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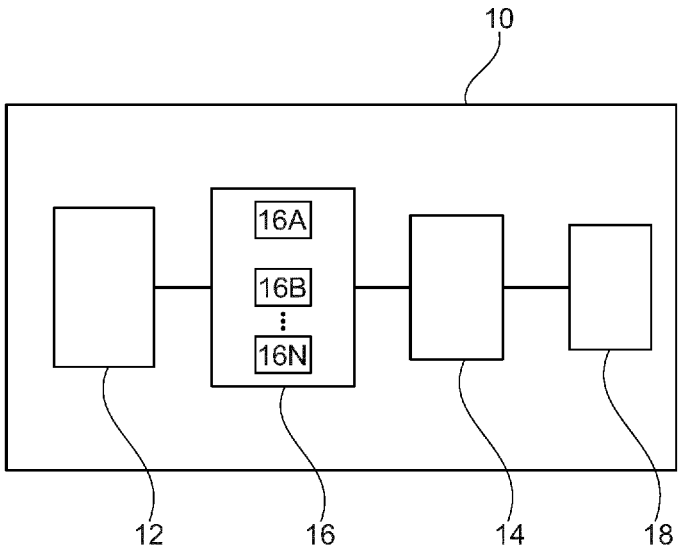


Fig. 1

(57) Abstract: The present invention relates to autonomous imaging. A system and method is proposed that automatically evaluates the readiness index of an autonomous scan procedure and continuously evaluates whether to continue, pause, or about the imaging procedure.

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AUTONOMOUS IMAGE ACQUISITION START-STOP MANAGING SYSTEM

FIELD OF THE INVENTION

The present invention relates to autonomous imaging. In particular, the present invention relates to a rule engine apparatus and a method for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient, an autonomous imaging system, a computer program product, and a computer readable medium.

BACKGROUND OF THE INVENTION

High patient throughput is crucial for many medical imaging facilities. Moreover, imaging will become more and more autonomous in future with less operator-dependent actions and automated workflow steps, for increasing the throughput while reducing the operational costs.

SUMMARY OF THE INVENTION

It is thus an object of the present invention to provide an improved autonomous imaging system and method.

The object of the present invention is solved by the subject-matter of the independent claims. Further embodiments and advantages of the invention are incorporated in the dependent claims. Furthermore, it shall be noted that all embodiments of the present invention concerning a method might be carried out with the order of the steps as described, nevertheless this has not to be the only and essential order of the steps of the method as presented herein. The method disclosed herein can be carried out with another order of the disclosed steps without departing from the respective method embodiment, unless explicitly mentioned to the contrary hereinafter.

According to a first aspect of the present invention, there is provided a rule engine apparatus for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient. The rule engine apparatus comprises an input unit, a master rule engine unit, a plurality of workflow step rule engine units, each workflow step rule engine unit being associated with a respective set of rules, and an output unit. The input unit is configured to receive a data input indicative of an event in an autonomous image acquisition workflow. The master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices, wherein each of the one or more selected workflow step rule engine units is configured to execute, in response to the data input, one or more rules of the respective rule set to generate a respective readiness index indicative of a state of being

prepared for a particular step in the autonomous image acquisition workflow. The master rule engine unit is further configured to determine an action of the autonomous imaging apparatus based on the set of readiness indices. The output unit is configured to output the determined action, which is usable for controlling the autonomous imaging apparatus.

The inventors of the present invention have found out that in an autonomous imaging system, a defined methodology should be in place to start, stop, or abort the imaging procedure. Criteria such as suitability of patient for autonomous scan, subsequent preparations, prevention of injury, and subjective human intervention are even more rigorously need to avoid any untoward situations. The inventors of the present invention have also found out that a well-defined procedure may be required in autonomous imaging system to put in place to cover any foreseen eventuality and some unforeseen ones.

To this end, a rule engine apparatus is proposed for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient. The proposed rule engine apparatus is implemented as “systems of self-contained systems” with each self-contained system can have its own “workflow step rule engine unit” and a master rule engine unit whose output may be states indicative of an action to be performed by the autonomous imaging apparatus, such as“ start”, “stop”, and “abort”. The proposed rule engine apparatus the ability to process input data in autonomous medical workflow settings and to decide on specific workflow steps readiness as well as readiness at the autonomous scan level.

Each self-contained system collects data from various data sources. For example, the data can be sourced from relevant sensors such as spirometer, camera based detection mechanism, Augmented Reality (AR), Virtual Reality (VR), physiological data sensor (e.g. Spo2 sensor, plethysmography sensor, etc.), clinical data (lung capacity, earlier incident of any lung/heart disease, etc.), patient profile (athletic/swimmer), etc. The data may be sourced from data (e.g. image data) collected from the environment in the imaging room. The data may be sourced from machine setting data (e.g. scan protocol). These data sources may be processed by different processing steps and finally fed as a data input for one or more rules.

Each workflow step rule engine for real-time data processing is a kind of decision engine that evaluates the data input according to a set of defined rule and determines an a readiness index. The readiness index may be a probability number between 0 and 1 or may be discrete states, such as “low”, “medium”, and “high”. Since each of the rule system, rules, processing steps are self-contained, the readiness index may be tailored based on e.g. risk factors, impact, and the like in the master rule engine unit.

The evaluation step of each self-contained system is a readiness index. The master rule engine takes these readiness indices evaluates the autonomous image acquisition workflow and outputs an action to be performed by the autonomous imaging apparatus, such as start, abort, stop the imaging procedure, or human intervention.

The proposed rule engine apparatus may also help drive clinical and operational efficiency across all phases of the image acquisition, from patient preparation to image quality assessment. The proposed rule engine apparatus may help reduce variability and staff workload, increase productivity, and increase patient throughput. Further, criteria, such as suitability of patient for autonomous scan, subsequent preparations, prevention of injury, subjective human intervention, and the like are reflected in the readiness indices, which are fed as an input to the master rule engine unit to make a decision. Therefore, untoward situations may be avoided.

According to an embodiment of the present invention, each rule corresponds to a specific workflow step in the autonomous image acquisition workflow, and workflow steps between different rules are different.

According to an embodiment of the present invention, the master rule engine unit is configured to associate the data input to at least one of the one or more selected workflow step rule engine units with a sub-step of the specific workflow step.

For example, the patient preparation workflow step may comprise different multiple processing steps including, but not limited to, breath holding, following instructions, anxiety level, etc. Each processing step may also be referred to as a sub-step of the corresponding workflow step.

According to an embodiment of the present invention, the data input comprises an output from a pre-trained machine-learning algorithm.

In other words, some data inputs may be pre-processed by a pre-trained machine-learning algorithm to determine the probability of whether an event is likely to happen. The predictions from the machine-learning algorithm are then an input into the rules. The rules then evaluate the output of the machine-learning model and provide an output value.

The machine-learning algorithm may be a neural network, a support vector machine, a decision tree, or the like. For training the machine-learning algorithm, workflow details from previous imaging examinations may be used.

The machine-learning algorithm may optimize some kind of process, which cannot be fully enumerated with a deterministic set of rules.

According to an embodiment of the present invention, the plurality of workflow step rule engine units are configured to use an active learning mechanism to update respective rule sets.

