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(54) **Title:** SYSTEMS AND METHODS FOR MAXIMIZING ENERGY EFFICIENCY AND REDUCING SUSTAINING COSTS OF NON-DESTRUCTIVE TESTING INSPECTION

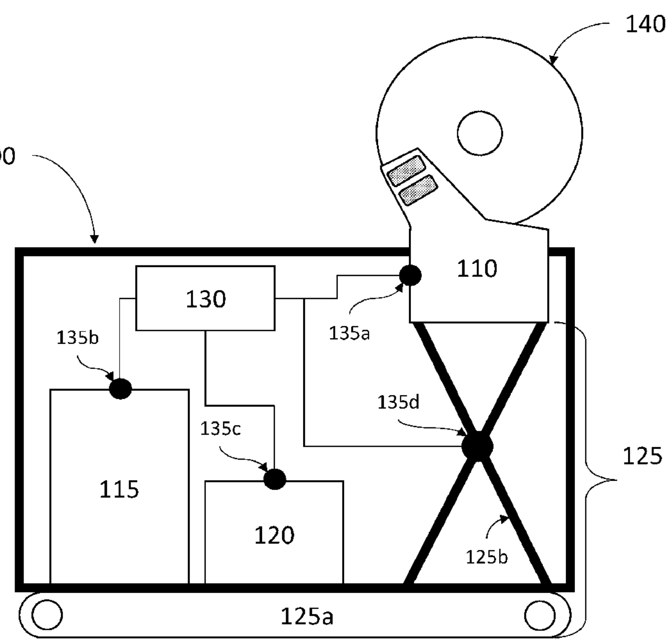

FIG. 1

(57) **Abstract:** An inspection system is provided that includes: a plurality of sensors arranged to acquire a plurality of energy measurements characterizing an energy consumption of each of a plurality of inspection tasks, a server system storing historical data characterizing energy consumption of each of the plurality of inspection tasks performed by the inspection system or one or more other inspection systems similar to the inspection system and a computing system including a processor and a memory storing instructions which, when executed by the processor, cause the processor to perform operations including: receiving the plurality of energy measurements, comparing the plurality of energy measurements to the historical data, determining a level of energy efficiency for the inspection and providing the level of energy efficiency.

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SYSTEMS AND METHODS FOR MAXIMIZING ENERGY EFFICIENCY AND REDUCING SUSTAINING COSTS OF NON-DESTRUCTIVE TESTING INSPECTION

RELATED APPLICATION

[0001] This application claims the benefit and priority from U.S. Provisional Patent Application Serial No. 63/472,967, filed on June 14, 2013, the entire contents of which are hereby expressly incorporated by reference herein.

FIELD

[0002] The subject matter described herein pertains to the monitoring of energy usage in the field of non-destructive testing (NDT).

BACKGROUND

[0003] Conventional systems for monitoring energy usage by non-destructive inspection (NDI)/non-destructive testing (NDT) systems operate by monitoring the overall energy consumption of fully integrated NDT systems, which typically operate continuously or semi-continuously. Due to the continuous/semi-continuous operation of such NDT systems, the metrics for energy consumption are usually analyzed based on a macro-scale timeline (e.g., energy consumption over the course of a 24 hour period, or number of inspections completed over a 24 hour period). These macro-scale metrics can then be compared to similar inspection systems, which are working in comparable usage scenarios, to determine overall efficiency. However, by overlooking micro-scale inspection tasks (e.g., durations of individual inspections, step-by-step energy consumption, varying operating situations, etc.) this conventional method for monitoring energy usage can lack detailed analysis. This lack of detail can result in overlooking or improperly diagnosing energy consumption issues within the inspection system.

SUMMARY

[0004] In one aspect, an inspection system for performing an inspection of an asset is provided. In some aspects, the inspection can include a plurality of inspection tasks to be performed by the inspection system. The inspection system can include a plurality of sensors arranged to acquire a plurality of energy measurements characterizing an energy consumption of each of the plurality of inspection tasks, a server system storing historical data characterizing energy consumption of each of the plurality of inspection tasks performed by the inspection system or one or more other inspection systems similar to the inspection system and a computing system communicatively coupled to the inspection system and the server system. The computing system can include at least one data processor and a memory storing computer-readable instructions which, when executed by the at least one processor, cause the at least one processor to perform operations including: receiving the plurality of energy measurements from the plurality of sensors, comparing the plurality of energy measurements to the historical data, determining, based on the comparing, a level of energy efficiency of the inspection system, and providing the level of energy efficiency.

