For example, each

inefficient pattern may be associated with a priority (e.g., high priority modes may be those with a potential for causing a downstream cascade of inefficiencies, patient harm, damage to equipment, etc., whereas lower priority modes may simply lead to temporal delays) and presented accordingly to reviewers. Consequently, each association may be scored as a weighted sum of a similarity between the score metric values and metric values associated with inefficient pattern and then weighted by the severity / priority of the inefficient pattern. In this manner, the most significant of the possible failures may be identified and returned first to the reviewer. The iterative nature of topology **450** may facilitate reconsideration and reweighting of the priorities for process **1600** as reviewers observe the impact of the proposed feedback over time. Similarly, the iterations may provide opportunities to identify additional remediation and inefficient pattern correspondences.

Example GUI Nonoperative Metrics Analysis Feedback Elements

[0150] Presentation of the analysis results, e.g., at block **910I**, may take a variety of forms in various embodiments. For example, FIG. 17 is a schematic representation of GUI elements in a quick review dashboard interface for nonoperative metrics review as may be implemented in some embodiments. In this example GUI **1705**, selectors **1710a-d** are provided for the user to select the temporal range of nonoperative period performance data that they wish to analyze. In this example, the user has selected to review the data captured during the past year. Following such a temporal selection, a “Nonoperative Metrics” region, a “Case Mix” region, and a “Metadata” region may be populated with values corresponding to the nonoperative periods for the selected range of data.

[0151] The “Case Mix” region may provide a general description of the data filtered from the temporal selection. Here, for example, there are 205 total cases (nonoperative periods) under consideration as indicated by label **1715a**. A decomposition of those 205 cases is then provided by type of surgery via labels **1715b-d** (specifically, that of the 205 nonoperative periods, 15 were associated with preparation for open surgeries, 180 with preparation for a robotic surgery, and 10 with preparation for a laparoscopic surgery). The nonoperative periods under consideration may be those occurring before and after

the 205 surgeries, only those before, or only those after, etc., depending upon the user's selection.

[0152] The "Metadata" region may likewise be populated with various parameters describing the selected data, such as the number of operating rooms involved (8 per label **1720a**), the number of specialties (4 per label **1720b**), the number of procedure types (10 per label **1720c**) and the number of different surgeons involved in the surgeries (27 per label **1720d**).

[0153] Within the "Nonoperative Metrics" region, a holistic composite score, such as an ORA score, may be presented in region **1725a** using the methods described herein (e.g., as described with respect to FIG. 8). Regions **1725b-f** may show corresponding statistics for the intervals of FIG. 5A, here, values for various intervals of FIG. 5A.

[0154] Some embodiments may also present scoring metrics results comprehensively, e.g., to allow reviewers to quickly scan the feedback and to identify effective and ineffective aspects of the nonoperative theater performance. For example, FIG. 18A is a schematic representation of a GUI element **1805** as may be used for global quick review feedback in some embodiments. Specifically, individual metrics score values, composite metric scores, departures from tolerances, nearness to desirable or undesirable clustering, etc. may be indicated in a numerical region **1805d**. The name of the metrics, etc., may be indicated in the name region **1805a** and a desired feedback in region **1805b**. A quick review icon **1805e** may also be included to facilitate ready identification of the nature of the numerical feedback. A quality relation arrow region **1805c** may be used to indicate whether the numerical value in region **1805d** is above or below an operational point or tolerance, or trending upward or downward over time, and whether this is construed as indicative of improving or decreasing efficiency.

[0155] Specifically, FIG. 18B is a schematic representation of arrow elements as may be used in the quality relation arrow region **1805c** of FIG. 18A in some embodiments. The arrow may be, e.g., color-coded to indicate whether the value is efficient (e.g., green) or inefficient (e.g., red). Thus, a rising arrow **1810a** may indicate that the value in region **1805d** is above a lower bound (e.g., when an idle time following successful completion of a task has increased above a historical average). Similarly, the falling arrow **1810b** may

indicate that the value in region **1805d** is below an upper bound (e.g., when an preparation time has decreased below a historical average). Conversely, a falling arrow **1810c** may indicate that the value in region **1805d** is below a desired minimum value (e.g., when a number of personnel ready for a required step is below a historical average). Similarly, the rising arrow **1810d** may indicate that the value in region **1805d** is above a desired upper bound (e.g., when an preparation time has increased beyond a historical average).

[0156] By associating relational value both with the arrow direction and highlighting (such as by color, bolding, animation, etc.), reviewers may readily scan a large number of values and discern results indicating efficient or inefficient feedback. Highlighting may also take on a variety of degrees (e.g., alpha values, degree of bolding, frequency of an animation, etc.) to indicate a priority associated with an efficient or inefficient value. For example, FIG. 18C is a schematic representation of GUI elements in a quick review feedback interface **1820** as may be used in some embodiments. Here, the individual quick review feedbacks (instances of the element **1805**) may be arranged in a grid and sized so that the reviewer may perceive multiple items at one time. Each element may be selectable, presenting details for the value determination, including, e.g., the corresponding historical data, theater-wide data, intermediate metrics calculation results, etc. One will appreciate that the figure is merely schematic and each “Action” or “Feedback” text may be replaced with one of the metrics described herein (e.g., a duration of intervals from FIGs. 5A-C) and remediations, respectively (though in some configurations the feedback may be omitted from all or some of the elements).

[0157] FIG. 19A is a plot of example analytic values as acquired in connection with a prototype implementation of an embodiment. Specifically, FIG. 19A shows results following processing for various of the intervals of FIG. 5A. Here, an outlier value **1905a** clearly indicates a deviation in the “skin close to patient out” interval from the median duration of ~10 minutes (taking instead approximately ~260 minutes). FIG. 19B is similarly a plot of example operating room analytic values as acquired in connection with a prototype implementation of an embodiment. Here, standard deviation intervals may be shown to guide the reviewer in recognizing outlier values (e.g., whether they reflect a longer or shorter duration than the standard deviation interval).

[0158] FIG. 20A is a plot of example values as acquired in connection with a prototype implementation of an embodiment. Even without performing the outlier detection and inefficient pattern recognition methods disclosed herein, one can readily determine by inspection that various of the values are outliers. For example, within the “case open to patient in” interval, the cases **2005a-c** clearly indicate outliers above the standard deviation. For the “patient in to skin cut” interval, the case **2010a** is shorter than the standard deviation interval. For the “skin close to patient out” interval, the cases **2015a-b** were outside the standard deviation for the selected historical cases. For the “patient out to case open” interval, the case **2020a** lies far outside the standard deviation for the selected historical cases. For the “wheels out to wheels in” interval, the cases **2025a** and **2025b** lie outside the standard deviation for the selected historical cases. FIG. 20B is similarly a plot of example operating room analytic values as acquired in connection with a prototype implementation of an embodiment.

[0159] Similarly, FIG. 21A is a plot of example operating room analytic values as acquired in connection with an example prototype implementation of an embodiment. FIG. 21B is a plot of example operating room analytic values as acquired in connection with an example prototype implementation of an embodiment, in a horizontal format. FIG. 21C is also a plot of example operating room analytic values as acquired in connection with an example prototype implementation of an embodiment.

[0160] FIG. 22 is a schematic representation of example elements in a graphical user interface for providing metrics-derived feedback, as may be used in some embodiments. In this example, the interface generally comprises two elements: a theater-wide sensor playback element **2205**; and a consolidated timeline element **2210** depicting the durations of various intervals within a plurality of nonoperative periods. For example, each of temporal interval breakdowns **2210a-g** may indicate the durations of intervals **550a-d** for ready comparison (though seven periods are shown in this example, one may readily envision variations with many more rows, as well as more instances of playback element **2205**).

[0161] Within the theater-wide sensor playback element **2205** may be a metadata section **2205a** indicating the identity of the case (“Case 1”), the state of the theater (though

a surgical operation “Gastric Bypass”, is shown here, in anticipation of the upcoming surgery, the nonoperative actions and intervals of FIG. 5A-C may be shown here additionally or alternatively), the date and time of the data acquisition (“May 27, 20XX 07:49:42”) and the number of identified personnel (here “2” as determined, e.g., in accordance with component **910h** and, e.g., the methods of FIGs. 11A-B). The theater-wide sensor playback element **2205** may also display the data from one or more theater-wide sensors in the playback section **2205b** with bounding boxes (e.g., boxes **2205c** and **2205d**), overlays, outlines, or other suitable indications of the personnel detected. In the consolidated timeline element **2210** a plurality of temporal intervals **2210a-g** may be rendered, indicating, e.g., a plurality of interval durations (e.g., the durations of intervals **550a-d** for seven nonoperative periods). The playback in the region **2205** may correspond to a selection of one of the intervals in the temporal interval breakdowns **2210a-g** (e.g., depicting corresponding theater-wide data playback for that interval). In this manner, the reviewer may readily perceive a corpus of results while simultaneously analyzing the state of a specific instance (e.g., as may have been called to the user’s attention based upon, e.g., correspondingly determined metric values or pattern similarities).

Computer System

[0162] FIG. 23 is a block diagram of an example computer system as may be used in conjunction with some of the embodiments. The computing system **2300** may include an interconnect **2305**, connecting several components, such as, e.g., one or more processors **2310**, one or more memory components **2315**, one or more input/output systems **2320**, one or more storage systems **2325**, one or more network adaptors **2330**, etc. The interconnect **2305** may be, e.g., one or more bridges, traces, busses (e.g., an ISA, SCSI, PCI, I2C, Firewire bus, etc.), wires, adapters, or controllers.

[0163] The one or more processors **2310** may include, e.g., an Intel™ processor chip, a math coprocessor, a graphics processor, etc. The one or more memory components **2315** may include, e.g., a volatile memory (RAM, SRAM, DRAM, etc.), a non-volatile memory (EPROM, ROM, Flash memory, etc.), or similar devices. The one or more input/output devices **2320** may include, e.g., display devices, keyboards, pointing

devices, touchscreen devices, etc. The one or more storage devices **2325** may include, e.g., cloud-based storages, removable Universal Serial Bus (USB) storage, disk drives, etc. In some systems memory components **2315** and storage devices **2325** may be the same components. Network adapters **2330** may include, e.g., wired network interfaces, wireless interfaces, Bluetooth™ adapters, line-of-sight interfaces, etc.

[0164] One will recognize that only some of the components, alternative components, or additional components than those depicted in FIG. 23 may be present in some embodiments. Similarly, the components may be combined or serve dual-purposes in some systems. The components may be implemented using special-purpose hardwired circuitry such as, for example, one or more ASICs, PLDs, FPGAs, etc. Thus, some embodiments may be implemented in, for example, programmable circuitry (e.g., one or more microprocessors) programmed with software and/or firmware, or entirely in special-purpose hardwired (non-programmable) circuitry, or in a combination of such forms.

[0165] In some embodiments, data structures and message structures may be stored or transmitted via a data transmission medium, e.g., a signal on a communications link, via the network adapters **2330**. Transmission may occur across a variety of mediums, e.g., the Internet, a local area network, a wide area network, or a point-to-point dial-up connection, etc. Thus, “computer readable media” can include computer-readable storage media (e.g., “non-transitory” computer-readable media) and computer-readable transmission media.

[0166] The one or more memory components **2315** and one or more storage devices **2325** may be computer-readable storage media. In some embodiments, the one or more memory components **2315** or one or more storage devices **2325** may store instructions, which may perform or cause to be performed various of the operations discussed herein. In some embodiments, the instructions stored in memory **2315** can be implemented as software and/or firmware. These instructions may be used to perform operations on the one or more processors **2310** to carry out processes described herein. In some embodiments, such instructions may be provided to the one or more processors **2310** by downloading the instructions from another system, e.g., via network adapter **2330**.

[0167] For clarity, one will appreciate that while a computer system may be a single machine, residing at a single location, having one or more of the components of FIG. 23, this need not be the case. For example, distributed network computer systems may comprise multiple individual processing workstations, each workstation having some, or all, of the components depicted in FIG. 23. Processing and various operations described herein may accordingly be spread across the one or more workstations of such a computer system. For example, one will appreciate that a process amenable to being run in a single thread upon a single workstation may instead be separated into an arbitrary number of sub-threads across one or more workstations, such sub-threads then run in serial or in parallel to achieve a same, or substantially similar, result as the process run within the single thread. Similarly, one will appreciate that while a non-transitory computer readable medium may stand alone (e.g., in a single USB storage device), or reside within a single workstation (e.g., in the workstation's random access memory or disk storage), such a medium need not reside at a single geographic location, but may include, e.g., multiple memory storage units residing across geographically separated workstations of a computer system in network communication with one another or across geographically separated storage devices.

Remarks

[0168] The drawings and description herein are illustrative. Consequently, neither the description nor the drawings should be construed so as to limit the disclosure. For example, titles or subtitles have been provided simply for the reader's convenience and to facilitate understanding. Thus, the titles or subtitles should not be construed so as to limit the scope of the disclosure, e.g., by grouping features which were presented in a particular order or together simply to facilitate understanding. Unless otherwise defined herein, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure pertains. In the case of conflict, this document, including any definitions provided herein, will control. A recital of one or more synonyms herein does not exclude the use of other synonyms. The use of examples anywhere in this specification including examples of any term discussed herein is illustrative only and is not intended to further limit the scope and meaning of the disclosure or of any exemplified term.

[0169] Similarly, despite the particular presentation in the figures herein, one skilled in the art will appreciate that actual data structures used to store information may differ from what is shown. For example, the data structures may be organized in a different manner, may contain more or less information than shown, may be compressed and/or encrypted, etc. The drawings and disclosure may omit common or well-known details in order to avoid confusion. Similarly, the figures may depict a particular series of operations to facilitate understanding, which are simply exemplary of a wider class of such collection of operations. Accordingly, one will readily recognize that additional, alternative, or fewer operations may often be used to achieve the same purpose or effect depicted in some of the flow diagrams. For example, data may be encrypted, though not presented as such in the figures, items may be considered in different looping patterns ("for" loop, "while" loop, etc.), or sorted in a different manner, to achieve the same or similar effect, etc.

[0170] Reference herein to "an embodiment" or "one embodiment" means that at least one embodiment of the disclosure includes a particular feature, structure, or characteristic described in connection with the embodiment. Thus, the phrase "in one embodiment" in various places herein is not necessarily referring to the same embodiment in each of those various places. Separate or alternative embodiments may not be mutually exclusive of other embodiments. One will recognize that various modifications may be made without deviating from the scope of the embodiments.

CLAIMS

We claim:

1. A computer-implemented method for assessing team member performance during a nonoperative period in a surgical theater, the method comprising:
 - detecting a team member from theater-wide data acquired during the nonoperative period;
 - determining a motion of the team member; and
 - determining a first metric result based, at least in part, upon the motion of the team member.
2. The computer-implemented method of Claim 1, wherein the theater-wide data comprises theater-wide visual image data and theater-wide depth data.
3. The computer-implemented method of Claim 2, wherein, the team member is associated with a role performed in the theater, and wherein, detecting the team member comprises determining that the team member is associated with the role.
4. The computer-implemented method of Claim 3, the method further comprising:
 - detecting an interval in the theater-wide data;
 - determining a duration of the interval; and
 - determining a second metric result based, at least in part, upon the duration of the interval.
5. The computer-implemented method of Claim 4, wherein the interval comprises one of:
 - a skin close to patient out interval;
 - a patient out to case open interval;
 - a case open to patient in interval;

a patient in to skin cut interval; and
a wheels out to wheels in interval.