The process of performing a scan is very dynamic and it may be difficult to determine all conditions on which a system should abort and restart. The system and condition under which the events happened may be learned during every scan of the device starting from patient preparing to scan complete. An active learning mechanism may be put in place, which captures each state of the machine and corresponding conditions of the machine during each event. In this process, each state of the machine may be tagged with the event. Any new state in which an abort action occurred may be a new rule for the system of systems. This will be explained in detail with respect to the example shown in Fig. 3.

According to an embodiment of the present invention, the data input comprises one or more of: data collected from the patient, data collected from a device used in the autonomous scan procedure, data collected from the autonomous imaging apparatus, data collected from an imaging room, and data collected from a user input.

The data input may be used to evaluate e.g. suitability of patient for an autonomous scan, subsequent preparations, prevention of injury, subjective human interventions, etc.

For example, data collected from the patient may include e.g. sensor data, clinical data, and patient profile data.

For example, data collected from a device used in the autonomous scan procedure may include data indicative of status and/or functionality of a device, such as electrical coil, sensors, and the like.

For example, data collected from the autonomous imaging apparatus may include data indicative of scan protocol, working status of the imaging apparatus, and the like.

For example, data collected from the imaging room may include image data of the imaging room, which may be used to detect whether a foreign object closed to the imaging system may interfere the imaging procedure.

According to an embodiment of the present invention, the data collected from the patient comprises one or more of: sensor data collected from sensors for monitoring the patient, clinical data of the patient, and patient profile data.

According to an embodiment of the present invention, the determined action comprises at least one of: starting image acquisition, aborting image acquisition, and stopping image acquisition.

According to an embodiment of the present invention, for determining the action of starting image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices about a device indicative a state of the autonomous imaging apparatus being prepared for starting image acquisition and a set of readiness indices about the patient indicative a state of the patient being prepared for starting image acquisition.

According to an embodiment of the present invention, for determining the action of aborting image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices about a device indicative a state of the autonomous imaging apparatus not being suitable for continuing image acquisition and/or a set of readiness indices about the patient indicative a state of the patient not being suitable for continuing image acquisition.

According to an embodiment of the present invention, for determining the action of stopping image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a

set of readiness indices indicative of one or more of the following: planned end, scan protocol completed, image quality assessment, coverage of organ of interest, and stable internet access by remote operator.

According to a second aspect of the present invention, there is provided an autonomous imaging system, comprising an autonomous imaging apparatus and a rule engine apparatus according to the first aspect and any associated example. The autonomous imaging apparatus is configured to acquire an image of a patient based on a determined action provided by the rule engine apparatus.

Examples of the autonomous imaging apparatus may include, but are not limited to, x-ray imaging apparatus, magnetic resonance imaging apparatus, computerized tomography scanner, positron emission tomography scanner, and the like.

According to a third aspect of the present invention, there is provided a method for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient, comprising:

a) receiving, by an input unit, a data input indicative of an event in an autonomous image acquisition workflow;

b) selecting, by a master engine unit, for the data input, one or more workflow step rule engine units from a plurality of workflow step rule engine units to determine a set of readiness indices, wherein each workflow step rule engine unit is associated with a respective set of rules; and

wherein each of the one or more selected workflow step rule engine units is configured to execute, in response to the data input, one or more rules of the respective rule set to generate a respective readiness index indicative of a state of being prepared for a particular step in the autonomous image acquisition workflow;

c) determining, by the master engine unit, an action of the autonomous imaging apparatus based on the set of readiness indices; and

d) outputting, by an output unit, the determined action, which is usable for controlling the autonomous imaging apparatus.

According to a fourth aspect of the present invention, there is provided a computer program product comprising instructions which, when executed by at least one processing unit, cause the at least one processing unit to perform the steps of the method according to the third aspect and any associated example.

According to a fifth aspect of the present invention, there is provided a computer readable medium having stored the program product.

It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below (provided such concepts are not mutually inconsistent) are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

Fig. 1 shows an exemplary rule engine apparatus 10 for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient.

Fig. 2 shows a schematic block diagram illustrating an overall rule engine flow.

Fig. 3 shows a schematic block diagram illustrating an exemplary overall workflow.

Fig. 4 shows an exemplary active learning mechanism.

Fig. 5 shows an exemplary autonomous imaging system.

Fig. 6 shows a flow chart of a method for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows an exemplary rule engine apparatus 10 for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient. The rule engine apparatus 10 may be any computing device, including desktop and laptop computers, smartphones, tablets, etc. The rule engine apparatus 10 may be a general-purpose device or a device with a dedicated unit of equipment suitable for providing the below-described functionality. In the example of Fig. 1, the components of the rule engine apparatus 10 are shown as integrated in one single unit. However, in alternative examples (not shown), some or all components may be arranged as separate modules in a distributed architecture and connected in a suitable communication network, such as a 3rd Generation Partnership Project (3GPP) network, a Long Term Evolution (LTE) network, Internet, LAN (Local Area Network), Wireless LAN (Local Area Network), WAN (Wide Area Network), and the like. The rule engine apparatus 10 and its components may be arranged as dedicated FPGAs or as hardwired standalone chips. In some examples, the rule engine apparatus 10 or some of its components may be resident in a console running as software routines.

The rule engine apparatus 10 comprises an input unit 12, a master rule engine unit 14, a plurality of workflow step rule engine units 16, and an output unit 18. In the example shown in Fig. 1, the plurality of workflow step rule engine units 16 comprises workflow step rule engine units 16A to 16N. Each unit may be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group) that

execute one or more software or firmware programs, a combinational logical circuit, and/or other suitable components that provide the described functionality.

The input unit 12 is configured to receive a data input indicative of an event in an autonomous image acquisition workflow. The input unit 12 is, in an example, implemented as an Ethernet interface, a USB (TM) interface, a wireless interface such as a WiFi (TM) or Bluetooth (TM) or any comparable data transfer interface enabling data transfer between input peripherals and the processing unit 14.

The event may be any event that may have an influence on the autonomous imaging procedure, which may cause the imaging process to start, abort, or stop. Examples of the events may include events that have an influence on e.g. suitability of patient for autonomous scan, subsequent preparations, prevention of injury, subjective human intervention, etc.

In an example, vital signs (e.g. oxygen saturation, heart rate, and systolic, and diastolic blood pressure) may be used to assess the patient's anxiety and the suitability of the patient for the autonomous scan. If it is determined that the patient has a high anxiety and high fear index, the autonomous imaging procedure may be aborted or stopped. In this example, the event is that the patient has a lot of anxiety, which has an influence on the autonomous imaging procedure.

In an example, a video signal from a video camera or a depth camera monitoring the face expression or the skin of the patient may be used to assess a pain level experienced by the patient. If the patient is experiencing a high level of pain, the autonomous imaging procedure may be aborted in order to prevent or reduce the severity of bodily injuries. In this example, the event is that the patient suffers a lot of pain, which has an influence on the autonomous imaging procedure.

Thus, the data input may comprise any data that is suitable for indicating that an event is happening or is likely to happen.

For example, the data input may comprise data collected from the patient.