[0005] In some aspects, the inspection system can also include one or more non-destructive inspection units arranged perform one or more of the plurality of inspection tasks over the course of the inspection and one or more power supplies arranged to power the inspection system over the course of the inspection. In this case, the plurality of sensors can include one or more first sensors arranged to acquire a first plurality of energy measurements characterizing an energy consumption of each of the one or more non-destructive inspection units and one or more second sensors arranged to acquire a second plurality of energy measurements characterizing an energy consumption of each of the one or more power supplies.

[0006] In some aspects, the one or more non-destructive inspection units can be arranged to use one or more of water, oil, and air conditioning and compressed air and the first plurality of energy measurements include data characterizing one or more of a water usage, an oil temperature, an oil pressure and an air pressure. In some aspects, the second plurality of energy measurements can further include data characterizing a battery storage capacity of the one or more power supplies.

[0007] In some aspects, the level of energy efficiency can be provided as a level relative to the one or more other inspection systems.

[0008] In some aspects, the inspection system can also include one or more positioning devices arranged to position the inspection system for the inspection. In this case, the plurality of sensors can further include one or more third sensors arranged to acquire a third plurality of energy measurements characterizing an energy consumption of each of the one or more positioning devices.

[0009] In some aspects, the historical data can further include one or more of time data characterizing an amount of time required to complete each of the plurality of inspection tasks performed by the inspection system or the one or more other inspection systems and a number of inspections performed by the inspection system. In some aspects, the operations performed by the at least one processor can further include: determining an amount of time required to complete each of the plurality of inspection tasks, comparing the amount of time required to complete each of the plurality of inspection tasks to the historical data and determining, based on the comparing, the level of energy efficiency for the inspection system.

[0010] In some aspects, the operations performed by the at least one processor can further include comparing one or more energy measurements of the plurality of energy measurements acquired for a first task of the plurality of inspection tasks or a first amount of time required to complete the first task to the historical data, determining, based on the comparing, a level of energy efficiency for the first task and providing the level of energy efficiency for the first task.

[0011] In some aspects, the plurality of inspection tasks can include one or more of a validation/calibration task, a positioning task, an evaluation task, a standby task and a re-validation task.

[0012] In some aspects, the inspection system can be arranged to perform the inspection of the asset on-demand.

[0013] In another aspect, a method of performing an inspection of an asset is provided. In some aspects, the inspection can include a plurality of inspection tasks to be performed by an inspection system. In some aspects, the method can include: acquiring plurality of energy measurements characterizing an energy consumption of each of the plurality of inspection tasks by a plurality of sensors operatively coupled to the inspection system, receiving, by at least one data processor of a computing system including a memory storing computer-readable instructions to be executed by the at least one processor, the plurality of energy measurements from the plurality of sensors, comparing, by the at least one data processor, the plurality of energy measurements to historical data stored within a server system, the historical data characterizing energy consumption of each of the plurality of inspection tasks performed by the inspection system or one or more other inspection systems similar to the inspection system, determining, by the at least one data processor, a level of energy efficiency for the inspection system and providing, by the at least one data processor, the level of energy efficiency.

[0014] In some aspects, the inspection system can further include one or more non-destructive inspection units arranged perform one or more of the plurality of inspection tasks over the course of the inspection and one or more power supplies arranged to power the inspection system over the course of the inspection. In this case, the method can further include: acquiring a first plurality of energy measurements characterizing an energy consumption of each of the one or more non-destructive inspection units, by one or more first sensors operatively coupled to the one or more non-destructive inspection units and acquiring a second plurality of energy measurements characterizing an energy consumption of each of the one or more power supplies, by one or more second sensors operatively coupled to the one or more power supplies.

[0015] In some aspects, the one or more non-destructive inspection units can be arranged to use one or more of water, oil, and air conditioning and compressed air and the first plurality of energy measurements include data characterizing one or more of a water usage, an oil temperature, an oil pressure and an air pressure over the course of the inspection. In some aspects, the second plurality of energy measurements can further include data characterizing a battery storage capacity of the one or more power supplies.