6. The computer-implemented method of Claim 4, wherein the method further comprises:
determining a third metric result, the third metric result comprising at least one of:
a metric result associated with temporal workflow;
a metric result associated with scheduling; and
a metric result associated with human resources.

7. The computer-implemented method of Claim 6, wherein determining the third metric result comprises determining one or more of:
an Efficiency metric result;
a Consistency metric result;
an Adverse Events metric result;
a Case Volume metric result;
a First Case Turnovers metric result;
a Delay metric result;
an OR Traffic metric result;
a Room Layout metric result; and
a Modality Conversion metric result.

8. The computer-implemented method of Claim 6, wherein the third metric result comprises a composite score result, the composite score result determined based upon one or more of the following component results:
an Efficiency metric result;
a Consistency metric result;
an Adverse Events metric result;
a Case Volume metric result;
a First Case Turnovers metric result;
a Delay metric result;

an OR Traffic metric result;
a Room Layout metric result; and
a Modality Conversion metric result.

9. The computer-implemented method of Claim 8, wherein the composite score result is a weighted average of one or more of the component results.

10. The computer-implemented method of Claim 6, wherein the method further comprises:

determining a duration of an action in the theater-wide data; and
determining a fourth metric result based upon the duration of the action.

11. The computer-implemented method of Claim 10, wherein the method further comprises:

determining, from the theater-wide data, a number of personnel in the theater during at least a portion of the nonoperative period; and
determining a fifth metric result based upon the determined number of personnel.

12. The computer-implemented method of Claim 11, wherein the method further comprises:

detecting an inefficiency, at least in part, by comparing:
a cluster of historical metric results; and
a group of metric results comprising two or more of:
the first metric result;
the second metric result;
the third metric result;
the fourth metric result; and
the fifth metric result.

13. The computer-implemented method of Claim 12, wherein detecting an inefficiency, comprises:

determining a distance in a space having dimensions corresponding to the metric results of the group of metric results, the distance between:

at least a portion of the cluster of historical metric results; and
a point associated with the group of metric results.

14. The computer-implemented method of Claim 12, wherein detecting an inefficiency, comprises:

determining that a point associated with the group of metric results exceeds a standard deviation from the cluster of historical metric results.

15. The computer-implemented method of one of Claims 1-14, wherein determining the motion of the team member comprises:

determining an optical flow of at least a portion of the theater-wide data;
determining that the optical flow of the at least a portion of the theater-wide data corresponds to the team member; and
determining a standardized motion associated with the optical flow.

16. The computer-implemented method of one of Claims 1-14, wherein determining the motion of the team member comprises:

applying a transformer-based attention model to at least a portion of the theater-wide data.

17. The computer-implemented method of one of Claims 1-14, wherein the method further comprises:

distinguishing the nonoperative period in the theater-wide data from an operative period in the theater-wide data using a transformer configured to implement a gated recurrent unit method for detecting nonoperative periods in theater-wide data.

18. The computer-implemented method of one of Claims 1-14, wherein detecting the team member comprises:

applying a transformer-based spatial model to at least a portion of the theater-wide data.

19. The computer-implemented method of one of Claims 4-14, wherein detecting the interval in the theater-wide data comprises:

applying a transformer configured to implement a gated recurrent unit method to at least a portion of the theater-wide data.

20. The computer-implemented method of one of Claims 11-14, wherein the method further comprises:

determining the number of personnel in the theater during the at least the portion of the nonoperative period comprises applying a transformer based spatial model configured to process theater-wide data.

21. A non-transitory computer-readable medium comprising instructions configured to cause at least one computer system to perform a method for assessing team member performance during a nonoperative period in a surgical theater, the method comprising:

detecting a team member from theater-wide data acquired during the nonoperative period;

determining a motion of the team member; and

determining a first metric result based, at least in part, upon the motion of the team member.

22. The non-transitory computer-readable medium of Claim 21, wherein the theater-wide data comprises theater-wide visual image data and theater-wide depth data.

23. The non-transitory computer-readable medium of Claim 22, wherein, the team member is associated with a role performed in the theater, and wherein,

detecting the team member comprises determining that the team member is associated with the role.

24. The non-transitory computer-readable medium of Claim 23, the method further comprising:

- detecting an interval in the theater-wide data;
- determining a duration of the interval; and
- determining a second metric result based, at least in part, upon the duration of the interval.

25. The non-transitory computer-readable medium of Claim 24, wherein the interval comprises one of:

- a skin close to patient out interval;
- a patient out to case open interval;
- a case open to patient in interval;
- a patient in to skin cut interval; and
- a wheels out to wheels in interval.

26. The non-transitory computer-readable medium of Claim 24, wherein the method further comprises:

- determining a third metric result, the third metric result comprising at least one of:
 - a metric result associated with temporal workflow;
 - a metric result associated with scheduling; and
 - a metric result associated with human resources.

27. The non-transitory computer-readable medium of Claim 26, wherein determining the third metric result comprises determining one or more of:

- an Efficiency metric result;
- a Consistency metric result;
- an Adverse Events metric result;
- a Case Volume metric result;

- a First Case Turnovers metric result;
- a Delay metric result;
- an OR Traffic metric result;
- a Room Layout metric result; and
- a Modality Conversion metric result.

28. The non-transitory computer-readable medium of Claim 26, wherein the third metric result comprises a composite score result, the composite score result determined based upon one or more of the following component results:

- an Efficiency metric result;
- a Consistency metric result;
- an Adverse Events metric result;
- a Case Volume metric result;
- a First Case Turnovers metric result;
- a Delay metric result;
- an OR Traffic metric result;
- a Room Layout metric result; and
- a Modality Conversion metric result.

29. The non-transitory computer-readable medium of Claim 28, wherein the composite score result is a weighted average of one or more of the component results.

30. The non-transitory computer-readable medium of Claim 26, wherein the method further comprises:

- determining a duration of an action in the theater-wide data; and
- determining a fourth metric result based upon the duration of the action.

31. The non-transitory computer-readable medium of Claim 30, wherein the method further comprises:

- determining, from the theater-wide data, a number of personnel in the theater during at least a portion of the nonoperative period; and

determining a fifth metric result based upon the determined number of personnel.

32. The non-transitory computer-readable medium of Claim 31, wherein the method further comprises:

detecting an inefficiency, at least in part, by comparing:

a cluster of historical metric results; and

a group of metric results comprising two or more of:

the first metric result;

the second metric result;

the third metric result;

the fourth metric result; and

the fifth metric result.

33. The non-transitory computer-readable medium of Claim 32, wherein detecting an inefficiency, comprises:

determining a distance in a space having dimensions corresponding to the metric results of the group of metric results, the distance between:

at least a portion of the cluster of historical metric results; and

a point associated with the group of metric results.

34. The non-transitory computer-readable medium of Claim 32, wherein detecting an inefficiency, comprises:

determining that a point associated with the group of metric results exceeds a standard deviation from the cluster of historical metric results.

35. The non-transitory computer-readable medium of one of Claims 21-34, wherein determining the motion of the team member comprises:

determining an optical flow of at least a portion of the theater-wide data;

determining that the optical flow of the at least a portion of the theater-wide data corresponds to the team member; and

determining a standardized motion associated with the optical flow.

36. The non-transitory computer-readable medium of one of Claims 21-34, wherein determining the motion of the team member comprises:

applying a transformer-based attention model to at least a portion of the theater-wide data.

37. The non-transitory computer-readable medium of one of Claims 21-34, wherein the method further comprises:

distinguishing the nonoperative period in the theater-wide data from an operative period in the theater-wide data using a transformer configured to implement a gated recurrent unit method for detecting nonoperative periods in theater-wide data.

38. The non-transitory computer-readable medium of one of Claims 21-34, wherein detecting the team member comprises:

applying a transformer-based spatial model to at least a portion of the theater-wide data.

39. The non-transitory computer-readable medium of one of Claims 24-34, wherein detecting the interval in the theater-wide data comprises:

applying a transformer configured to implement a gated recurrent unit method to at least a portion of the theater-wide data.

40. The non-transitory computer-readable medium of one of Claims 31-34, wherein the method further comprises:

determining the number of personnel in the theater during the at least the portion of the nonoperative period comprises applying a transformer based spatial model configured to process theater-wide data.

41. A computer system, the computer system comprising:
at least one processor; and

at least one memory, the at least one memory comprising instructions configured to cause the computer system to perform a method for assessing team member performance during a nonoperative period in a surgical theater, the method comprising:

- detecting a team member from theater-wide data acquired during the nonoperative period;
- determining a motion of the team member; and
- determining a first metric result based, at least in part, upon the motion of the team member.

42. The computer system of Claim 41, wherein the theater-wide data comprises theater-wide visual image data and theater-wide depth data.

43. The computer system of Claim 42, wherein, the team member is associated with a role performed in the theater, and wherein, detecting the team member comprises determining that the team member is associated with the role.

44. The computer system of Claim 43, the method further comprising:
detecting an interval in the theater-wide data;
determining a duration of the interval; and
determining a second metric result based, at least in part, upon the duration of the interval.

45. The computer system of Claim 44, wherein the interval comprises one of:
a skin close to patient out interval;
a patient out to case open interval;
a case open to patient in interval;
a patient in to skin cut interval; and
a wheels out to wheels in interval.

46. The computer system of Claim 44, wherein the method further comprises:

determining a third metric result, the third metric result comprising at least one of:
a metric result associated with temporal workflow;
a metric result associated with scheduling; and
a metric result associated with human resources.

47. The computer system of Claim 46, wherein determining the third metric result comprises determining one or more of:

- an Efficiency metric result;
- a Consistency metric result;
- an Adverse Events metric result;
- a Case Volume metric result;
- a First Case Turnovers metric result;
- a Delay metric result;
- an OR Traffic metric result;
- a Room Layout metric result; and
- a Modality Conversion metric result.

48. The computer system of Claim 46, wherein the third metric result comprises a composite score result, the composite score result determined based upon one or more of the following component results:

- an Efficiency metric result;
- a Consistency metric result;
- an Adverse Events metric result;
- a Case Volume metric result;
- a First Case Turnovers metric result;
- a Delay metric result;
- an OR Traffic metric result;
- a Room Layout metric result; and
- a Modality Conversion metric result.

49. The computer system of Claim 48, wherein the composite score result is a weighted average of one or more of the component results.

50. The computer system of Claim 46, wherein the method further comprises:
determining a duration of an action in the theater-wide data; and
determining a fourth metric result based upon the duration of the action.

51. The computer system of Claim 50, wherein the method further comprises:
determining, from the theater-wide data, a number of personnel in the theater during at least a portion of the nonoperative period; and
determining a fifth metric result based upon the determined number of personnel.

52. The computer system of Claim 51, wherein the method further comprises:
detecting an inefficiency, at least in part, by comparing:
a cluster of historical metric results; and
a group of metric results comprising two or more of:
the first metric result;
the second metric result;
the third metric result;
the fourth metric result; and
the fifth metric result.

53. The computer system of Claim 52, wherein detecting an inefficiency, comprises:
determining a distance in a space having dimensions corresponding to the metric results of the group of metric results, the distance between:
at least a portion of the cluster of historical metric results; and
a point associated with the group of metric results.

54. The computer system of Claim 52, wherein detecting an inefficiency, comprises:

determining that a point associated with the group of metric results exceeds a standard deviation from the cluster of historical metric results.

55. The computer system of one of Claims 41-54, wherein determining the motion of the team member comprises:

- determining an optical flow of at least a portion of the theater-wide data;
- determining that the optical flow of the at least a portion of the theater-wide data corresponds to the team member; and
- determining a standardized motion associated with the optical flow.

56. The computer system of one of Claims 41-54, wherein determining the motion of the team member comprises:

- applying a transformer-based attention model to at least a portion of the theater-wide data.

57. The computer system of one of Claims 41-54, wherein the method further comprises:

- distinguishing the nonoperative period in the theater-wide data from an operative period in the theater-wide data using a transformer configured to implement a gated recurrent unit method for detecting nonoperative periods in theater-wide data.

58. The computer system of one of Claims 41-54, wherein detecting the team member comprises:

- applying a transformer-based spatial model to at least a portion of the theater-wide data.

59. The computer system of one of Claims 44-54, wherein detecting the interval in the theater-wide data comprises:

- applying a transformer configured to implement a gated recurrent unit method to at least a portion of the theater-wide data.

60. The computer system of one of Claims 51-54, wherein the method further comprises:

determining the number of personnel in the theater during the at least the portion of the nonoperative period comprises applying a transformer based spatial model configured to process theater-wide data.

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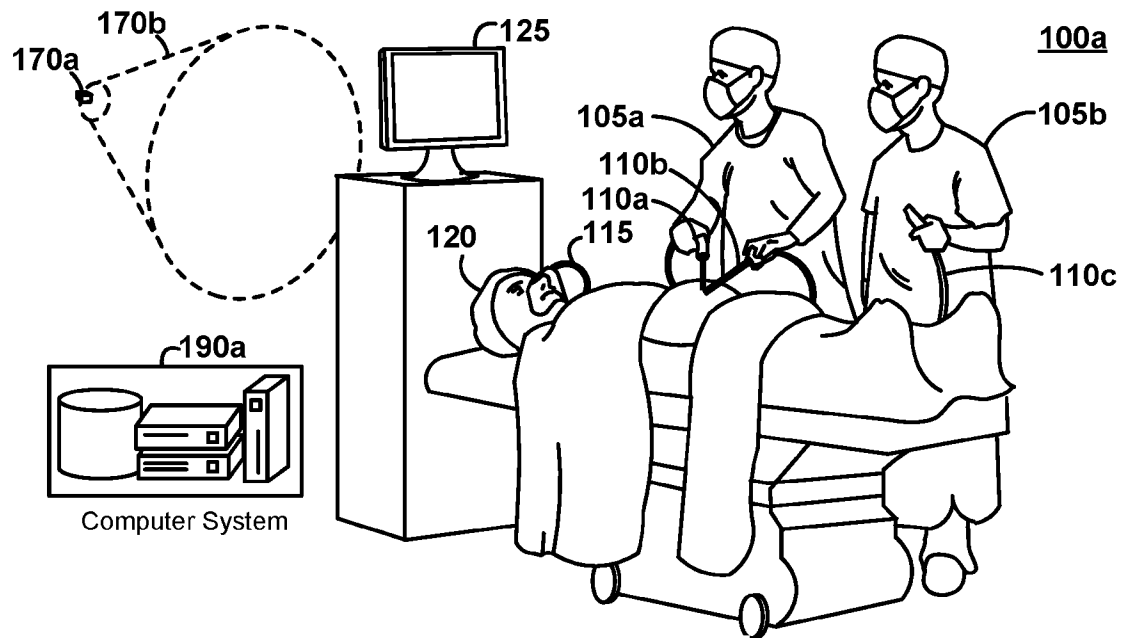