In some examples, the data collected from the patient may comprise sensor data collected from one or more sensors configured to measure the patient's reaction prior to and during an autonomous imaging procedure. The sensors may be used to measure e.g. patient motion, patient pain, nervousness, etc. In an example, the sensor data may be collected from one or more physiological data sensors, which record waveforms and provide periodic measurements of vital signs such as heart rate (HR), respiratory rate (RR), peripheral arterial oxygen saturation (SpO2), arterial blood pressure (ABP), and temperature (T). In another example, the sensor data may be collected from a camera-based detection mechanism, which may be used to detect the movement of the patient. In a further example, the sensor data may be collected from three-dimensional radar sensors, which are used to monitor movement patterns of patients, persons, and devices. Radar array sensors have the advantage of creating three-dimensional point-cloud images suitable for recognition of body posture and motion, but do not allow face recognition. Radar array sensors also have the advantage of working in all lighting conditions and of not being distracted by

clothing or other non-conductive objects. For example, radar arrays can detect arm or leg prostheses even when covered by clothes. Radar array sensors should ideally be set up in a way that they can monitor the patient and imaging room without requiring additional action.

In some examples, the data collected from the patient may further comprise clinical data of the patient, such as lung capacity, earlier incident of any lung or heat disease, and the like. Likewise, the patient profile (such as athletic or swimmer) may also be included in the data input. The clinical data and the patient profile may be received from a hospital database.

In some examples, the data input may comprise data collected from devices and systems. For example, the data input may comprise machine-setting data of an autonomous imaging apparatus. For example, the machine setting data may include the scan protocol, the working state of a medical equipment, etc.

In some examples, the data input may comprise data collected from the imaging room. For example, image data may be used to detect whether a foreign object closed to the imaging system may interfere the imaging procedure.

In some examples, the data input may comprise data collected from a user input, which allows subjective human intervention e.g. in case of medical emergency.

In some examples, the data input may comprise an output from a pre-trained machine-learning algorithm. In other words, some data inputs may be pre-processed by a pre-trained machine-learning algorithm to determine the probability of whether an event is likely to happen. The predictions from the machine-learning algorithm are then an input into the rules. The rules then evaluate the output of the machine-learning model and provide an output value. The machine-learning algorithm may optimize some kind of process, which cannot be fully enumerated with a deterministic set of rules. For example, one machine-learning algorithm may be used to correlate face expression in the image data with an anxiety level. In this example, instead of directly feeding the image data as a data input for one or more rules, the image data is firstly pre-processed by a machine-learning algorithm and the output of the machine-learning algorithm, i.e. the determined anxiety level, is provided for the one or more rules. The machine-learning algorithm may be a neural network, a support vector machine, a decision tree, or the like. For training the machine-learning algorithm, workflow details from previous imaging examinations may be used.

The master rule engine unit 14 is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units 16 to determine a set of readiness indices. Each of the selected one or more selected workflow step rule engine units 16 is configured to execute, in response to the data input, one or more rules 20 of the respective rule set to generate a respective readiness index indicative of a state of being prepared for a particular step in the autonomous image acquisition workflow.

In other words, the proposed rule engine apparatus 10 is implemented as "systems of self-contained systems" with each self-contained system can have its own "workflow step rule engine unit" and a master rule engine unit whose output may be states indicative of an action to be performed by the autonomous imaging apparatus, such as" start", "stop", and "abort". The state "re-start" may be similar to the state "start".

Fig. 2 shows a schematic block diagram illustrating an overall rule engine flow. As shown in Fig. 2, each self-contained system comprises a workflow step rule engine unit 16 and a self-contained system of rules 20. Each self-contained system works on defined rules for a specific segment of an autonomous image acquisition workflow. In other words, each workflow step rule engine 16 for real-time data processing is a kind of decision engine that evaluates the data input according to a set of defined rule and determines an output value.

For example, the workflow step rule engine 16A receives the data input from one or more data sources 24, such as data sources A and B shown in Fig. 2. The data input may comprise data collected from the patient, devices, system, the imaging room, and/or the user input as discussed above.

The master rule engine unit 14 is configured to select, for the data input, one or more workflow step rule engine units 16 from the plurality of workflow step rule engine units 16, such as units 16A-16N shown in Fig. 2, to determine a set of readiness indices. As shown in Fig. 2, one or more rules 20 may involve multiple processing steps. For example, the patient preparation workflow step may comprise different multiple processing steps including, but not limited to, breath holding, following instructions, anxiety level, etc. Each processing step may also be referred to as a sub-step of the corresponding workflow step.

The evaluation step of each self-contained system is a readiness index. Each workflow step rule engine unit 16 may evaluate data from various sources and provide a readiness index. As discussed above, some rules may involve multiple processing steps. For example, rule 20A comprises processing steps 22A and 22B. For example, in the above-mentioned patient preparation workflow steps, one of the readiness indices may be "patient readiness index", which is focused on whether the patient is ready for the scan in autonomous settings. This index may have different readiness indices and corresponding rules engine setup. Exemplary readiness indices may include, but are not limited to, "breath hold readiness index", "instruction following index", "anxiety index", and "Metal object risk index".

Some readiness indices may be a probability number between 0 and 1. Some readiness indices may be discrete states, such as "low", "medium", and "high".

Turning back to Fig. 1, the master rule engine unit 14 takes all these readiness indices to evaluate the autonomous image acquisition workflow and output an action to be performed by the autonomous imaging apparatus via the output unit 18 as mentioned above. The determined action is usable for controlling the autonomous imaging apparatus.

The output unit 18 is, in an example, implemented as an Ethernet interface, a USB (TM) interface, a wireless interface such as a WiFi (TM) or Bluetooth (TM) or any comparable data transfer interface enabling data transfer between output peripherals and the processing unit 14.

Fig. 3 shows a schematic block diagram illustrating an exemplary overall workflow 50. For purposes of illustration, the exemplary autonomous image acquisition workflow is broadly classified into six specified workflow steps: readiness checklist, scan start prompt, abort event lookout, scan end prompt, image assessment, and end.

In the first workflow step 52, i.e. readiness checklist, one or more workflow step rule engine units may be provided to evaluate data from one or multiple data sources and to provide one or more readiness indices, such as a patient readiness index indicative of the readiness of the patient for the scan in autonomous settings and a device readiness index indicative of the readiness of the system for the scan in autonomous settings.

In this workflow step, the data input may comprise data collected from the patient. In some examples, the data may comprise sensor data obtained from one or more sensors that measure the patient's reaction. For example, the sensor data may comprise image data obtained from monitoring the patient movement before the scan procedure and vital signs obtained from monitoring the patient's anxiety level before the scan procedure. In some examples, if a contrast material is needed for the imaging procedure, the data input may further comprise data indicative of whether the contrast material has been injected. In some examples, if anesthesia or sedatives are needed for the imaging procedure, the data input may further comprise data indicative if whether the anesthesia or sedatives have been given to the patient. Further, the data input may comprise identification of the patient, data indicative of whether there is any metal objects in the body, and pre-existing conditions like pregnancy, allergy, medication, and the like, which may be collected from a hospital database. These data inputs may be used to determine whether the patient is ready for starting the scan. Thus, multiple workflow step rule engine units 16 may be used to provide different readiness indices, such as "anxiety index", "sedation index", "contrast material index", "metal object risk index", and "patient condition risk index".

In some examples, the data input may comprise data collected from devices and systems. For example, the data input may comprise data indicative of scan protocol selection, data indicative of coil selection, data indicative of working status of a medical equipment, data indicative of disinfection of device performed, data indicative of stress-test of remote VPN connection to remote operator, data indicative of status and positioning of a camera system, data indicative of balance in patient support, and data indicative of cardiac gating probe placement. These data inputs may be used to determine whether devices and systems are well prepared for starting the scan. Thus, multiple workflow step rule engine units16 may be used to provide different readiness indices, such as "coil readiness index", "scan protocol readiness index", "medical equipment readiness index", "camera system readiness index", "VPN

connection readiness index", "patient support readiness index", and "cardiac gating probe placement readiness index".