[0016] In some aspects, the level of energy efficiency can be provided as a level relative to the one or more other inspection systems.

[0017] In some aspects, the inspection system can further include one or more positioning devices. In this case, the method can further include: positioning, by the one or more positioning devices, the inspection system for one or more inspection tasks of the plurality of inspection tasks, and acquiring a third plurality of energy measurements characterizing an energy consumption of each of the one or more positioning devices, by one or more third sensors operatively coupled to the one or more positioning devices.

[0018] In some aspects, the historical data can further include one or more of time data characterizing an amount of time required to complete each of the plurality of inspection tasks performed by the inspection system or the one or more other inspection systems and a number of inspections performed by the inspection system. In this case, the method can further include: determining, by the at least one data processor, an amount of time required to complete each of the plurality of inspection tasks, comparing, by the at least one data processor, the amount of time required to complete each of the plurality of inspection tasks to the historical data and determining, by the at least one data processor, the level of energy efficiency for the inspection based on the comparing.

[0019] In some aspects, the method can further include: comparing, by the at least one data processor, one or more energy measurements of the plurality of energy measurements acquired for a first task of the plurality of inspection tasks or a first amount of time required to complete the first task to the historical data, determining, based on the comparing, a level of energy efficiency for the first task and providing the level of energy efficiency for the first task.

[0020] In some aspects, the plurality of inspection tasks can include one or more of a validation/calibration task, a positioning task, an evaluation task, a standby task and a re-validation task.

[0021] In some aspects, the inspection method described above can be performed on-demand, as described in greater detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] These and other features will be more readily understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

[0023] FIG. 1 is a diagram illustrating an exemplary inspection system for performing an inspection of an asset according to the systems and methods described herein;

[0024] FIG. 2 is a diagram illustrating another exemplary inspection system for performing an inspection of an asset according to the systems and methods described herein;

[0025] FIG. 3 is a diagram illustrating a collection of inspection systems similar to the inspection systems of FIGS. 1-2, which are all communicatively coupled to a central server used for data analysis and comparison of inspection data from inspection system in the collection;

[0026] FIG. 4 is a diagram illustrating an operation of a conventional inspection system that operates continuously/semi-continuously and that is fully integrated into a production line;

[0027] FIG. 5 is a diagram illustrating an operation of an inspection system as described in FIGS. 1-3 that is configured to carry out inspection operations on-demand over the course of a plurality of days;

[0028] FIG. 6 is a diagram illustrating an extraction process which can be performed by the inspection systems described herein for extracting task related inspection data from inspection operations performed by the inspection systems on-demand over the course of a plurality of days;

[0029] FIG. 7 is a diagram illustrating an exemplary graphical user interface (GUI) display of an the inspection systems described herein;

[0030] FIG. 8 is a block diagram of a computing system suitable for use in implementing the computerized components of the inspection systems according to the subject matter described herein;

[0031] It is noted that the drawings are not necessarily to scale. The drawings are intended to depict only typical aspects of the subject matter disclosed herein, and therefore should not be considered as limiting the scope of the disclosure.

DETAILED DESCRIPTION

[0032] Traditionally, systems for monitoring energy usage by NDT devices/systems operate by monitoring the overall energy consumption of fully integrated NDT systems, which typically operate continuously or semi-continuously. Due to the continuous/semi-continuous operation of such NDT systems, the metrics for energy consumption are usually analyzed based on a macro-scale timeline, however, micro-scale inspection tasks (e.g., durations of individual inspections, step-by-step energy consumption etc.) are overlooked. Accordingly, these traditional systems/methods for monitoring energy usage can lack detailed analysis. This lack of detail can result in overlooking or improperly diagnosing energy consumption issues within the inspection system.

[0033] Further, in many production environments, NDT inspection systems are not fully integrated into the production system, but are rather used on-demand, when inspection is needed. Additionally, in many cases, the frequency at which similar NDT systems are used by different organizations/production environments can vary greatly as a result of differing production line organization, site capacities, production volumes, or the like. Accordingly, it can be difficult, if not impossible, to compare energy consumptions from similar NDT inspection systems that are used on-demand at different frequencies to those that are used continuously/semi-continuously using the conventional systems and methods for monitoring energy usage, as their usage varies juristically. For example, two identical inspection systems inspecting different production lines at different frequencies will consume different amounts of energy. Accordingly, it does not make sense to compare the two inspection systems simply based on a number of specimen inspected or a duration of usage, as this comparison may lead to an incorrect diagnosis of either systems' efficiency.