FIG. 1A

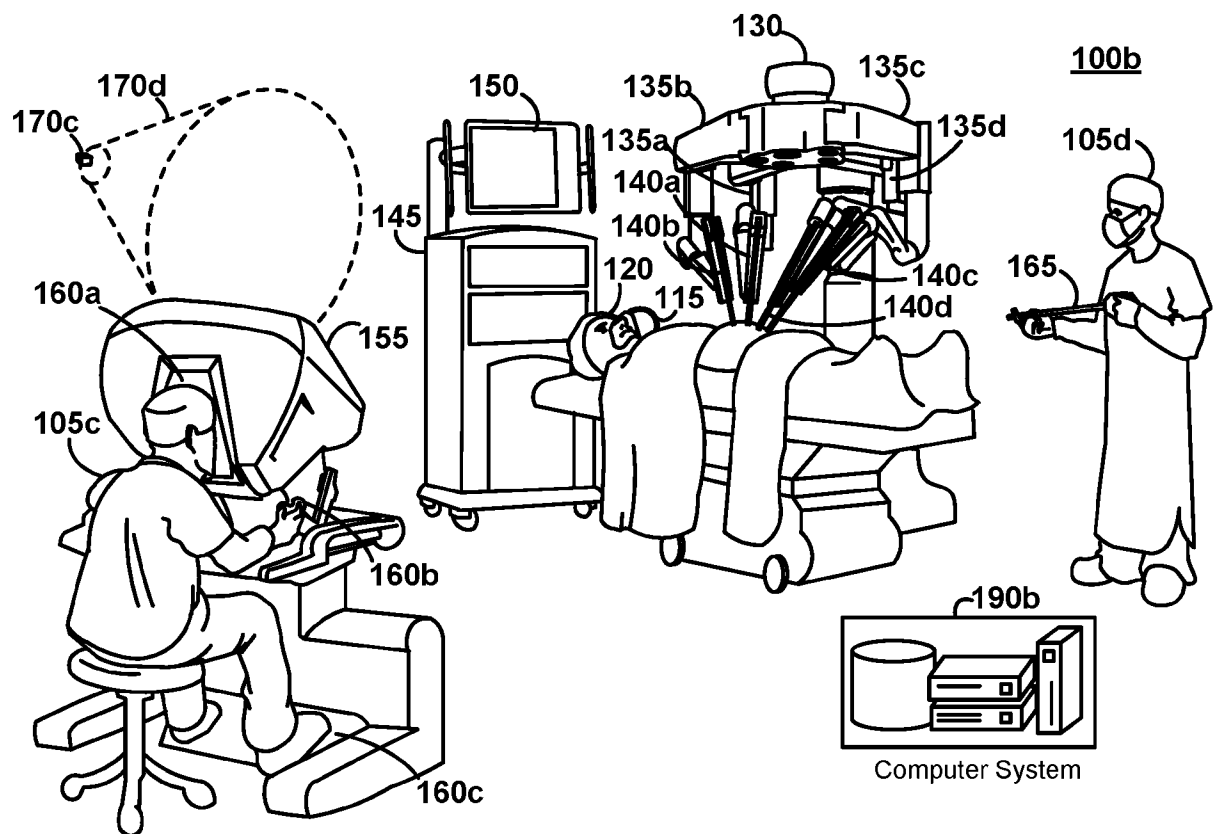


FIG. 1B

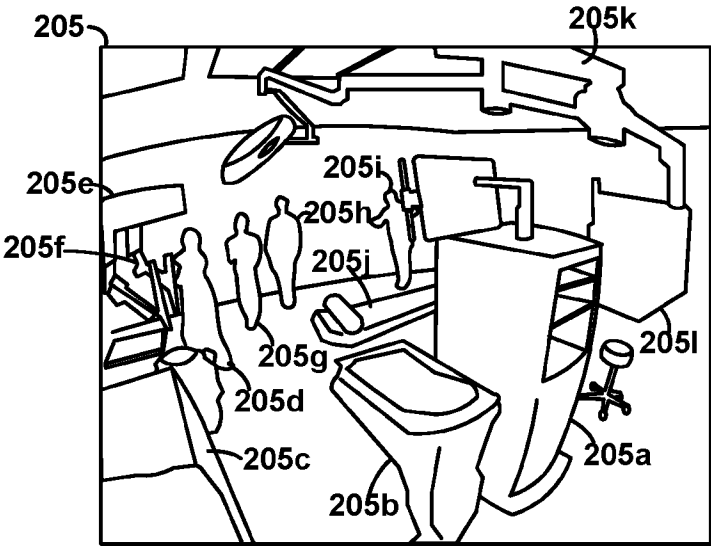


FIG. 2A

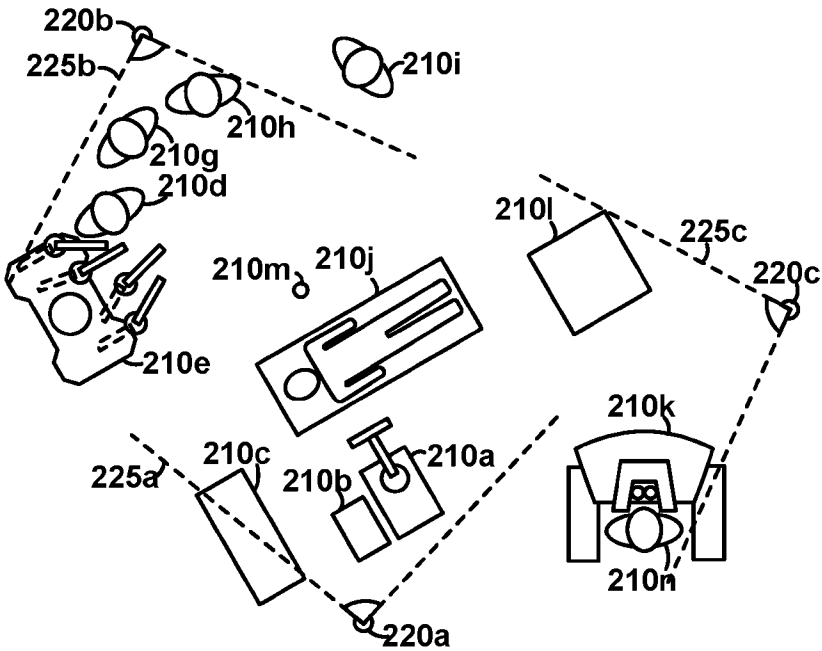


FIG. 2B

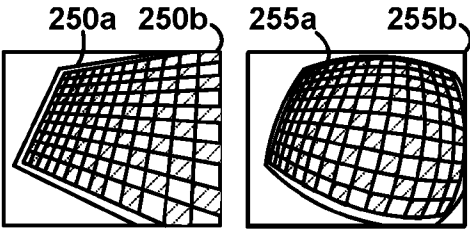


FIG. 2C

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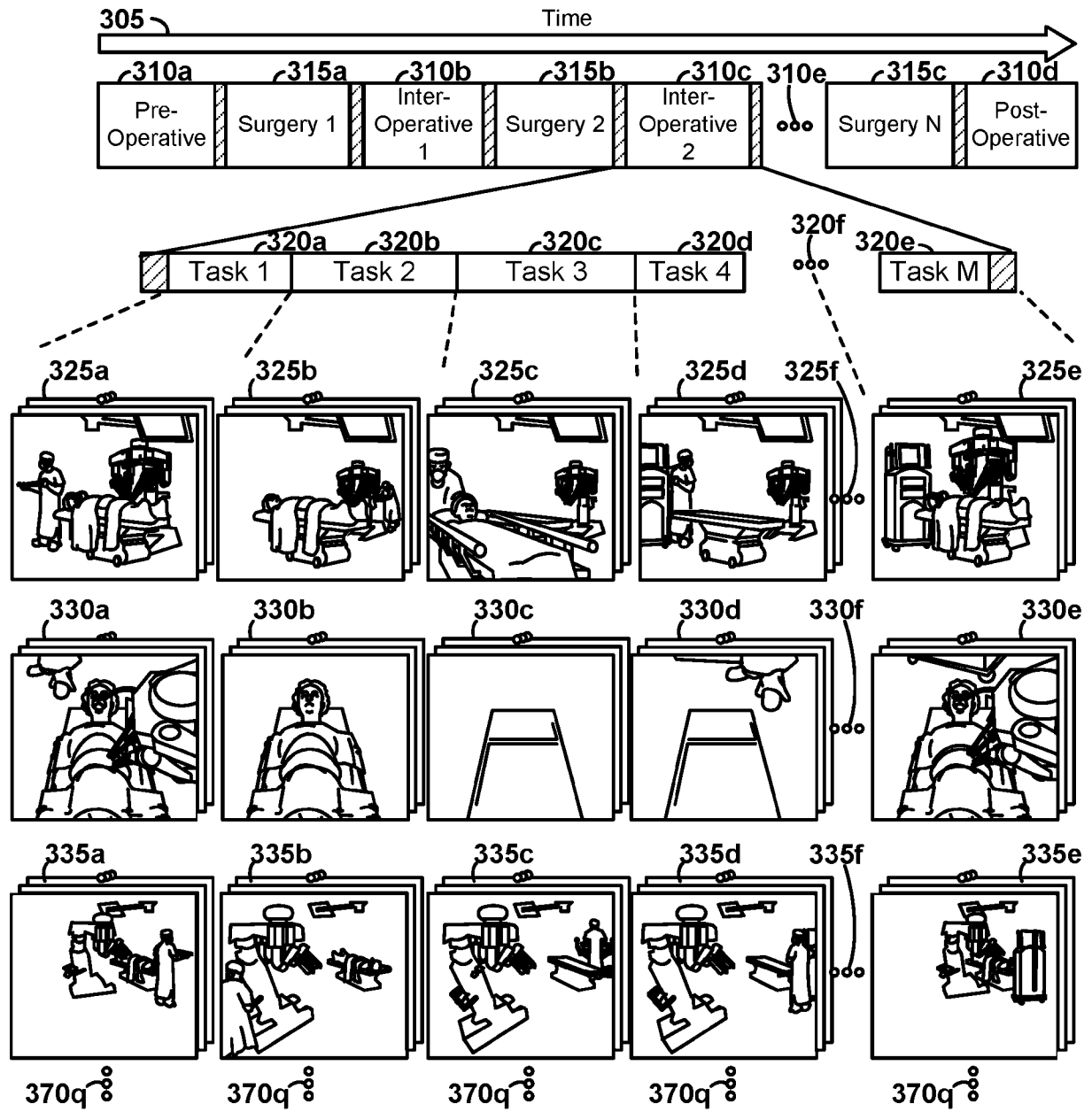


FIG. 3

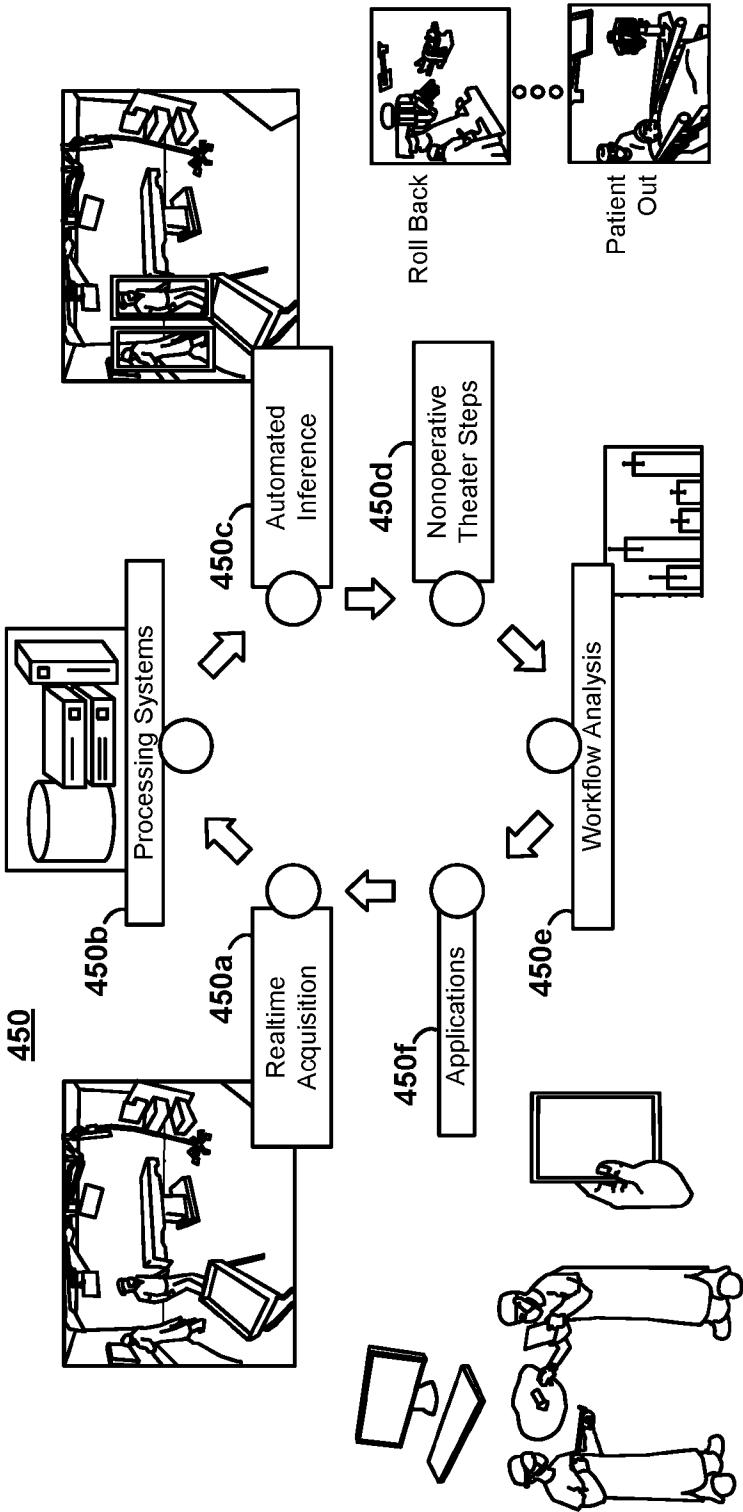


FIG. 4

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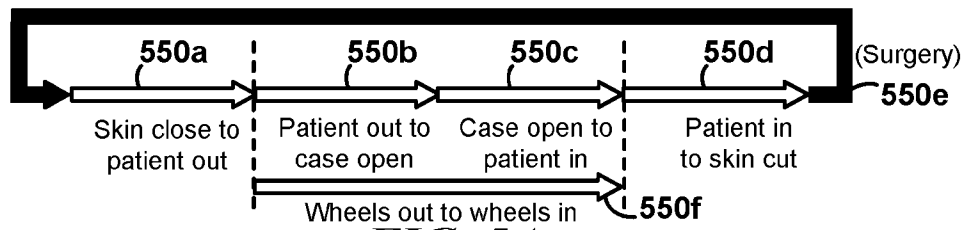