In some examples, the data input may comprise user input data, such as patient confirmation, obtained via a user interface. Examples of user interfaces that may be employed in various implementations of the present disclosure include, but are not limited to, switches, potentiometers, buttons, dials, sliders, track balls, display screens, various types of graphical user interfaces (GUIs), touch screens, microphones, cameras and other types of sensors that may receive some form of human-generated stimulus and generate a signal in response thereto. The user input data thus allows subjective human intervention.

In some examples, the data input may comprise data collected from one or more sensors that monitor the environment in the scanner room. The sensor data may comprise video signals from a video camera that monitors e.g. devices present in the scanner room, which may generate noise or image artifacts and whether the door of the scanner room is closed. These data inputs allow the system to determine whether the environment in the scanner room is suitable for the start condition. Thus, multiple workflow step rule engine units may be used to provide different readiness indices, such as "object risk index" and "scanner room readiness index".

The master rule engine unit 14 then takes the above-mentioned exemplary readiness indices in order to evaluate the autonomous image acquisition workflow and determines whether to start the scan (block 54).

Once the imaging procedure starts, one or more workflow step rule engine units 16 associated with the workflow step "Abort Event Lookout" evaluate data inputs and determine, based on these data inputs, whether an overriding emergency mechanism is required (block 56).

In some examples, the data input may comprise data collected from the patient. For examples, the data may comprise sensor data obtained from one or more sensors that measure the patient's reaction. The sensor data may comprise image data obtained from monitoring the patient movement, vital signs obtained from monitoring the patient anxiety and medical emergency, data obtained from sedation monitoring devices for monitoring premature wakeup from sedation, and/or data obtained from monitoring a pain level that is experienced by the patient. In some examples, video feeds having a field of view that covers the body part of interest received from a combination of various three-dimensional contactless motion scanner using e.g. light detection and ranging (LIDAR), radio detection and ranging (RADAR), and camera based sensor at different position may be used to measure one or more of patient motion, patient pain, and nervousness. Thus, multiple workflow step rule engine units may be used to provide different readiness indices, such as "pain index", "anxiety index", "sedation index", and "medical emergency index". For each readiness index, a threshold level may be set to determine if it is necessary to abort the scan procedure.

In some examples, the data input may comprise user input data obtained via a user interface, e.g. via an integrated emergency button integrated with an MRI scanner or a command received from a remote operator to abort the scan procedure. The user input data thus allows subjective human intervention. For example, the patient may press the integrated emergency button in case of pain and anxiety. Thus, multiple workflow step rule engine units 16 may be used to provide different readiness indices, such as "patient intervention index" and "operator intervention index".

In some examples, the data input may comprise data collected from various devices and systems. For example, the data input may comprise data indicative of electrical coil status, position of sensors, position of a mattress in the imaging system, and/or the status of internet connection to remote client. The data input thus allows the system to determine whether the status and functionality of e.g. imaging devices, systems, and internet connect are good enough to continue the autonomous imaging procedure. Thus, multiple workflow step rule engine units may be used to provide different readiness indices, such as "electrical coil status index", "sensor position index", "mattress position index", and "internet connection index".

In some examples, the data input may comprise data collected from one or more sensors that monitor the environment in the scanner room. The sensor data may comprise video signals from a video camera that monitors objects brought in the scanner room or close to the scanner during imaging and/or patient's relatives in the scanner room. These data inputs allow the system to detect whether an object and/or a person may interfere the scanning process. Thus, one or more workflow step rule engine units 16 may provide different readiness indices, such as "object interference index" and "person interference index".

The above-described exemplary readiness indices are then provided to the master rule engine unit 14 to determine whether to abort the imaging procedure.

If the imaging procedure is not aborted, one or more workflow step rule engine units associated with the workflow step "Scan End Prompt" evaluate data input and determine, based on these data inputs, whether to stop the imaging procedure (step 58). The data input may comprise data indicative of a planned end, data indicative of scan procedure completed, data indicative a coverage of organ of interest, and data indicative of stable internet access by remote operator. Thus, multiple workflow step rule engine units may provide different readiness indices, such as "planned end index", "scan procedure completeness index", "organ coverage index", and "internet connection index".

Once the imaging procedure stops, one or more workflow step rule engine units associated with the workflow step "Image Assessment" evaluate image data and determine, based on these data inputs, whether it is necessary to perform another scan (step 60).

If the image quality meets predefined criteria, the autonomous imaging procedure ends (step 62).

It will be appreciated that since each of the rule engine system, rules, and processing steps are self-contained, the above-discussed exemplary readiness indices may be tailored individually based on e.g. risk factors and impact in the master rule engine unit.

The process of performing a scan is very dynamic and it may be difficult to determine all conditions on which a system should abort and restart. The system and condition under which an event happened may be learned during every scan of the device starting from patient preparing to scan complete. An active learning mechanism may be put in place, which captures each state of the machine and corresponding conditions of the machine during each event. In this process, each state of the machine may be tagged with the event. Any new state in which an abort action occurred may be a new rule for the system of systems.

Fig. 4 shows an exemplary active learning mechanism. In this example, if the system fails to take the right action (block 70), the states of the scan, machine, patient, and environment captured during the scan (block 72) are provided as a feedback to update the initial set of rules (block 74). The updated rules (block 76) are then used as new rules for the system to output states (block 78) like "start", "stop", "abort", "re-start", "continue", etc. Additionally, since the system fails to take the right action (block 70), a user intervention (block 80) may be needed to e.g. stop or abort the scan procedure. The scan procedure may be re-started after the rules have been updated.

Fig. 5 shows an exemplary autonomous imaging system 100, which comprises an autonomous imaging apparatus 90 and a rule engine apparatus 10 as described above. The autonomous imaging apparatus 90 is configured to acquire an image of a patient based on a determined action provided by the rule engine apparatus 10.

Examples of the autonomous imaging apparatus 90 may include, but are not limited to, x-ray imaging apparatus, magnetic resonance imaging apparatus, computerized tomography scanner, positron emission tomography scanner, and the like.

In the example of Fig. 5, the rule engine apparatus 10 is a separate device configured to communicate with the autonomous imaging apparatus 90 through a wireless and/or a wire-based interface. However, in alternative examples, the rule engine apparatus 10 may resident in the autonomous imaging apparatus 90 e.g. running as software routines.

Fig. 6 shows a flow chart of a method 200 for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient. The method may be carried out by the exemplary apparatus shown in Fig. 1.

In step 210, i.e. step a), a data input indicative of an event in an autonomous image acquisition workflow is received e.g. via an input unit of the exemplary apparatus 10.

As discussed in detail hereinbefore, the data input may comprise data collected from the patient, data collected from a device and the autonomous imaging apparatus, data collected from an imaging room, and/or data collected from a user input. These data input may be used to evaluate the

suitability of patient for autonomous scan, subsequent preparations, prevention of injury, subjective human intervention, etc.