[0034] Energy used by inspection systems can also extend beyond simply the form of electrical energy. Inspection systems can also consume energy in the form of air pressure, hydraulic pressure, water usage (e.g., as a coupling medium in ultrasonic testing), etc. Accordingly, it can be advantageous for an operator to be able to see a breakdown of the types of energy usage that comprise the overall energy consumption of the inspection system in order to properly address issues within the system.

[0035] The systems and methods described herein address the aforementioned shortcomings. The systems and methods described herein provide a user with a system capable of maximizing energy efficiency and reducing sustaining costs of NDT inspection. In some aspects, the system can include an inspection system configured to inspect an asset at a site. The inspections performed by the inspection system can include a plurality of tasks, which each require various amounts of time and energy to execute. In some cases, the tasks can include, for example, a calibration task, a positioning task, an evaluation task, etc. All of these tasks will be discussed in greater detail below. Accordingly, the system described herein can further include further a plurality of sensors configured to acquire energy measurements characterizing an energy consumption of each of the plurality of tasks. The system can also include a computing system communicatively coupled to the inspection system, as will be discussed in greater detail below. The computing system can be in communication with a server system that stores energy measurements acquired from other inspection systems or historical data characterizing energy consumption of each of the plurality of inspection tasks performed by the inspection system in the past. In some aspects, some or all of the other inspection systems can be similar to the inspection systems described herein. The computing system can be configured to receive the energy measurements from the plurality of sensors and the plurality of energy measurements to data stored within the server system. Based on the comparison, the computing system can be configured to determine a level of energy efficiency for the inspection system and/or distinct levels of energy efficiency for the sub-components of the inspection system that are each arranged to perform various tasks of the plurality of inspection tasks. In some aspects, the levels of energy efficiency determined can be provided as levels of efficiency relative to the other inspection systems communicating with the server.

[0036] The systems and methods described herein advantageously provide an inspection system operator with the ability to determine detailed, task specific energy consumption, and compare those consumptions to consumptions of other inspection systems (either at that site, or at a different site) performing a similar task. Accordingly, the operator is able to determine a relative level of energy efficiency of the inspection system (even in a case where the inspection system is being used on-demand), which can be used to diagnose issues in the system and correct for them. In addition to relying on a number of inspections completed as a base for comparison, the systems and methods described herein also be configured to monitor task-level performance over the course of inspections (e.g., inspection validation/calibration tasks, positioning tasks, inspecting tasks, standby, re-validating tasks, etc.). By monitoring task-level performance, alternatively or in addition to macro-scale performance (e.g., energy consumption over the course of a 24 hour period, or number of inspections completed over a 24 hour period), the systems and methods described herein can provide more accurate determinations regarding the system's performance than conventional systems. Further, monitoring task-level performance allows for more detailed, useful comparisons to be made between on-demand inspection systems having varying levels of usage, and operated by users having different levels of inspection efficiency.

[0037] Further, the systems and methods described herein provide commercial benefits including reduction of carbon footprint of inspection systems, reduced sustaining costs of operating inspection systems, reducing energy and/or water usage of existing devices. Additionally, the systems and methods described herein can provide users with predictive maintenance to increase availability of inspection systems and energy optimization of future inspection systems based on well-defined, task specific energy usage data.

[0038] FIG. 1 is a diagram illustrating an exemplary inspection system 100 for performing an inspection of an asset 140. In some aspects, the inspection system 100 is configured to maximize energy efficiency and reduce sustaining costs of an NDT inspection that includes a plurality of inspection tasks. In some aspects, the system 100 can be integrated into a continuously/semi-continuously operating production line. However, in some aspects, the system 100 can be used on-demand and can be moved around a production facility to carry out inspections as needed.