FIG. 5A

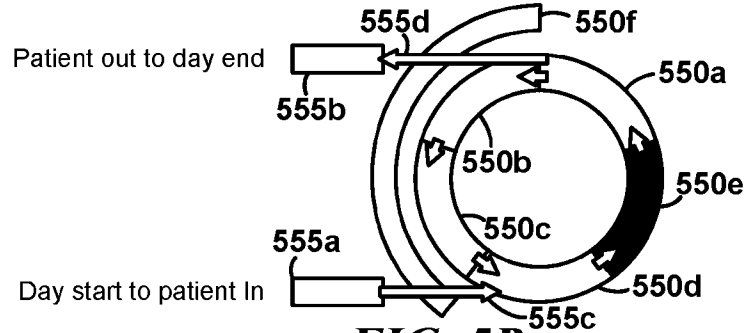


FIG. 5B

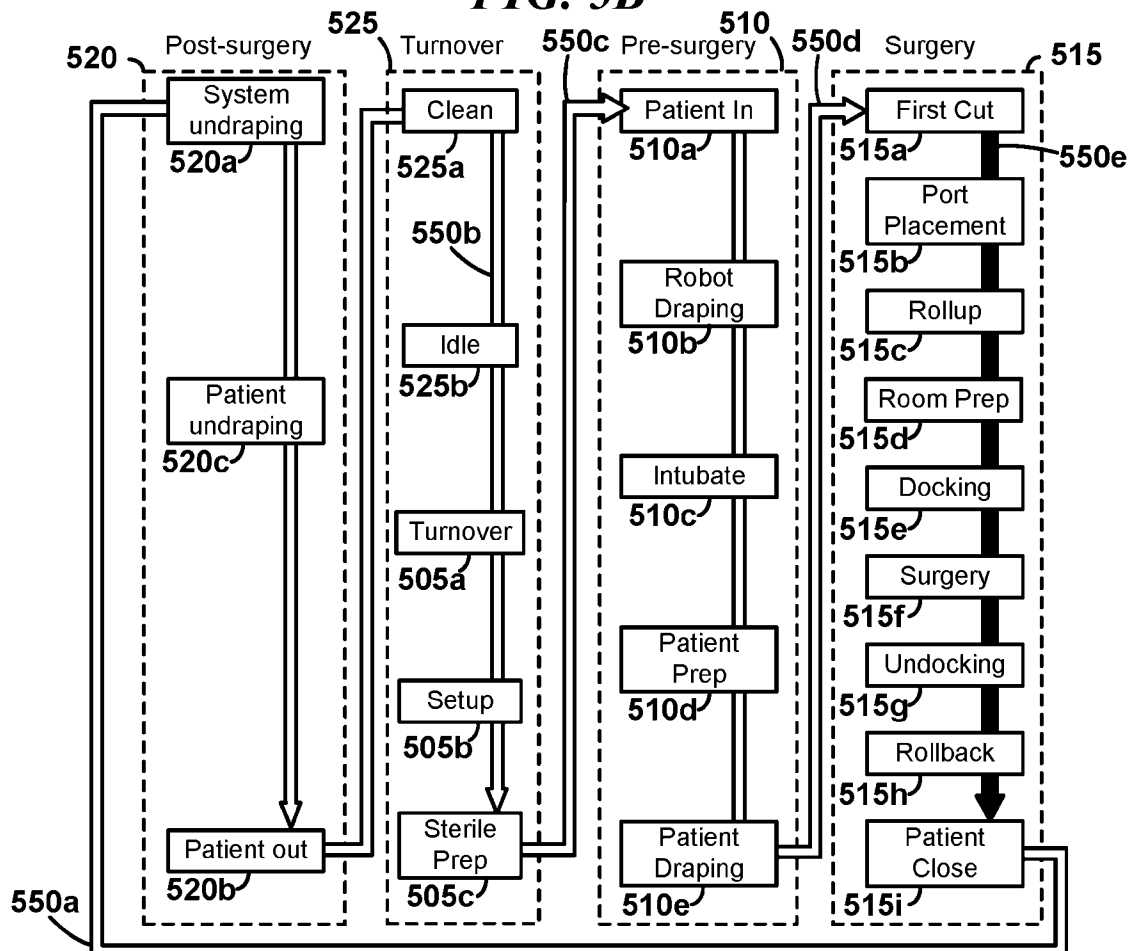


FIG. 5C

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	Activity	Start	End
605a	First Cut (within Patient Prep)	When the surgeon reaches for the scalpel	When surgeon has completed first incision
605b	Port Placement (within Patient Prep)	After first cut has been made	When all ports have been placed and the surgeon is done placing ports
605c	Roll Up	When robot starts to be pushed	When robot is finished being pushed
605d	Room Prep (within Patient Prep)	When the first light or monitor is moved out of the way	When the last light or monitor is moved out of the way
605e	Docking	When rollup ends	When all arms are docked and surgeon leaves patient side (e.g., when surgeon takes off their gown)
615a	Turnover	When patient is rolled out	When next patient is rolled in
615b	Set Up (within Turnover)	When cleaning from previous case is over	When first sterile item is opened
615c	Sterile Prep (within Turnover)	When the first sterile package is opened	When scrub tech is done prepping sterile items for the case
620a	Patient In	When the patient is wheeled in	When the empty gurney is wheeled out
620b	Robot Draping (within Turnover within sterile prep)	When the first arm starts being draped	When all arms have been draped (e.g., when cover/blanket drape is put on)
620c	Intubate (within Patient Prep)	When anesthesiologist tilts patients head back	When stylet is removed
620d	Patient Prep	When the patient is on the OR table	When port placement ends
620e	Patient Draping (within Patient Prep)	When drape is initially placed on patient	When patient is fully draped (usually when head tent is formed)

FIG. 6

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	Activity	Start	End
705a	Surgery	When the surgeon walks away from the table/finishes docking	When the surgeon leaves the console
705b	Lap Surgery	When port placement ends	Before patient close begins
705c	Open Surgery	After first cut	Before patient close begins
705d	Undocking	When surgeon leaves the console	When roll back begins
705e	Roll Back	When the robot is first pulled back	When robot is no longer being pulled back from the table
705f	Patient Close	When surgeon looks at the patient during roll back	When surgeon finished looking and working on the patient (typically ends in patient draping)
705g	Robot Undrapping	When first drape starts to be removed	When all drapes have been removed
705h	Patient Out	When the empty gurney is wheeled into the room	When the patient is wheeled out of the room
705i	Patient Undrapping	When first drapes are removed from patient after patient close has ended	When all drapes have been removed
705j	Clean (within Turnover)	When cleaning begins	When room has been mopped and no more cleaning is happening
705k	Idle (Within Turnover)	When no activity is taking place in the OR during turnover	When any activity starts up again
720a	Imaging	When a team member first starts interacting with the machine (start draping or moving)	When the team members are done interacting with the machine
720b	Walk in	When the patient walks in	When patient prep starts

FIG. 7

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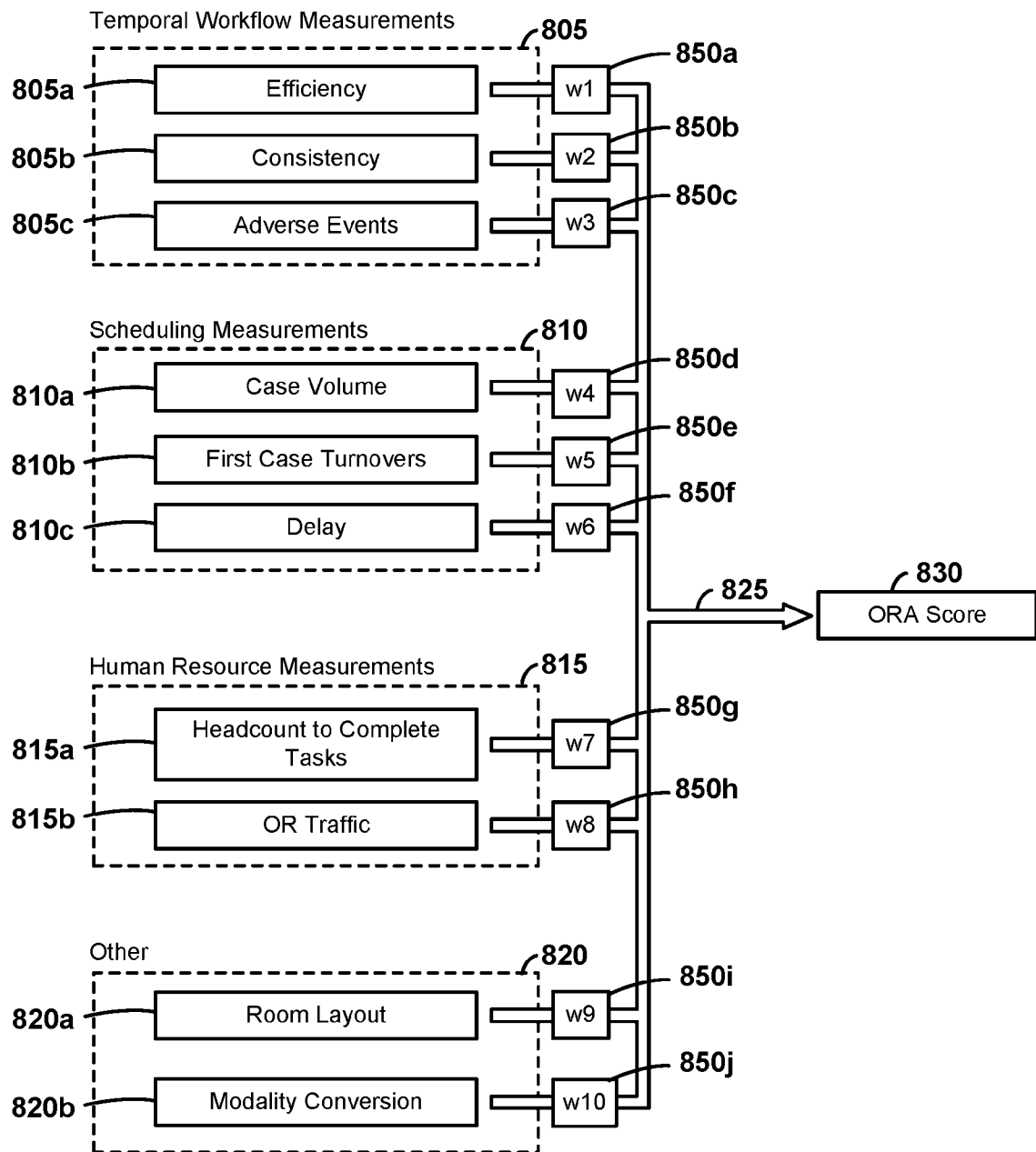


FIG. 8

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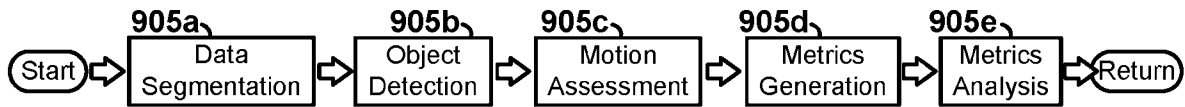