In step 220, i.e. step b), a master engine unit selects, for the data input, one or more workflow step rule engine units from a plurality of workflow step rule engine units to determine a set of readiness indices. Each workflow step rule engine unit is associated with a respective set of rules. Each of the one or more selected workflow step rule engine units is configured to execute, in response to the data input, one or more rules of the respective rule set to generate a respective readiness index indicative of a state of being prepared for a particular step in the autonomous image acquisition workflow. For example, in the patient preparation phase, the master rule engine may select one or more workflow step rule engine units that are associated with patient preparation to determine a set of readiness indices.

In some examples, each rule may correspond to a specific workflow step in the autonomous image acquisition workflow, and workflow steps between different rules may be different. The master rule engine unit is configured to associate the data input to at least one of the one or more selected workflow step rule engine units with a sub-step of the specific workflow step. For example, in the patient preparation phase, multiple workflow step rule engine units may be used to provide different readiness indices, such as “anxiety index”, “sedation index”, “contrast material index”, “metal object risk index”, and “patient condition risk index”. These workflow steps may also be referred to as sub-steps of the patient preparation workflow step.

In step 230, i.e. step c), the master engine unit then determines an action of the autonomous imaging apparatus based on the set of readiness indices. The determined action may comprise one or more of starting image acquisition, aborting image acquisition, and stopping image acquisition.

For determining the action of starting image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices about a device indicative a state of the autonomous imaging apparatus being prepared for starting image acquisition and a set of readiness indices about the patient indicative a state of the patient being prepared for starting image acquisition.

For determining the action of aborting image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices about a device indicative a state of the autonomous imaging apparatus not being suitable for continuing image acquisition and/or a set of readiness indices about the patient indicative a state of the patient not being suitable for continuing image acquisition.

For determining the action of stopping image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices indicative of one or more of the

following: planned end, scan protocol completed, image quality assessment, coverage of organ of interest, and stable internet access by remote operator.

In step 240, i.e. step d), an output unit of the exemplary apparatus 10 outputs the determined action, which is usable for controlling the autonomous imaging apparatus.

All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

The indefinite articles "a" and "an," as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean "at least one."

The phrase "and/or," as used herein in the specification and in the claims, should be understood to mean "either or both" of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases. Multiple elements listed with "and/or" should be construed in the same fashion, i.e., "one or more" of the elements so conjoined. Other elements may optionally be present other than the elements specifically identified by the "and/or" clause, whether related or unrelated to those elements specifically identified.

As used herein in the specification and in the claims, the phrase "at least one," in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase "at least one" refers, whether related or unrelated to those elements specifically identified.

In another exemplary embodiment of the present invention, a computer program or a computer program element is provided that is characterized by being adapted to execute the method steps of the method according to one of the preceding embodiments, on an appropriate system.

The computer program element might therefore be stored on a computer unit, which might also be part of an embodiment of the present invention. This computing unit may be adapted to perform or induce a performing of the steps of the method described above. Moreover, it may be adapted to operate the components of the above described apparatus. The computing unit can be adapted to operate automatically and/or to execute the orders of a user. A computer program may be loaded into a working memory of a data processor. The data processor may thus be equipped to carry out the method of the invention.

This exemplary embodiment of the invention covers both, a computer program that right from the beginning uses the invention and a computer program that by means of an up-date turns an existing program into a program that uses the invention.

Further on, the computer program element might be able to provide all necessary steps to fulfil the procedure of an exemplary embodiment of the method as described above.

According to a further exemplary embodiment of the present invention, a computer readable medium, such as a CD-ROM, is presented wherein the computer readable medium has a computer program element stored on it which computer program element is described by the preceding section.

A computer program may be stored and/or distributed on a suitable medium, such as an optical storage medium or a solid state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the internet or other wired or wireless telecommunication systems.

However, the computer program may also be presented over a network like the World Wide Web and can be downloaded into the working memory of a data processor from such a network. According to a further exemplary embodiment of the present invention, a medium for making a computer program element available for downloading is provided, which computer program element is arranged to perform a method according to one of the previously described embodiments of the invention.

While several inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, inventive embodiments may be practiced otherwise than as specifically described and claimed. Inventive embodiments of the present disclosure are directed to each individual feature, system, article, material, kit, and/or method described herein. In addition, any combination of two or more such features, systems, articles, materials, kits, and/or methods, if such features, systems, articles, materials, kits, and/or methods are not mutually inconsistent, is included within the inventive scope of the present disclosure.

CLAIMS:

1. A rule engine apparatus (10) for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient, comprising:

- an input unit (12);
- a master rule engine unit (14);
- a plurality of workflow step rule engine units (16), each workflow step rule engine unit being associated with a respective set of rules; and
- an output unit (18);

wherein the input unit is configured to receive a data input indicative of an event in an autonomous image acquisition workflow;

wherein the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices, wherein each of the one or more selected workflow step rule engine units is configured to execute, in response to the data input, one or more rules of the respective rule set to generate a respective readiness index indicative of a state of being prepared for a particular step in the autonomous image acquisition workflow;

wherein the master rule engine unit is further configured to determine an action of the autonomous imaging apparatus based on the set of readiness indices; and

wherein the output unit is configured to output the determined action, which is usable for controlling the autonomous imaging apparatus.

2. Rule engine apparatus according to claim 1,

wherein each rule corresponds to a specific workflow step in the autonomous image acquisition workflow, and workflow steps between different rules are different.

3. Rule engine apparatus according to claim 2,

wherein the master rule engine unit is configured to associate the data input to at least one of the one or more selected workflow step rule engine units with a sub-step of the specific workflow step.

4. Rule engine apparatus according to any one of the preceding claims,

wherein the data input comprises an output from a pre-trained machine-learning algorithm.

5. Rule engine apparatus according to any one of the preceding claims, wherein the plurality of workflow step rule engine units are configured to use an active learning mechanism to update respective rule sets.

6. Rule engine apparatus according to any one of the preceding claims, wherein the data input comprises one or more of:
- data collected from the patient;
- data collected from a device used in the autonomous scan procedure;
- data collected from the autonomous imaging apparatus;
- data collected from an imaging room; and
- data collected from a user input.

7. Rule engine apparatus according to claim 6, wherein the data collected from the patient comprises one or more of:
- sensor data collected from sensors for monitoring the patient;
- clinical data of the patient; and
- patient profile data.

8. Rule engine apparatus according to any one of the preceding claims, wherein the determined action comprises at least one of:
- starting image acquisition;
- aborting image acquisition; and
- stopping image acquisition.

9. Rule engine apparatus according to claim 8, wherein for determining the action of starting image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices about a device indicative a state of the autonomous imaging apparatus being prepared for starting image acquisition and a set of readiness indices about the patient indicative a state of the patient being prepared for starting image acquisition.

10. Rule engine apparatus according to claim 8, wherein for determining the action of aborting image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the

plurality of workflow step rule engine units to determine a set of readiness indices about a device indicative a state of the autonomous imaging apparatus not being suitable for continuing image acquisition and/or a set of readiness indices about the patient indicative a state of the patient not being suitable for continuing image acquisition.

11. Rule engine apparatus according to claim 8,

wherein for determining the action of stopping image acquisition, the master rule engine unit is configured to select, for the data input, one or more workflow step rule engine units from the plurality of workflow step rule engine units to determine a set of readiness indices indicative of one or more of the following:

- planned end;
- scan protocol completed;
- image quality assessment;
- coverage of organ of interest; and
- stable internet access by remote operator.