[0039] The inspection system 100 can include one or more non-destructive inspection units 110 arranged perform one or more of the plurality of inspection tasks over the course of the inspection. For example, in a case where the inspection system 100 is configured to inspect/test a plurality of secure-critical components for transportation, the asset 140 can be a train wheel and the one or more non-destructive inspection units 110 can include any of ultrasonic probes, eddy current probes, calipers, temperature sensors, x-ray sensors, camera sensors, or the like, which are configured to detect defects within the wheel 140. The inspection system can also include one or more power supplies 115 configured to power the inspection system 100 over the course of the inspection. In some aspects, the inspection system 100 can also include one or more miscellaneous devices 120. For example, in some aspects, the one or more miscellaneous devices 120 can include air conditioning systems, water/couplant supply systems or user interfaces. In some aspects, the inspection system 100 can also include one or more positioning/navigation devices 125 configured to position the inspection system 100 for the inspection. In some aspects the one or more positioning/navigation devices 125 can include a navigation system 125a (e.g., wheels powered by a motor and controlled by a controller of the inspection system (e.g., a controller of the computing system 130, not shown)). In some aspects, the one or more positioning/navigation devices 125 can also include a positioning device 125b. For example, in some aspects, the positioning device 125b can be a lifting mechanism, or the like that is configured to properly position the one or more non-destructive inspection units 110 prior to performing the inspection or configured to lift/rotate the train wheel 140 into a desired position prior to or during the inspection.

[0040] The inspection system 100 can also include a computing system 130, as described in greater detail below. In some aspects, the computing system 130 can be provided integrally with the inspection system 100 or can be provided separately (e.g., as a desk top, laptop, tablet, smartphone, or the like). The inspection system 100 can also include a plurality of sensors 135a-135d which are configured to acquire a plurality of energy measurements characterizing an energy consumption of each of the one or more non-destructive inspection units 110, power supplies 115, miscellaneous devices 120 and/or positioning devices 125 as they perform the plurality of inspection tasks.

[0041] For example, in some aspects, the one or more non-destructive inspection units can be require the use of air or hydraulics to operate, or can use water or another type of fluid as a coupling medium (e.g., in the case of ultrasonic testing). Accordingly, in some aspects, the plurality of sensors 135a-135d can include one or more sensors 135a configured to measure air pressure, hydraulic pressure, oil temperature, oil pressure, coupling medium usage, etc. Additionally, the plurality of sensors 135a-135d can include one or more sensors 135b configured to measure energy consumption and/or battery storage capacity of the one or more power supplies 115. The plurality of sensors 135a-135d can further include one or more sensors 135c arranged to acquire measurements characterizing an energy consumption of each of the one or more miscellaneous devices 120. Similarly, the plurality of sensors 135a-135d can further include one or more sensors 135d arranged to acquire measurements characterizing an energy consumption of the one or more positioning devices 125. In some aspects, the computing system 130 can also be configured to monitor an amount of time that it takes to complete each of the plurality of inspection tasks performed by the inspection system 100 during an inspection.

[0042] For example, in some aspects, the plurality of sensors 135a-135d can include, but are not limited to pressure sensors (e.g., piezoelectric, capacitive, strain gauge, hydraulic pressure, oil pressure, diaphragm pressure sensors, etc.), resistance temperature detectors (RTDs), thermocouples, infrared temperature sensors, flowmeters (e.g., ultrasonic, turbine flow sensors, etc.), current transformers (CTs), power meters, battery management systems (BMS).

[0043] FIG. 2 is a block diagram illustrating another exemplary inspection system 200 for performing an inspection of an asset. In some aspects, the inspection system 200 can be similar to the inspection system 100 of FIG. 1. Accordingly, the inspection system 200 can also include a plurality of sensors 205, 210, 215 that are configured to monitor energy consumption of specific task related inspection components of the inspection system. The task related inspection components can include, for example, the one or more non-destructive inspection units 110, power supplies 115, miscellaneous devices 120 and/or positioning devices of FIG. 1, accordingly, like components will not be described. Similarly to as described above, the plurality of sensors 205, 210, 215 can include, for example, water usage sensors, temperature sensors, pressure sensors, battery monitors, etc. The system 200 can also include a computing system 220 communicatively coupled to the plurality of energy sensors 205, 210, 215. In some aspects, the computing system 220 can be similar to the computing system 130 of FIG. 1 and can include at least one processor and a memory storing computer readable instructions, along with other components, as discussed in greater detail below.