FIG. 9A

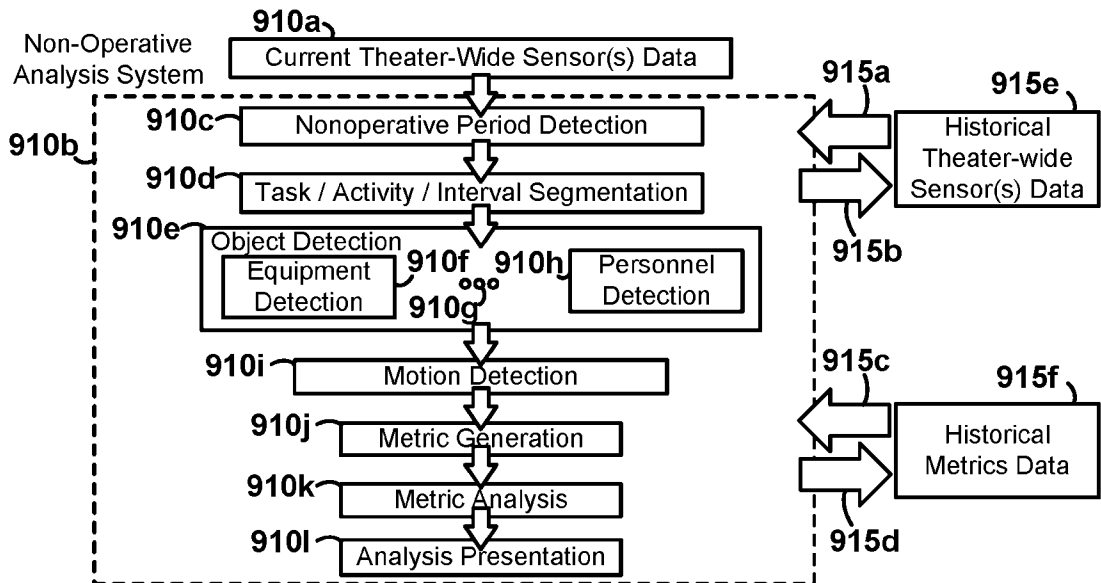


FIG. 9B

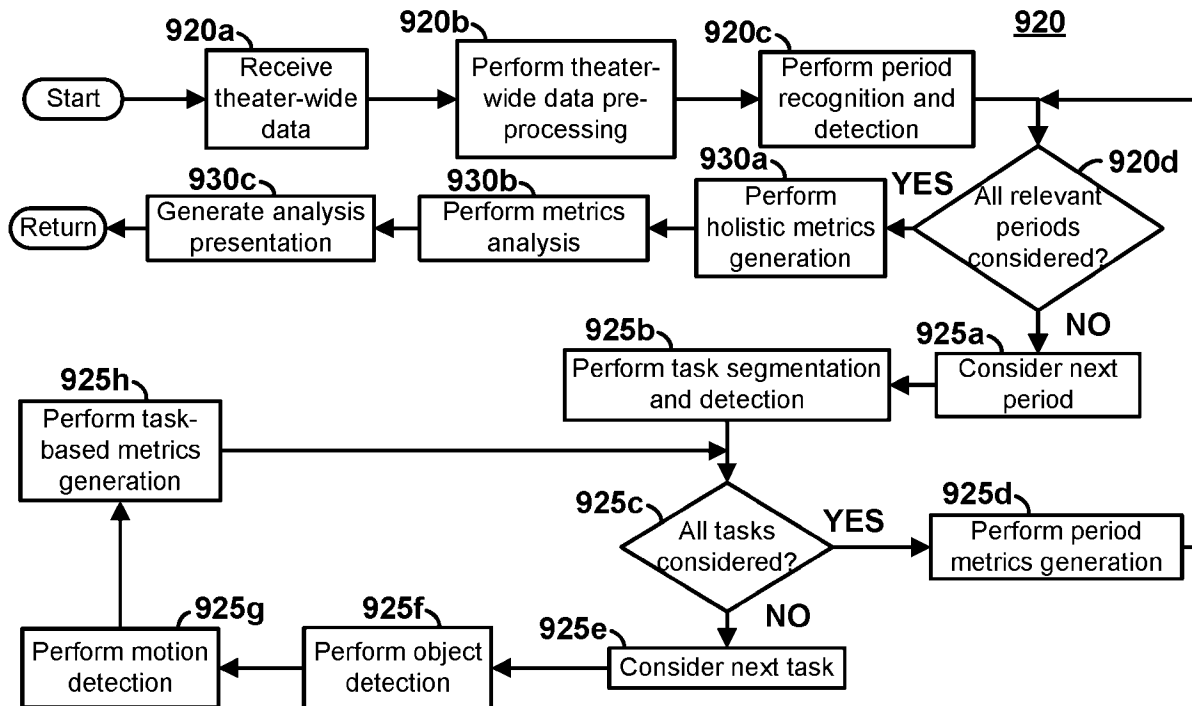


FIG. 9C

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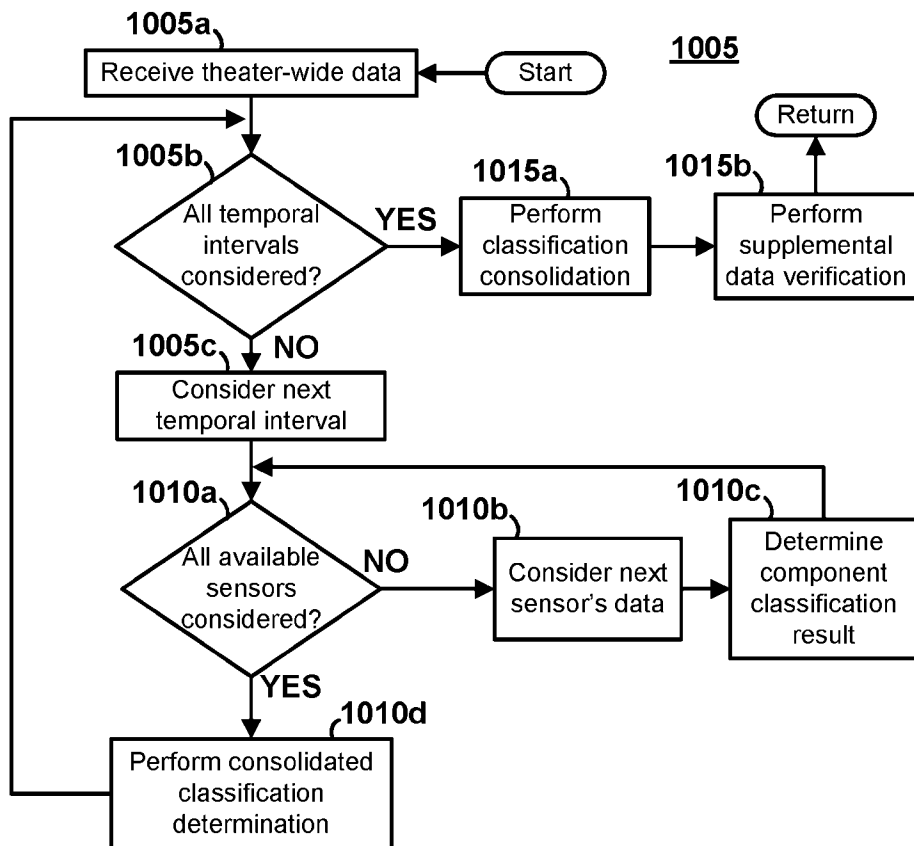


FIG. 10

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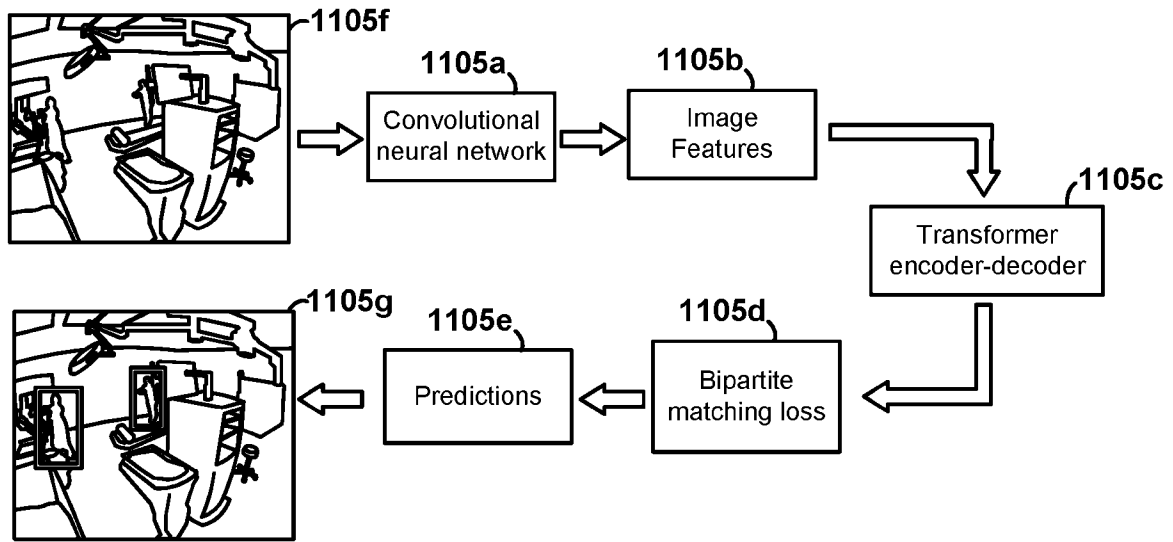


FIG. 11A

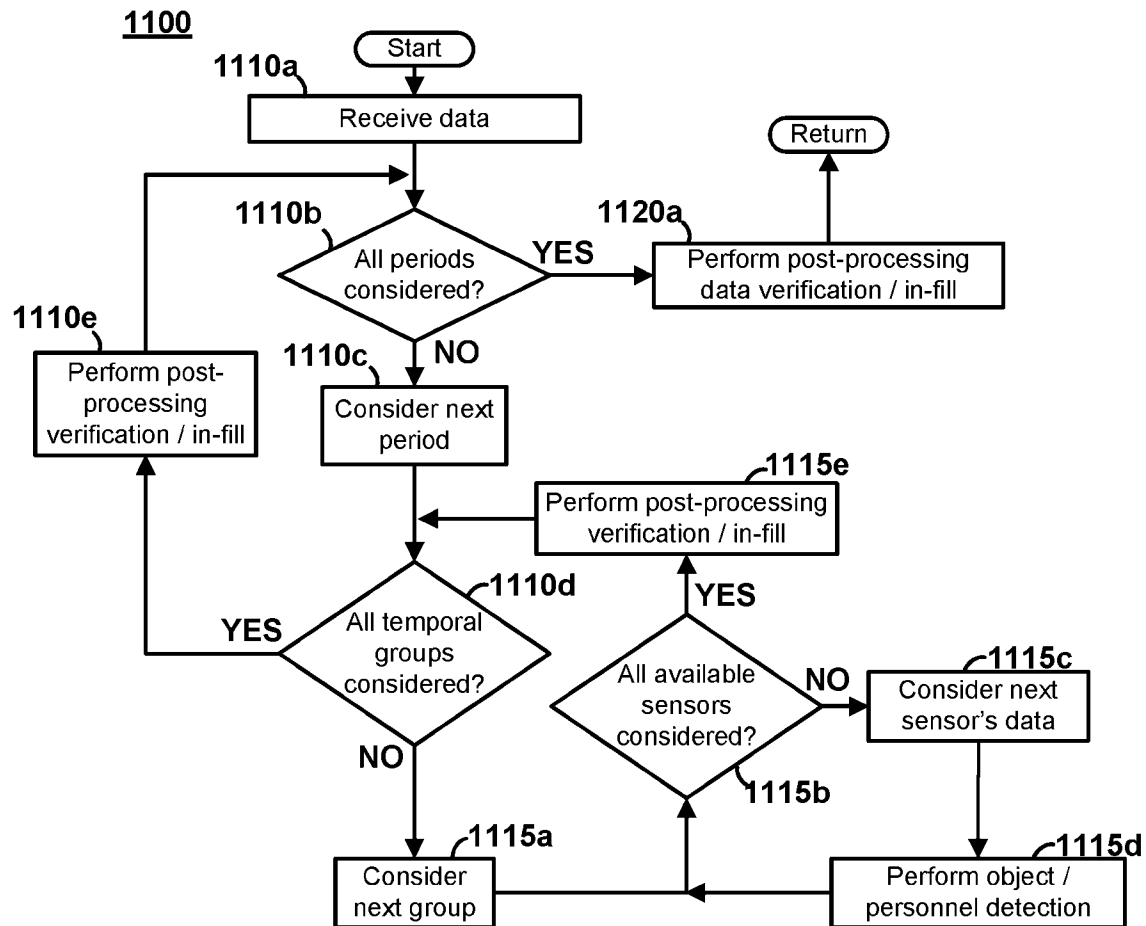


FIG. 11B

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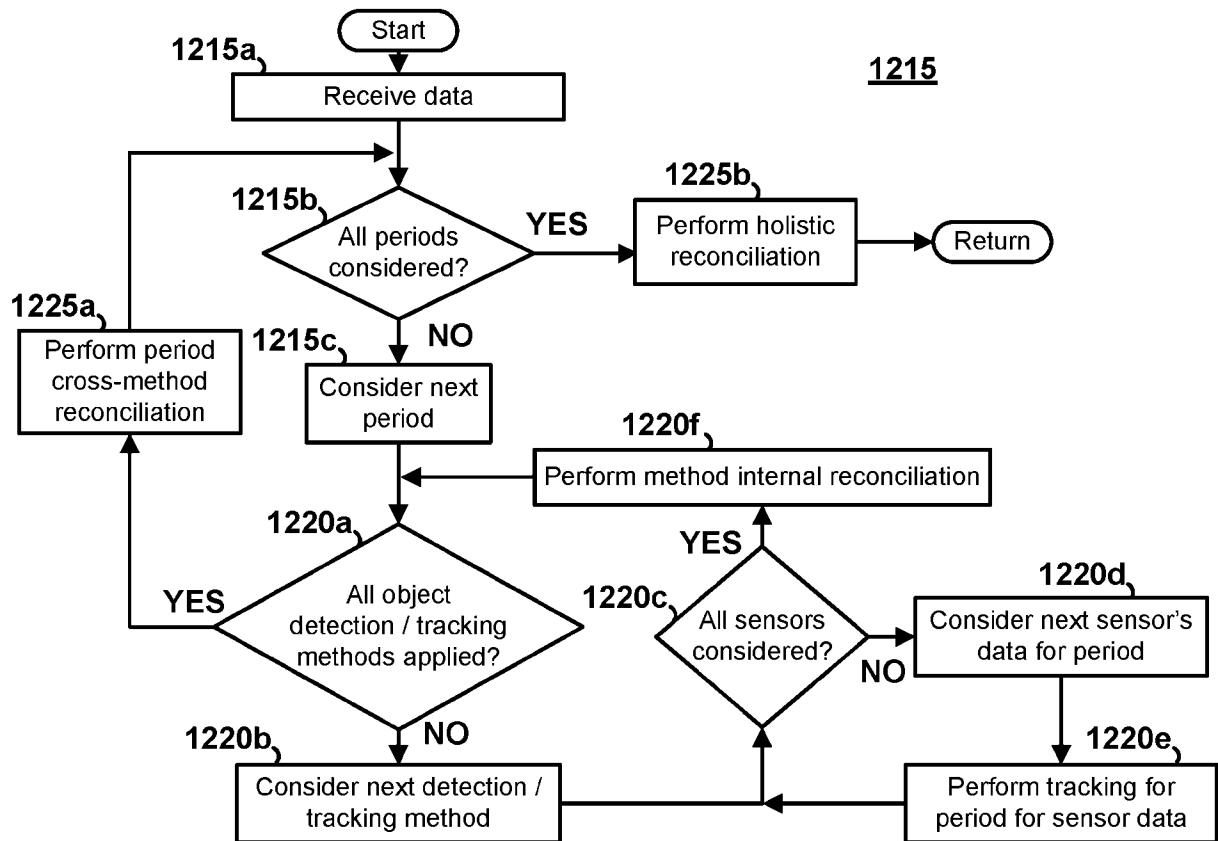
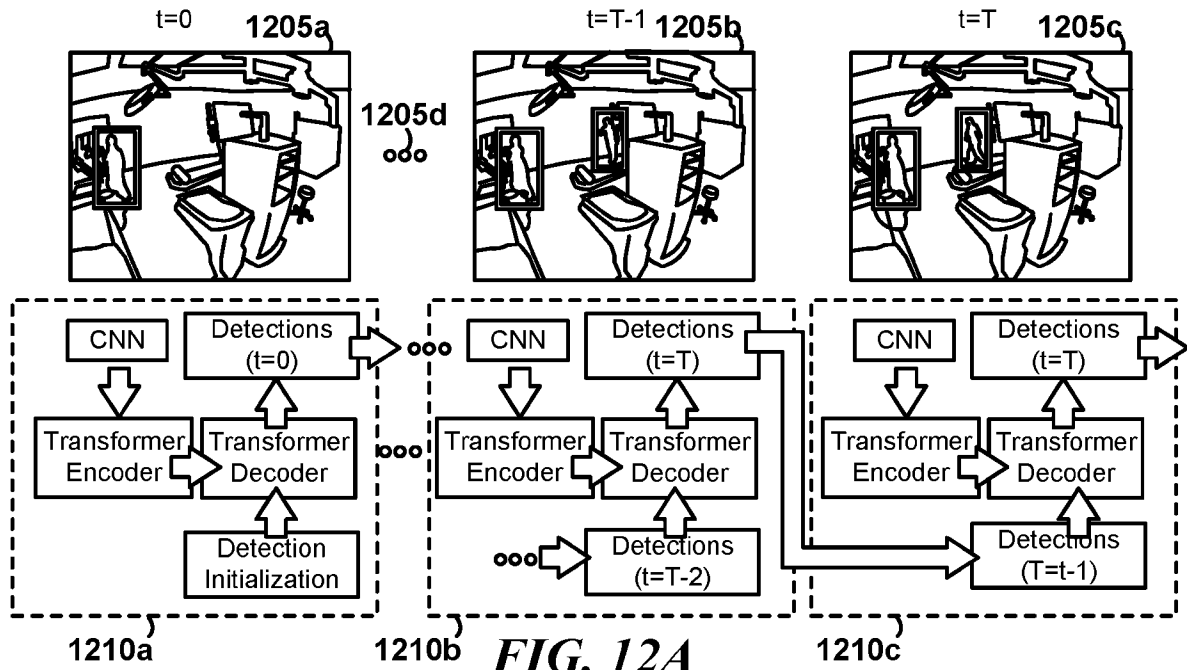


FIG. 12B

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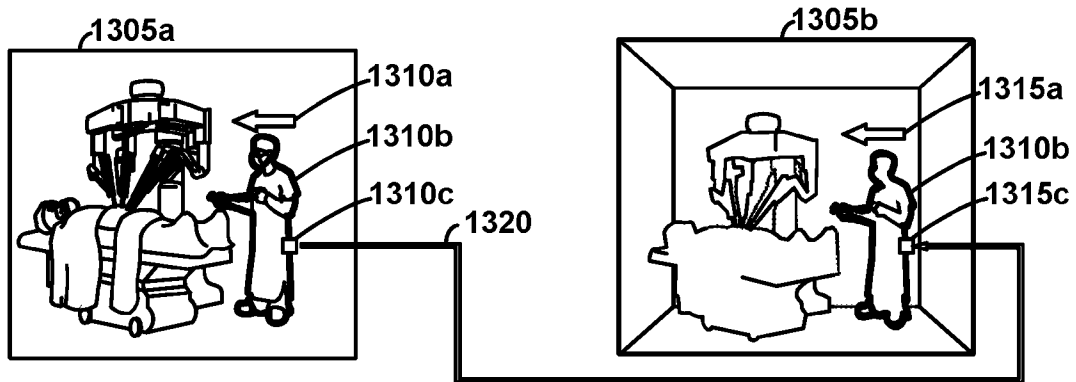