12. An autonomous imaging system (100), comprising:

- an autonomous imaging apparatus (90); and
- a rule engine apparatus (10) according to any one of the preceding claims;

wherein the autonomous imaging apparatus is configured to acquire an image of a patient based on a determined action provided by the rule engine apparatus.

13. A method (200) for evaluating an autonomous scan procedure for controlling an autonomous imaging apparatus to acquire an image of a patient, comprising:

a) receiving (210), by an input unit, a data input indicative of an event in an autonomous image acquisition workflow;

b) selecting (220), by a master engine unit, for the data input, one or more workflow step rule engine units from a plurality of workflow step rule engine units to determine a set of readiness indices, wherein each workflow step rule engine unit is associated with a respective set of rules; and

wherein each of the one or more selected workflow step rule engine units is configured to execute, in response to the data input, one or more rules of the respective rule set to generate a respective readiness index indicative of a state of being prepared for a particular step in the autonomous image acquisition workflow;

c) determining (230), by the master engine unit, an action of the autonomous imaging apparatus based on the set of readiness indices; and

d) outputting (240), by an output unit, the determined action, which is usable for controlling the autonomous imaging apparatus.

14. A computer program product comprising instructions which, when executed by at least one processing unit, cause the at least one processing unit to perform the steps of the method according to claim 13.

15. Computer readable medium having stored the program product of claim 14.

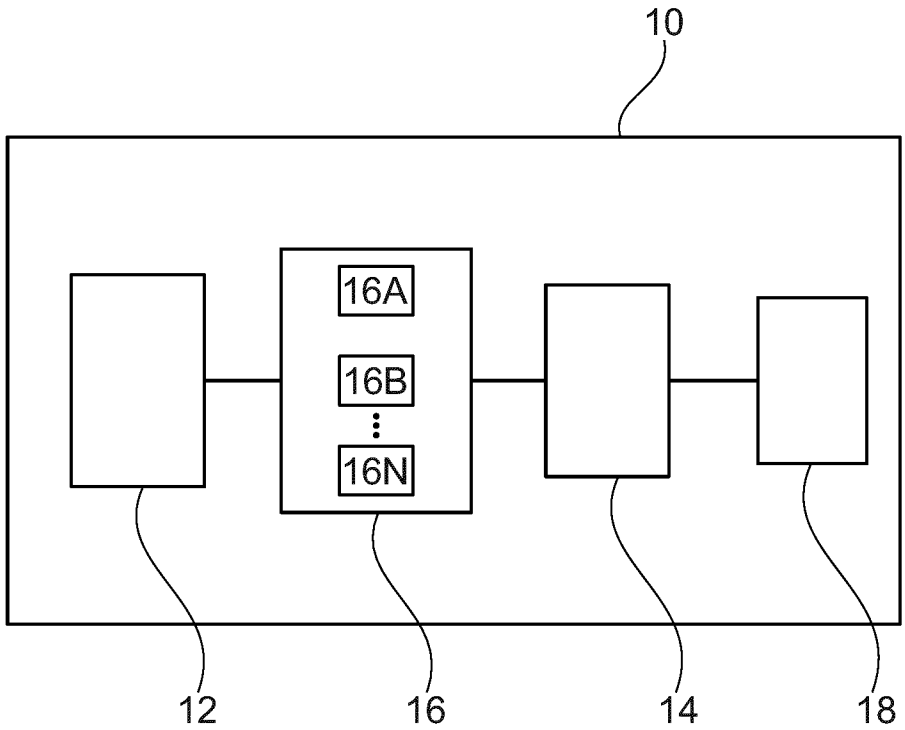


Fig. 1

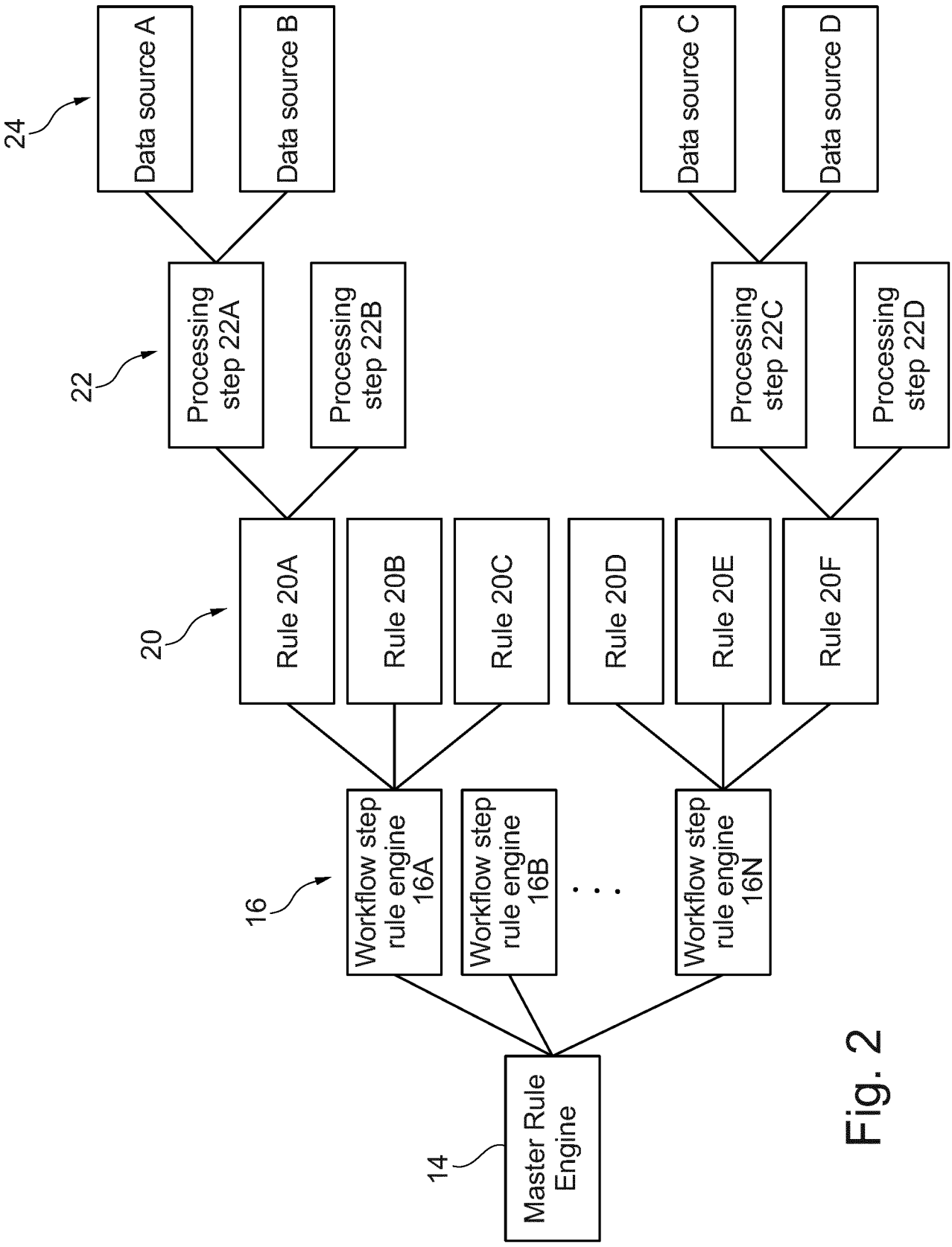

24
Data source A
Data source B
Data source C
Data source D
22
Processing step 22A
Processing step 22B
Processing step 22C
Processing step 22D
20
Rule 20A
Rule 20B
Rule 20C
Rule 20D
Rule 20E
Rule 20F
16
Workflow step rule engine 16A
Workflow step rule engine 16B
Workflow step rule engine 16N
14
Master Rule Engine