[0044] The inspection system 200 can also include a server 230. In some aspects, the server 230 can be configured to store historical data characterizing energy consumption of each of the task related inspection components as they perform the plurality of inspection tasks. Additionally, the server 230 can be configured to store data characterizing energy consumption of each of a plurality of task related inspection components of one or more other inspection systems similar to the inspection system 200. For example, the server 230 can be communicatively coupled to a plurality of inspection systems that are similar to (or different from) the inspection system 200, which are used either by a single organization or by a variety dispersed organizations having similar or different assets/production environments.

[0045] In some aspects, the computing system 220 can be configured to receive, from the plurality of sensors 205, 210, 215, data characterizing energy measurements corresponding to energy consumptions by the specific task related inspection components and compare the energy measurements to the data stored in the server 230, as discussed in greater detail below. Based on this comparing, the computing system 220 can be configured to determine and provide users with energy efficiency levels of the inspection system 200, as discussed in greater detail below.

[0046] FIG. 3 is a block diagram illustrating a collection 300 of inspection systems 310, 320, 330, 340. On some aspects, the inspection systems 310, 320, 330, 340 can be similar or identical inspection systems which are used for various inspection processes within an organization or being used by different organizations at different locations. In some aspects, the similar or identical inspection systems 310, 320, 330, 340 can be operating within a singular facility, however, they may alternatively be inspection systems of different clients located at various client sites. In some aspects, each of the inspection systems 310, 320, 330, 340 can be similar to inspection system 200 of FIG. 2. In the collection 300, each inspection system 310, 320, 330, 340 can be communicatively coupled to the a server 350 to allow for comparison of task related data, as described above. Accordingly, the server 350 can be similar to the server 230 of FIG. 2. In some aspects, each inspection system (e.g., 310) of the plurality of inspections systems 310, 320, 330, 340 can be configured to acquire a plurality of energy measurements from a plurality of sensors characterizing energy consumptions by the specific task related inspection components of the inspection system 310, similarly to as described above in reference to FIGS. 1-2. A computing system of each inspection system 310, 320, 330, 340 can further be configured to compare, via server 350, the energy measurements from the inspection system to the data stored in the server 350 characterizing energy measurements from the other inspection systems of the plurality, as discussed in greater detail below. For example, during an inspection by the inspection system 310, the computing system of the inspection system 310 can compare the energy measurements acquired during the inspection to energy measurements from inspections performed by the other inspection systems 320, 330, 340 (or to historical data from inspections performed by the inspection system 310) to make determinations about the level of energy efficiency of the inspection system 310, as described in greater detail below.

[0047] FIG. 4 is a diagram illustrating an operation 400 of a conventional inspection system that operates continuously/semi-continuously and that is fully integrated into a production line. As shown in FIG. 4, the operations of the inspection system over the course of days 1-n display minimal variations in the times to complete inspections. Accordingly, traditional methods for monitoring energy consumption for continuously operating inspection systems typically only focus on the overall consumption of the system on a macro-scale (e.g., over the course of consecutive days, or based on a total number of inspections performed in a given time period. Accordingly, under traditional methods for monitoring energy consumption of inspection systems, important detail regarding task specific energy consumption are often overlooked, as a result of focusing on the aforementioned macro-scale data. While this data can be compared to day-to-day, or to similar inspection systems that are also operating continuously, on the same task, in similar production environments, the data becomes useless when the inspection systems being compared, such as the inspection systems described herein, are being used on-demand, for different inspections, at different frequencies, by operators having varying degrees of efficiency.