FIG. 13A

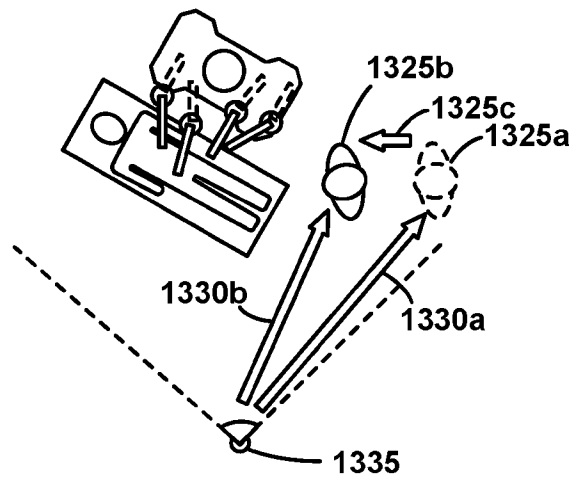


FIG. 13B

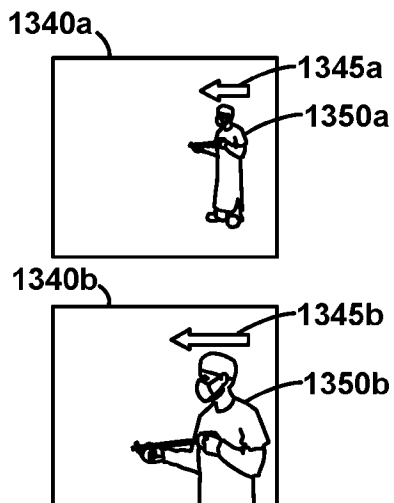


FIG. 13C

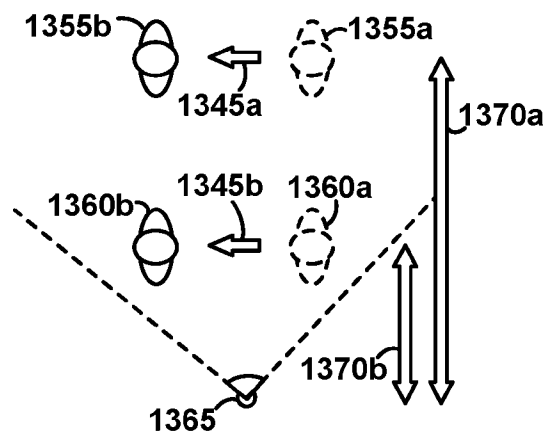
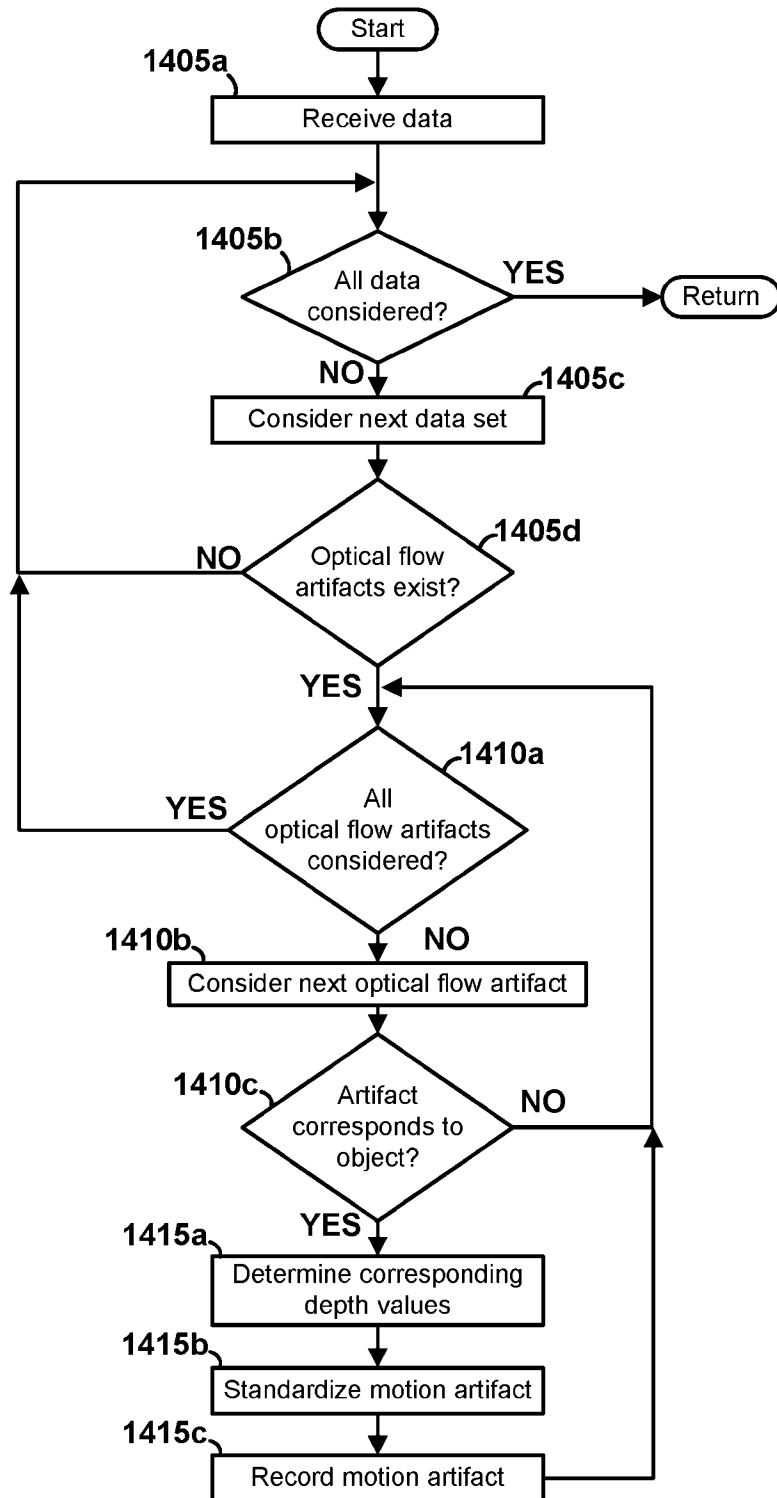
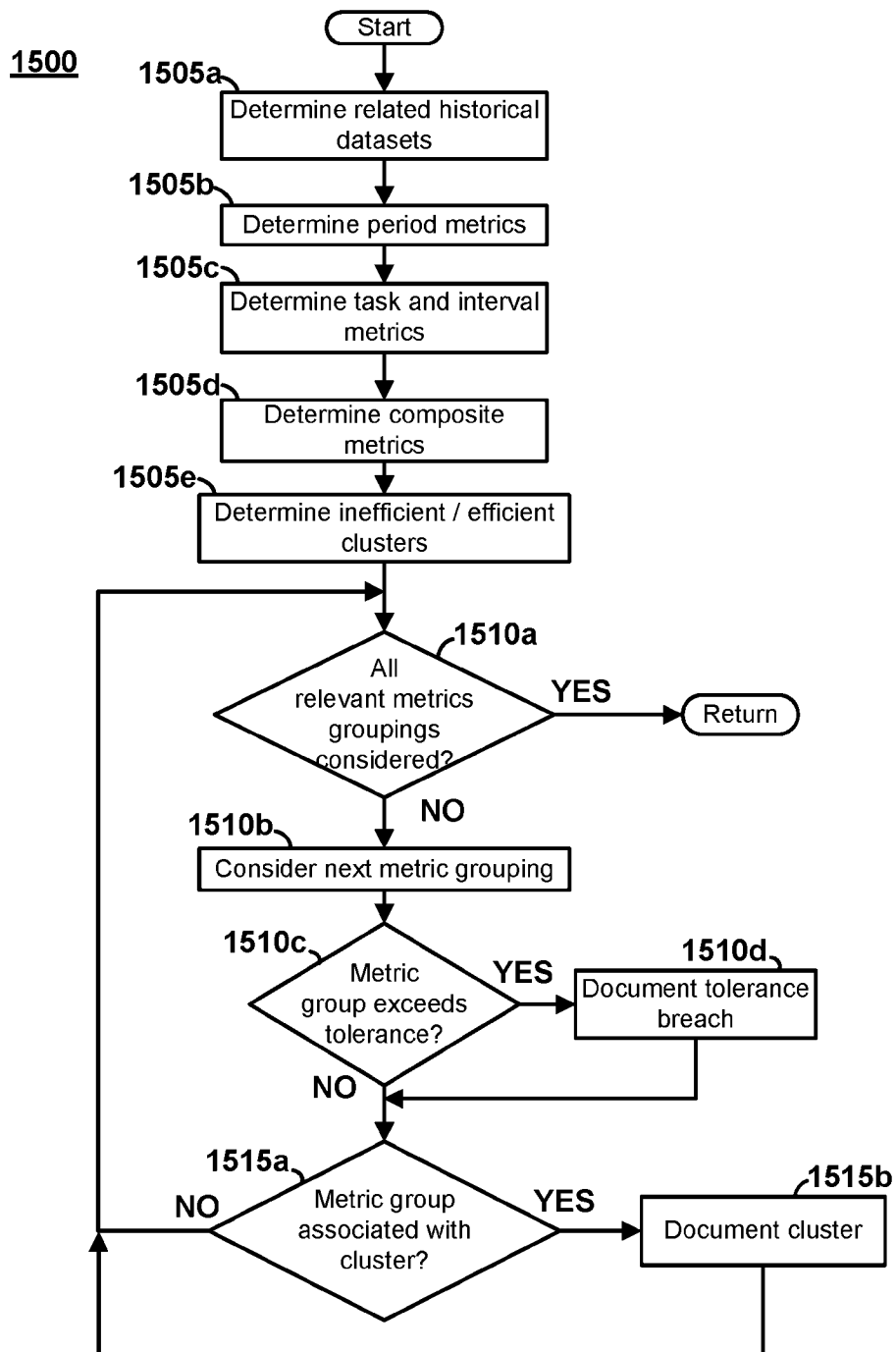


FIG. 13D

*14 / 23***1400****FIG. 14**

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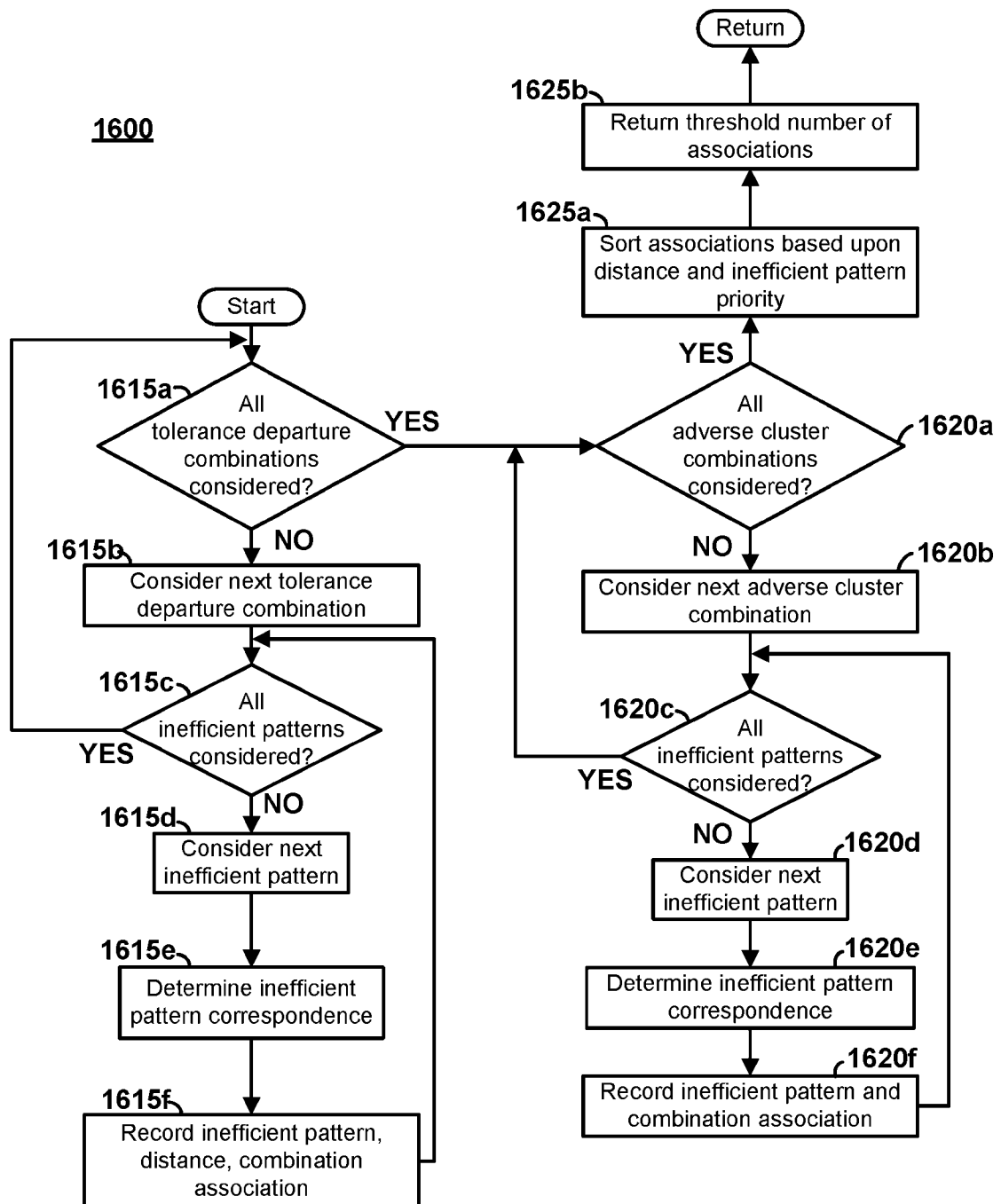