Fig. 2

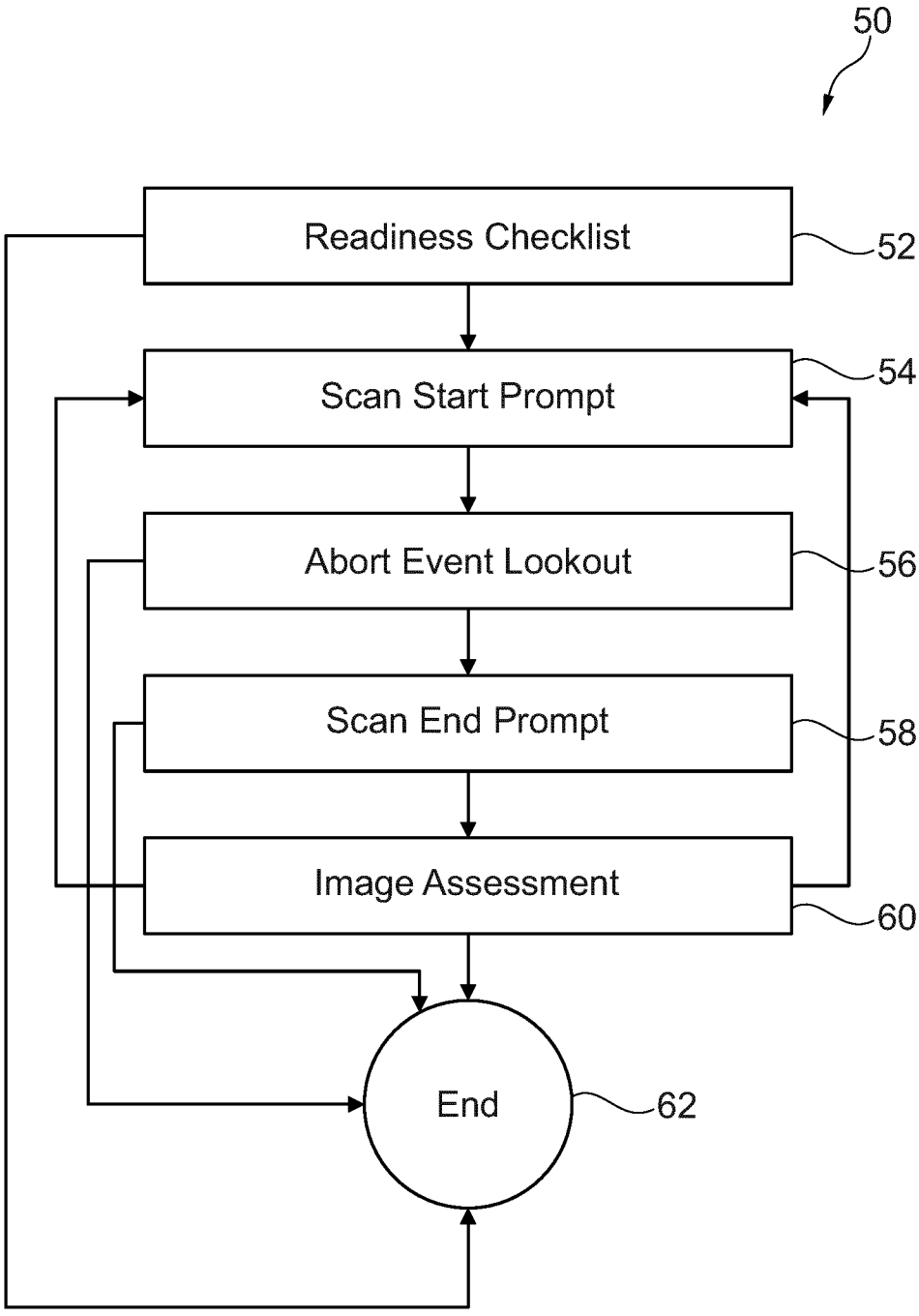

50
Readiness Checklist
52
Scan Start Prompt
54
Abort Event Lookout
56
Scan End Prompt
58
Image Assessment
60
End
62

Fig. 3

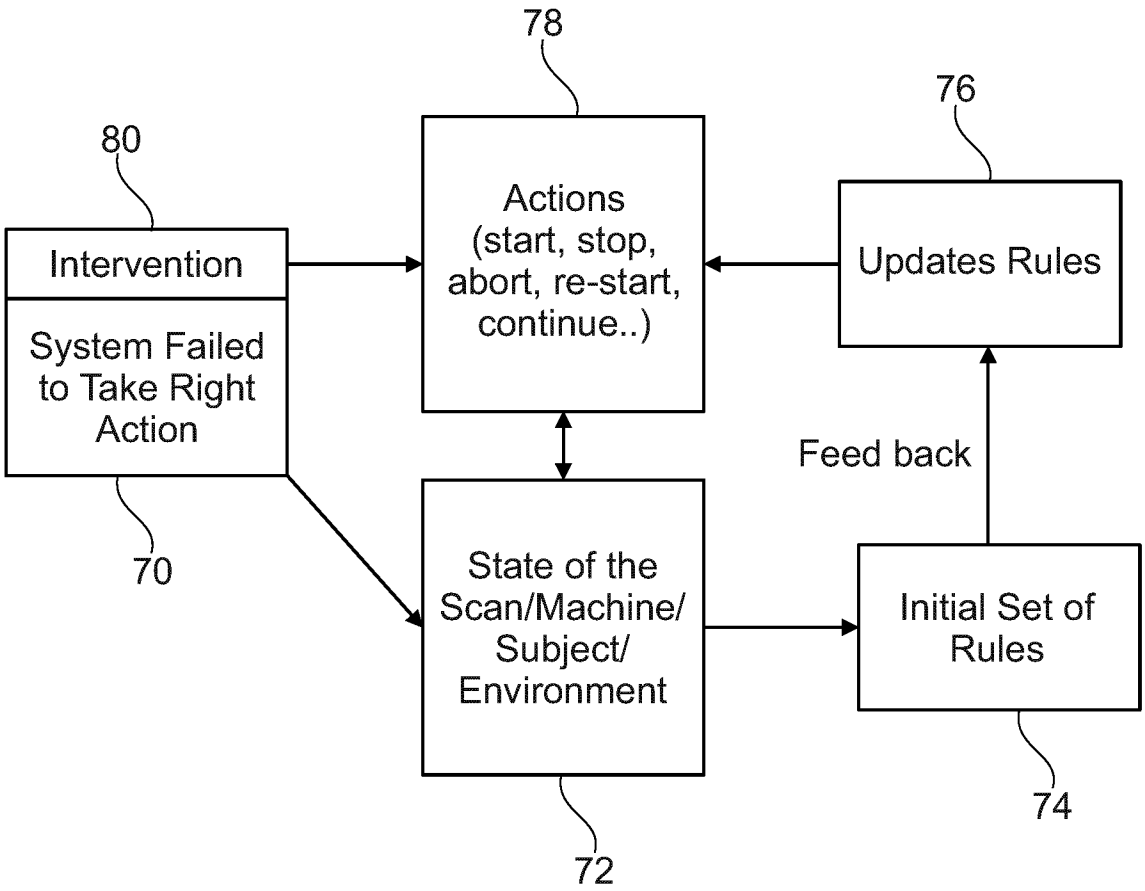

78
76
80
Actions (start, stop, abort, re-start, continue..)
Updates Rules
Intervention
System Failed to Take Right Action
Feed back
70
State of the Scan/Machine/ Subject/ Environment
Initial Set of Rules
74
72