[0048] Alternatively, FIG. 5 is a diagram illustrating an operation 500 of an inspection system (e.g., inspection system 200) that is configured to carry out inspection operations on-demand throughout a day and over the course of days 1-n. As shown in FIG. 5, the inspection tasks 1, 2, 3a, 3b can be performed by the inspection system variously, depending on the demand. In some cases, for example, the inspection tasks 1 and 2 can correspond to a validation/calibration task and a positioning task, respectively. In some cases, the inspection tasks 3a and 3b can both correspond to an evaluation task, where instances of inspection task 3a correspond to evaluations of the asset where no errors/flaws are found, and instances of inspection task 3b correspond to evaluations of the asset where a flaw (e.g., a crack, corrosion, etc.) is found. An evaluation task can include, for example, performing an inspection of the asset using a variety of sensors, probes, and other measurement devices of the one or more non-destructive inspection units 110 of FIG. 1. As shown in FIG. 5, instances of inspection tasks 3b over the course of days 1-n can be shown to require more time (and energy) to complete when compared to the instances of inspection task 3a. For example, if a flaw is found during an evaluation task 3b, another evaluation task may need to be performed again once the specimen being inspected is repaired, replaced, etc., which would require additional amounts of time and energy to complete. Additionally, the times required to complete the inspections or various inspection tasks can display variations throughout a single day and over the course of several days 1-n as a result of, for example, production capacity/volume changing day-to-day, or changing from inspection system to inspection system. For example, as shown in FIG. 5, on day 1, the on-demand inspection system (e.g., inspection system 200) may be tasked with performing inspections 505, 510, 515, 520. As shown in FIG. 5, while the overall time required to complete each inspection 505, 510, 515, 520 varies, the instances of inspection task 3a (e.g., evaluation tasks) within each inspection 505, 510, 515, 520 require similar times to complete. Accordingly, the systems and methods described herein are advantageously capable of breaking down the inspection systems' performance based on energy consumption and duration of individual inspection tasks in order to more accurately compare the inspection tasks with equivalents from other inspection systems, as described in greater detail below.

[0049] As described above, some of the tasks (e.g., inspection tasks 1, 2, 3a, 3b of FIG. 5) that can go into a particular on-demand inspection (e.g., inspection 505) can include, for example, a validation/calibration task, positioning, inspecting, standby, and re-validating. For example, with reference to FIG. 1, in a case where the inspection system 100 is configured used to perform on-demand inspections of train wheels (e.g., train wheel 140), the inspection can require one or more tasks including, but not limited to, positioning the inspection system 100 properly, calibrating the one or more non-destructive inspection units 110 before the inspection, performing the inspection, a standby task, re-validating the inspection coupling and/or results, etc.

[0050] For example, referring back to FIG. 5, in some aspects, inspection task 1 can be a validation/calibration task. In this case, the system can be configured to validate/calibrate the inspection system for a specific inspection. This can include, for example, performing a validation/calibration inspection on a known phantom (a device having known specifications that can be compared to the results of the validation/calibration inspection to be sure that the inspection system is accurate). For example, in a case where the inspection system is configured to inspect/test a plurality of secure-critical components for transportation, such as train wheels, the validation/calibration task can include performing a test inspection on a phantom train wheel of known specifications. Energy used during a validation/calibration task can include, for example, water used as a coupling mechanism for ultrasonic inspection probes, air and/or oil pressure used in any actuators (or heating/cooling devices) of the system, energy consumed by the motive power supplies of the system, etc. At the end of an inspection cycle (e.g., at the end of a day 1-n) the inspection system can be configured to execute another validation/calibration task (e.g., inspection task 1) to ensure that the system is still operating properly. This re-validation/calibration task can also require varying levels of time and energy, depending on whether or not issues are found in the system.

[0051] Further, using the example of the train wheel inspection from FIG. 1, an inspection task 2 can be a positioning task, including the steps of positioning the inspection system 100 under wheel 140 to be inspected using the positioning/navigation system 125. The positioning task can further include handling of the specimen being inspected (e.g. lifting and/or rotating the train wheel into a desired position). Additionally, the positioning task can include properly positioning any probes/sensors around the specimen to perform the inspection, similarly to as described above. All of these positioning tasks consume time and energy that vary juristically from inspection to inspection in an on-demand inspection environment, as shown in FIG. 5 by the changes in duration of the plurality of inspection task 2's across days 1-n.

[0052] Further, in on-demand inspection, the inspection system may experience downtime where it is not being used for an inspection (e.g., "Standby Task" of FIG. 5). A standby task can correspond to a temporary pause in inspection, a lack of need for inspection, or some other factor. In this case, rather than fully powering off, the inspection system can be configured to enter a standby operation mode. While the standby operation mode can require much less energy than, for example, an inspection, the inspection system still uses some energy during standby, which can be useful to know during an energy consumption analysis as described herein.