FIG. 16

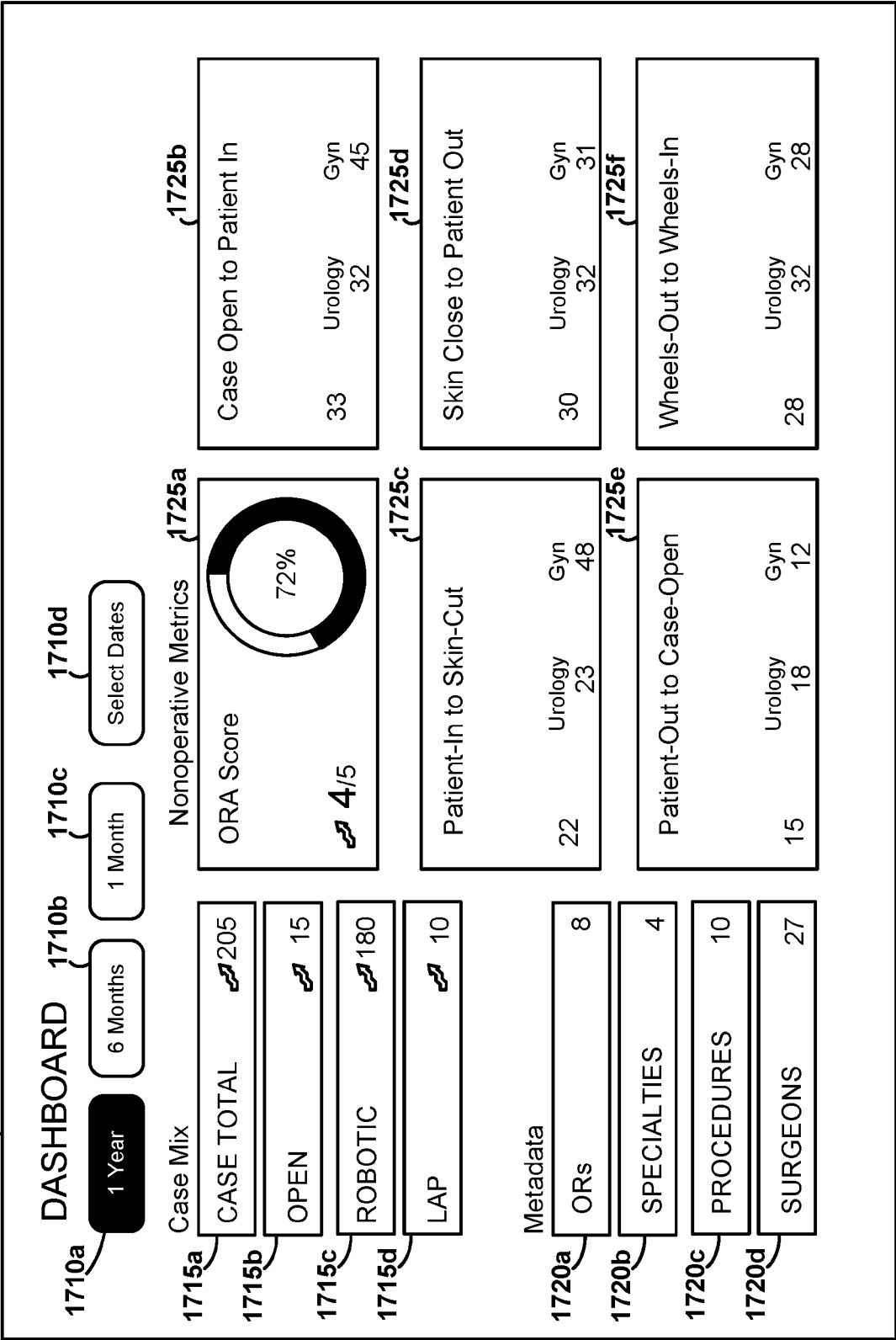


FIG. 17

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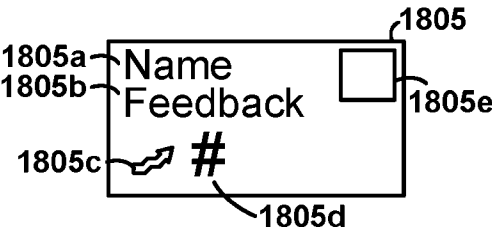


FIG. 18A

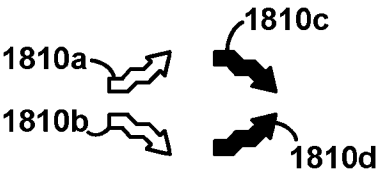


FIG. 18B

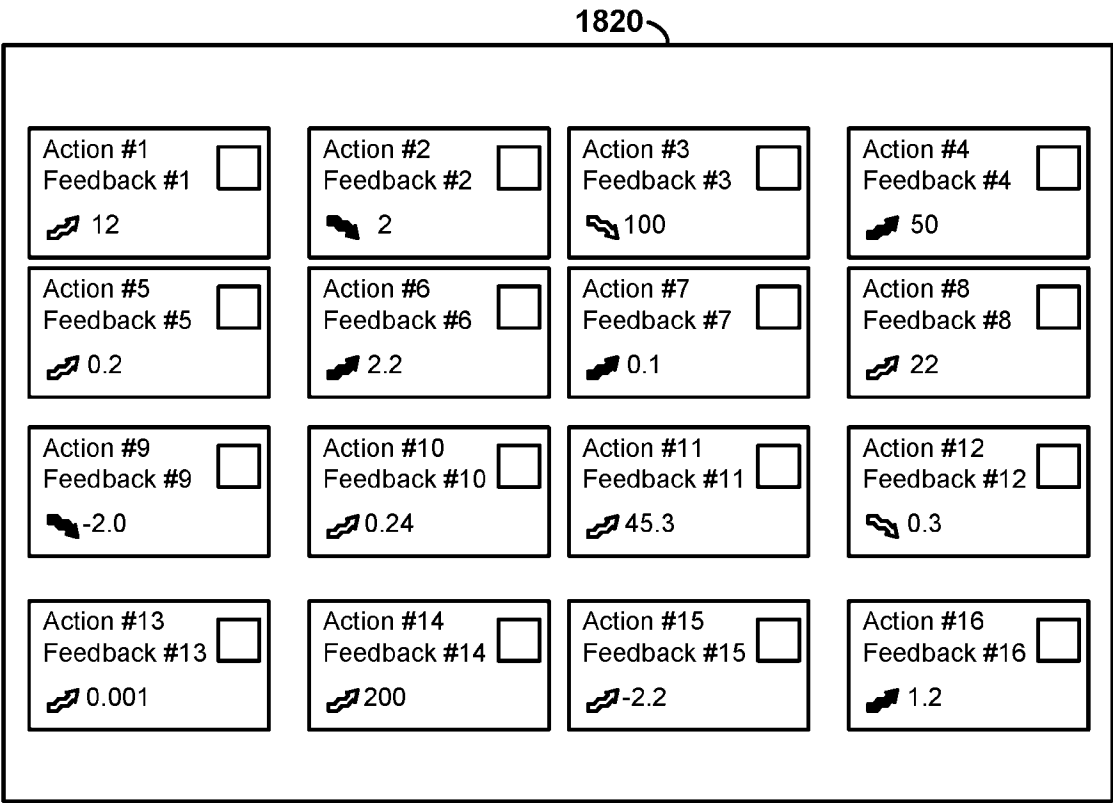


FIG. 18C

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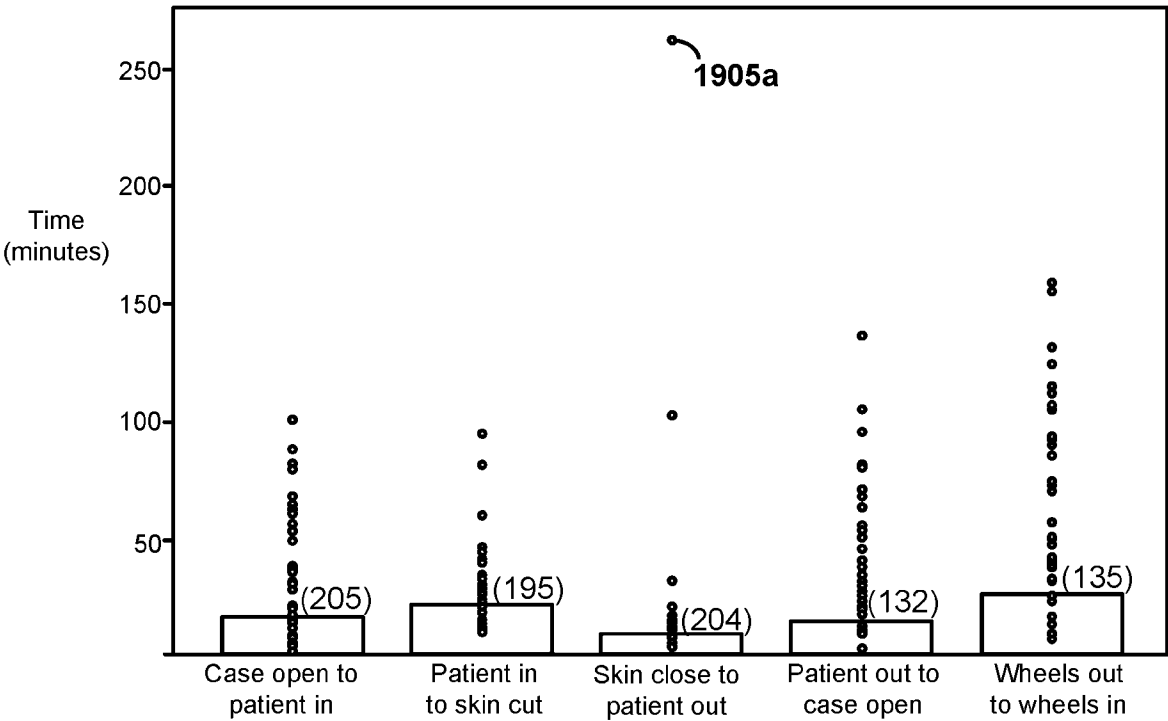


FIG. 19A

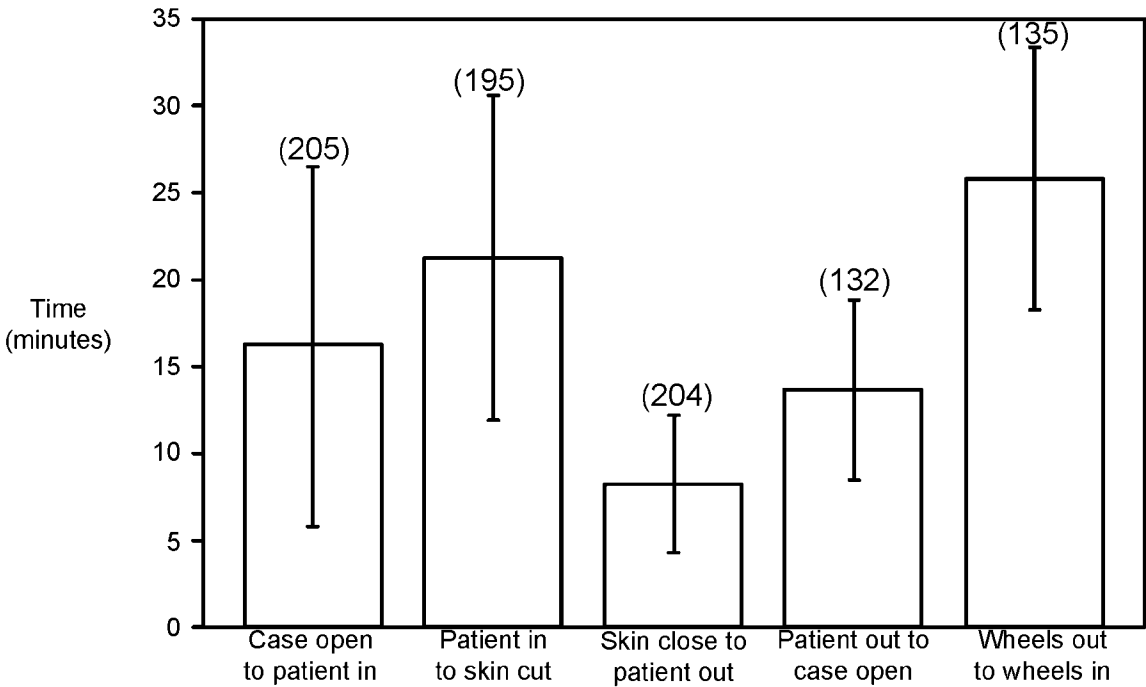


FIG. 19B

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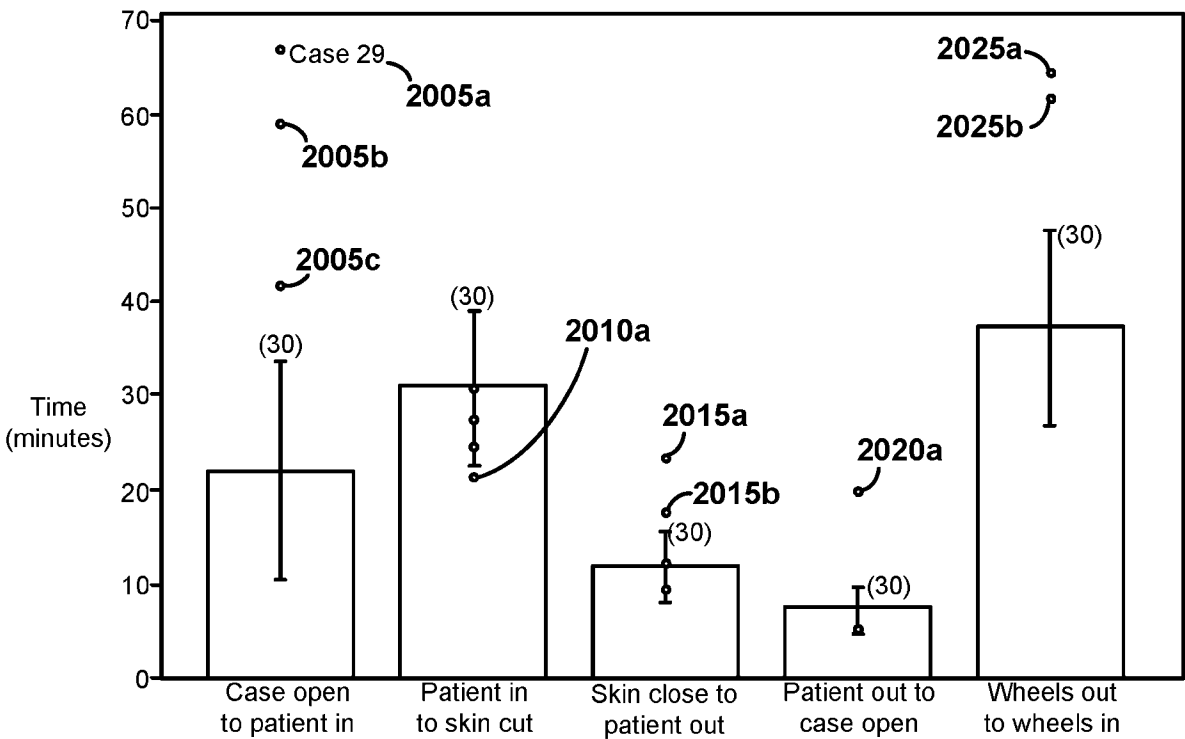