Fig. 4

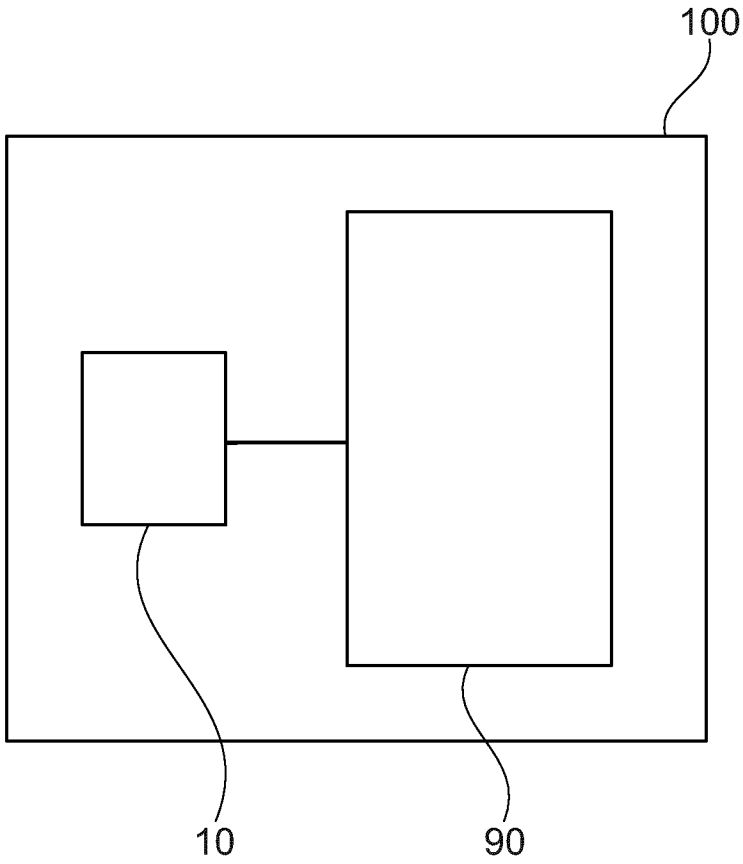


Fig. 5

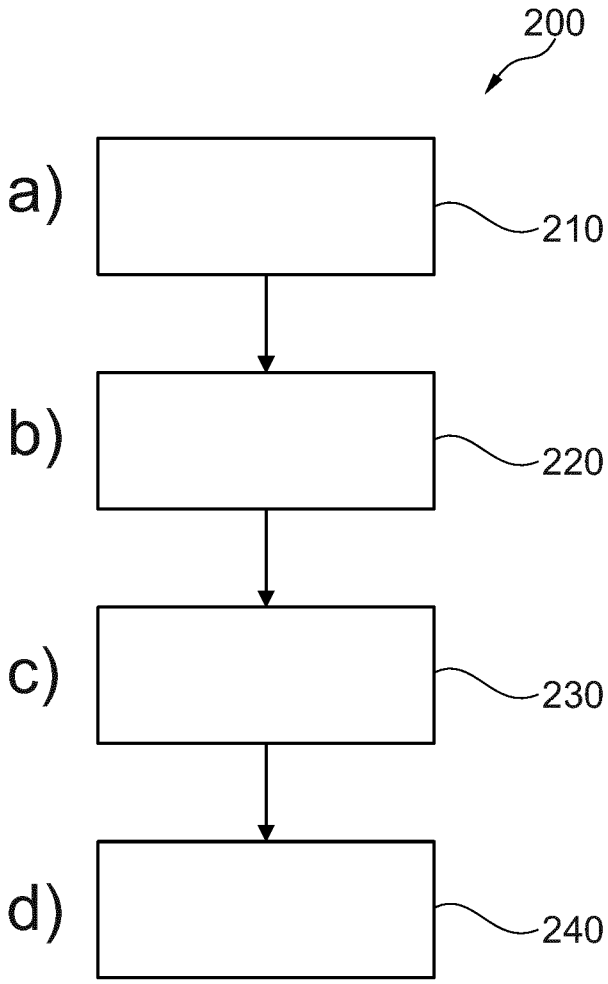


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/063394

A. CLASSIFICATION OF SUBJECT MATTER
INV. G16H30/20 G16H40/20 G16H40/63 G16H40/67 A61B5/055
A61B6/03 A61B6/00
ADD. A61B8/08
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 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	US 2009/150184 A1 (SPAHN MARTIN [DE]) 11 June 2009 (2009-06-11)	1-15
Y	the whole document, in particular paragraphs [0002], [0004]-[0017], [0021], and figures 1-4	9,10
X	US 2019/148011 A1 (RAO BIMBA [US] ET AL) 16 May 2019 (2019-05-16)	1-15
Y	figures 1-6 page 1, paragraph 0003 - page 3, paragraph 0028 page 5, paragraph 0056 - page 7, paragraph 0076; figure 1 page 7, paragraph 0081 - page 9, paragraph 0098	9,10

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[X] Further documents are listed in the continuation of Box C.
[X] 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
25 August 2022	02/09/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sasa Bastinos, Ana

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/063394

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/026958 A1 (AGFA HEALTHCARE [BE]) 20 February 2014 (2014-02-20)	1-15
Y	page 1, paragraph 01 - paragraph 02 page 2, paragraph 05 - page 5, paragraph 14 page 7, paragraph 28 - page 13, paragraph 36 figures 1, 2	9,10

Y	US 2020/205748 A1 (PAUTSCH ADAM GREGORY [US] ET AL) 2 July 2020 (2020-07-02) figures 1-7 page 1, paragraph 0001 - paragraph 0012 page 2, paragraph 0018 - page 4, paragraph 0040 page 8, paragraph 0070 - page 10, paragraph 0081	9,10

A	Oberweis Andreas: "Person-to-Application Processes: Workflow Management : Bridging People and Software through Process Technology" In: "Process-Aware Information Systems : Bridging People and Software through Process Technology", 2 September 2005 (2005-09-02), John Wiley & Sons, Inc., Hoboken, NJ, USA, XP55953068, ISBN: 978-0-471-66306-5 pages 21-36, DOI: 10.1002/0471741442.ch2, the whole document & Van Der Aalst Wil M. P. ET AL: "Patterns of Process Modeling : Bridging People and Software through Process Technology" In: "Process-Aware Information Systems : Bridging People and Software through Process Technology", 2 September 2005 (2005-09-02), John Wiley & Sons, Inc., Hoboken, NJ, USA, XP55953120, ISBN: 978-0-471-66306-5 pages 179-203, DOI: 10.1002/0471741442.ch8, the whole document	1-15

A	Anonymous: "Workflow management system - Wikipedia", , 1 June 2021 (2021-06-01), XP55953051, Retrieved from the Internet: URL:https://en.wikipedia.org/w/index.php?title=Workflow_management_system&oldid=1026291329 [retrieved on 2022-08-19] the whole document	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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