FIG. 20A

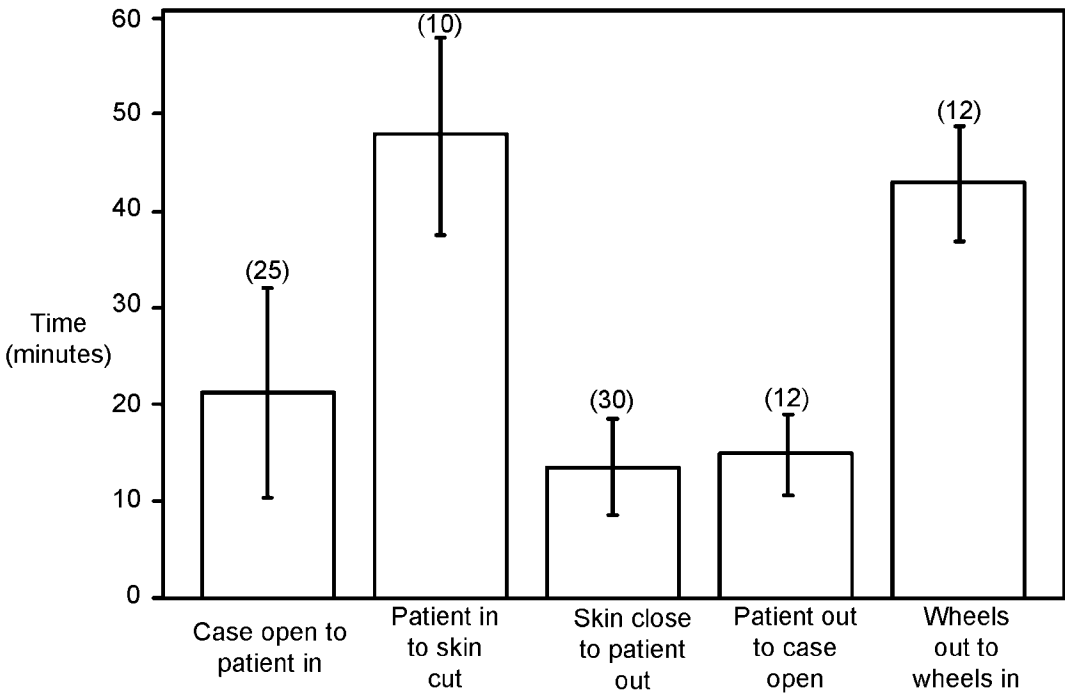
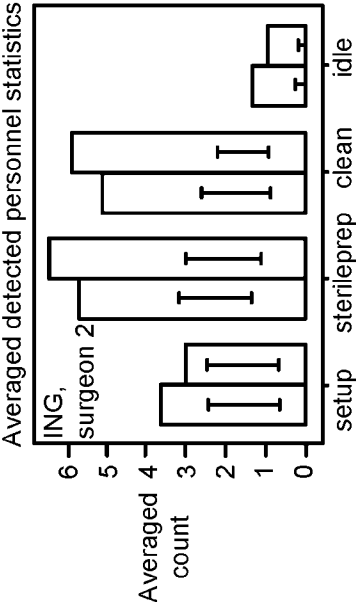
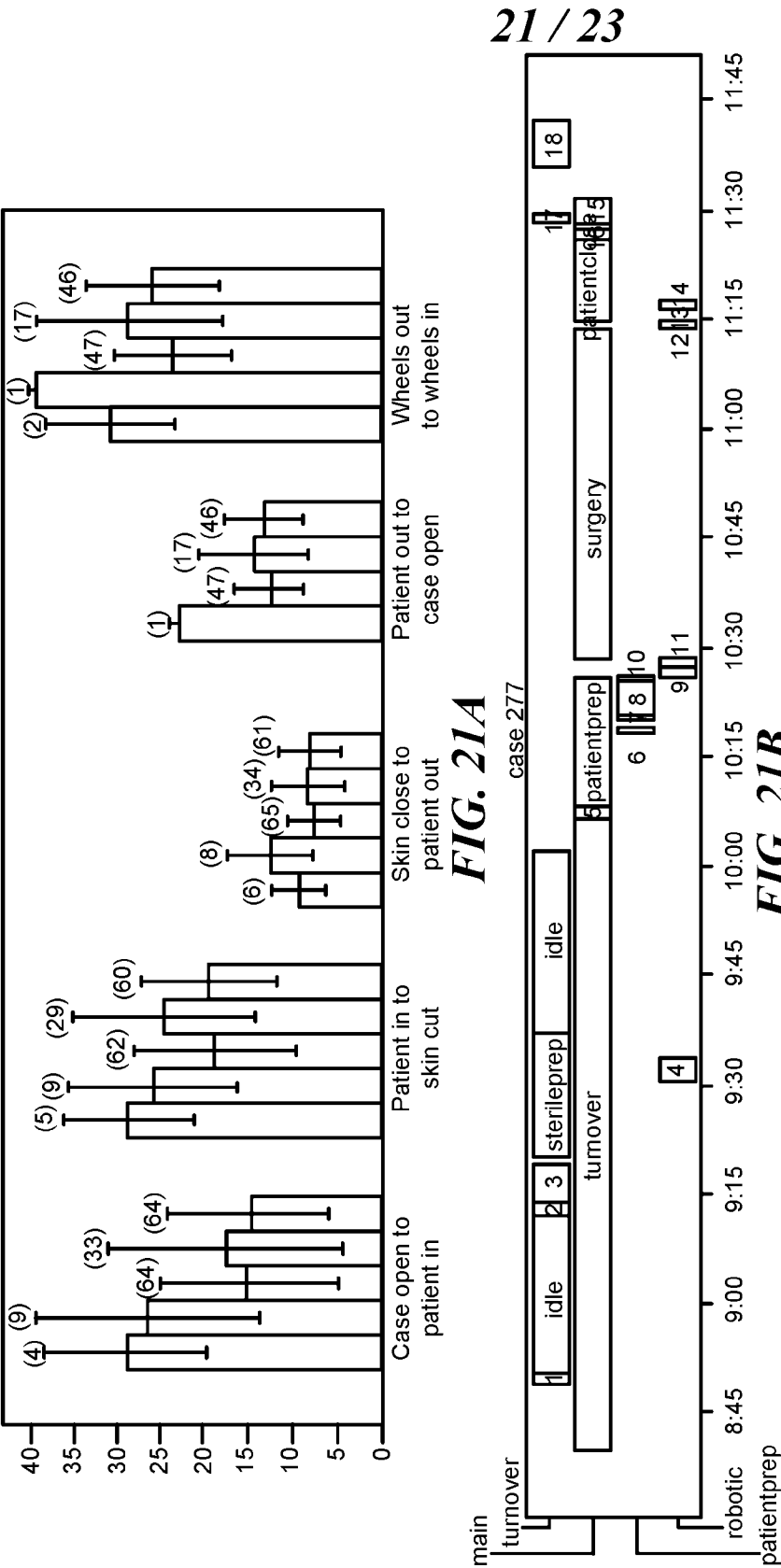


FIG. 20B



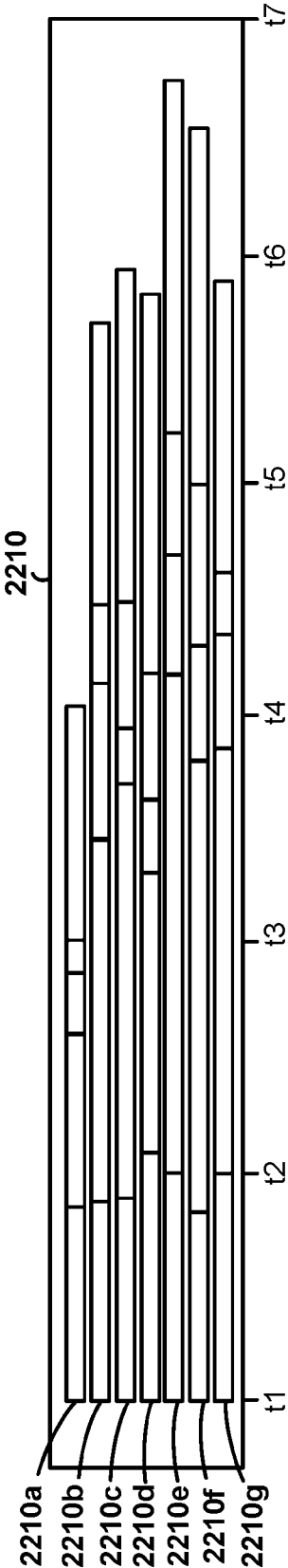
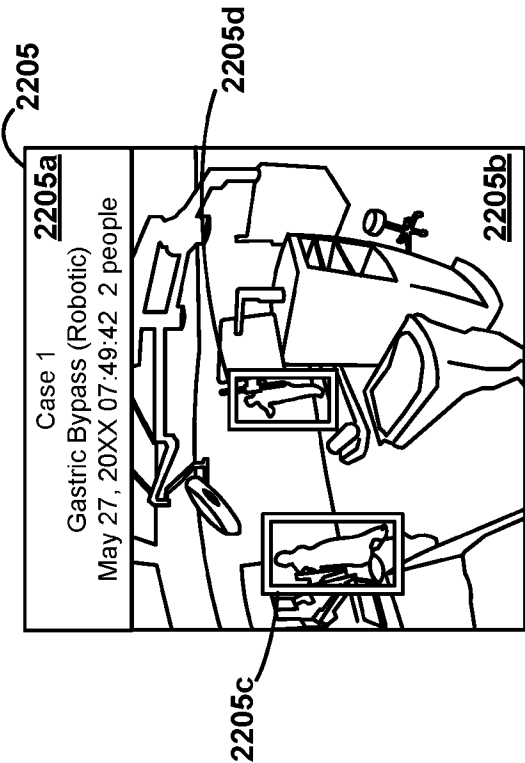
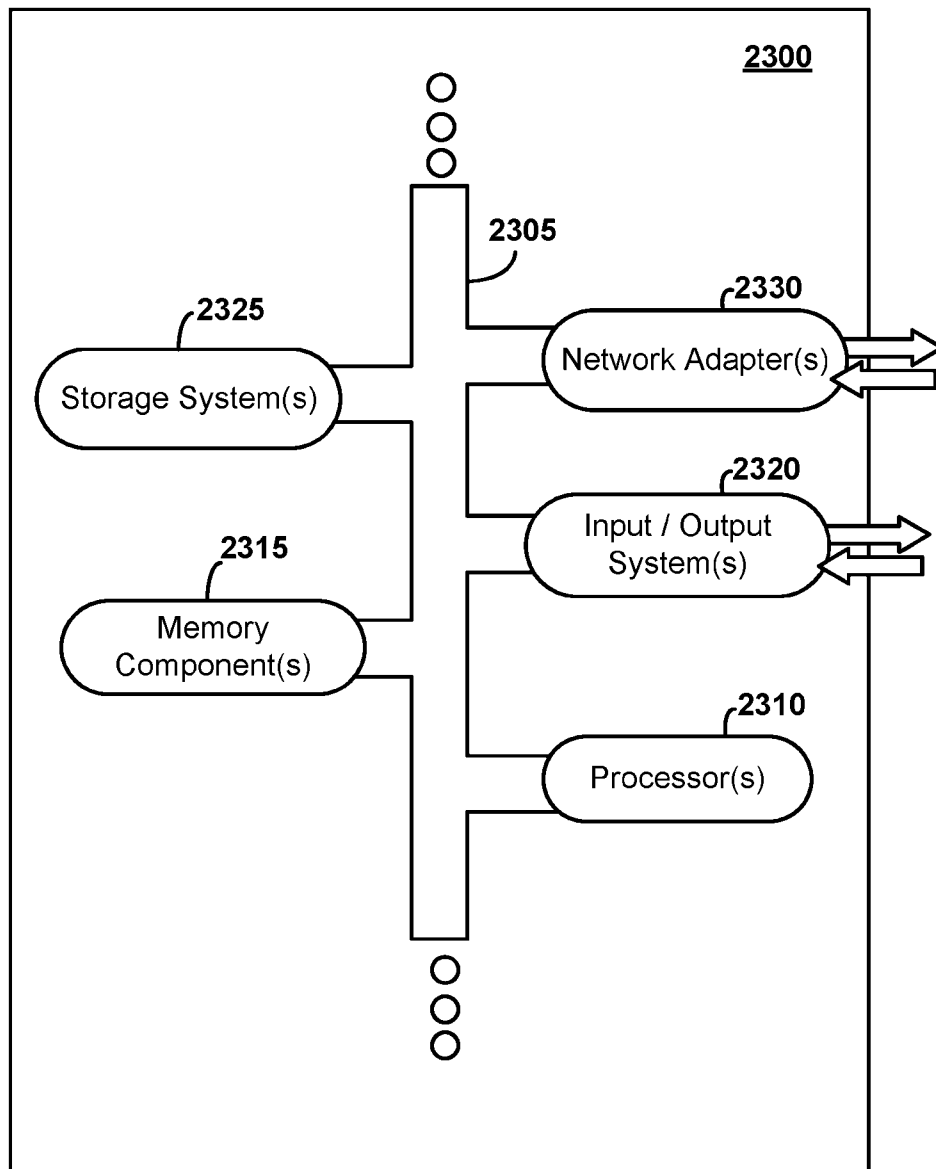


FIG. 22

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**FIG. 23**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/037438

A. CLASSIFICATION OF SUBJECT MATTER INV. G16H20/40 A61B34/20 G06Q10/06 G06Q10/0639 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G16H G06Q A61B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO - Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GERYANE M H ET AL: "Time-motion analysis of operation theater time use during laparoscopic cholecystectomy by surgical specialist residents", SURGICAL ENDOSCOPY ; AND OTHER INTERVENTIONAL TECHNIQUES OFFICIAL JOURNAL OF THE SOCIETY OF AMERICAN GASTROINTESTINAL AND ENDOSCOPIC SURGEONS (SAGES) AND EUROPEAN ASSOCIATION FOR ENDOSCOPIC SURGERY (EAES), SPRINGER-VERLAG, NE, vol. 18, no. 11, 30 November 2004 (2004-11-30), pages 1597-1600, XP019366322, ISSN: 1432-2218	1,3-14, 21, 23-34, 41,43-54
Y	the whole document	2,15-20, 22, 35-40, 42,55-60
- / - -		
☒ Further documents are listed in the continuation of Box C.	☒ See patent family annex.	
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search	Date of mailing of the international search report	
4 October 2024	28/10/2024	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Hauber, Jörg	

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/037438

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	----- RODRIGUES VINICIUS F. ET AL: "A multi-sensor architecture combining human pose estimation and real-time location systems for workflow monitoring on hybrid operating suites", FUTURE GENERATION COMPUTER SYSTEMS, vol. 135, 13 May 2022 (2022-05-13), pages 283-298, XP093164971, NL ISSN: 0167-739X, DOI: 10.1016/j.future.2022.05.006 Retrieved from the Internet: URL:https://www.sciencedirect.com/science/article/pii/S0167739X22001716/pdf?md5=6420d742478de951025fd3262f84efdf&pid=1-s2.0-S0167739X22001716-main.pdf> abstract Section 3 Section 4 figures 2, 7, 8 page 285 - page 292 -----	2,22,42
Y	----- US 2022/384019 A1 (SHELTON IV FREDERICK E [US] ET AL) 1 December 2022 (2022-12-01) paragraph [0010] paragraph [0197] paragraph [0422] paragraph [0501] -----	15,35,55
Y	----- WO 2023/021074 A1 (ZEISS CARL MEDITEC AG [DE]; FREYTAG ALEXANDER [DE] ET AL.) 23 February 2023 (2023-02-23) page 1 - page 20 -----	16-20, 36-40, 56-60

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Information on patent family members

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PCT/US2024/037438

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			WO 2023021074 A1	23-02-2023