[0053] As described above, for a given on-demand inspection, each task that goes into the inspection can vary in time and energy consumption. For example, a single task (e.g., an evaluation) can take a longer amount of time and/or consume a higher amount of energy than another task of the same type. Due to the significant variations in inspection times for different on-demand inspections, conventional methods of comparing and analyzing the macro-scale consumption for different on-demand inspection systems provides little value. Accordingly, the systems and methods described herein are capable of extracting and comparing task specific inspection data from the inspection system to task specific inspection data from a large number of identical inspection systems. The aforementioned comparison allows for individual analysis of a large quantity of data from comparable or even identical inspection systems, in order to determine where the inspection system described herein falls in terms of efficiency on a task level, as described in greater detail below. For example, the system described herein provides a user with the ability to compare their inspection system to other similar systems in order to determine why a single probe/actor/sensor/system of the inspection system requires more or less energy compared to others. This capability aids a user in properly diagnosing issues within an on-demand inspection system. By comparing task specific energy data to that of other systems, a user can have more information to help determine a leakage in the inspection system (e.g., a water leak or and air pressure leak), a stick in a movement of the mechanic, a need for maintenance/repair, etc. Accordingly, the systems and methods described herein advantageously provide cost and energy savings via detailed insights into the energy consumption of inspection systems on the task level and can significantly reduce energy usage and maximize performance of existing machines by leveraging the above mentioned predictive maintenance.

[0054] FIG. 6 is a diagram illustrating an extraction process 600, by the systems described herein, for extracting task related inspection data from the overall operation of an inspection system. As shown in FIG. 6, the extraction process 600 can start with the overall operation 500 of the inspection system as shown in FIG. 5. By individually defining the inspection tasks 1, 2, 3a, 3b and standby, the systems and methods described herein can extract the task related inspection data which can then be compared to similar task related data of other similar/identical systems, as described above. For example, as shown in FIG. 6, the extraction process 600 can extract all of the inspection data 605 corresponding to all instances where the inspection system performed the inspection task 2. Similarly, the extraction process 600 can extract all of the inspection data 610 corresponding to all instances where the inspection system performed the inspection tasks 3a and 3b. The extraction process 600 can also extract all of the inspection data corresponding to all instances where the inspection system performed the inspection tasks 1 and standby (not shown). In reference to FIG. 1, the extraction process 600 can be performed by the computing system 130 of the inspection system 100. In this case, the computing system 130 can be configured to receive the energy measurements from the plurality of energy sensors 135a-135d over the course of days 1-n, where the energy measurements characterize a time of use and an energy consumption of components 110, 115, 120, 125 of the inspection system 100 as the variously execute the inspection tasks 1, 2, 3a, 3b and standby over the course of days 1-n. By performing the extraction process 600 to extract time and energy consumption for individual tasks (e.g., data 605, 610), rather than energy consumption over the course of an entire day, the systems and methods described herein provide common, comparable parameters for on-demand inspection systems which can be compared similar extracted data from other on-demand inspection systems, regardless of the production volume, inspection frequency, etc., of each inspection system being compared. Accordingly, the extraction process 600 allows the inspection system to determine a relative level of energy efficiency for each inspection task when compared to other similar inspection systems.

[0055] Based on the comparison of extracted data 605, 610 to that of other, similar on-demand inspection systems, the inspection system can be configured to provide a user with relative levels of energy efficiency for each task. The levels of energy efficiency for each task, which are provided to the user can be used to more accurately diagnose issues within the system by being able to hone in on specific, high consumption tasks. Based on the levels of energy efficiency determined, a user can be more equipped to improve energy efficiency of the system. For example, in reference to FIG. 1, based on a level of efficiency of an evaluation task performed by the one or more non-destructive inspection units 110, the user can be more equipped to determine if a water usage of the unit 110 is relatively high when compared to similar evaluation tasks from other on-demand inspection systems. This determination can also prompt the systems to notify the user to check, for example, a water supply of the unit 110 for a leakage. Similar determinations can be made for air pressure usage of one system, or difficulty of mechanical movements, potentially requiring oil, or any of the other measured metrics described herein. In some aspects, the results of data analysis by the system, including the levels of energy efficiency for each task can be integrated onto inspection application software, which can be further configured to provide a user with tasks to improve energy efficiency based on the data, as well as hints for predictive maintenance. In some aspects, the results of the data analysis by the system, including predictive maintenance, can also be communicated to original equipment manufacturer.

[0056] FIG. 7 is a diagram illustrating an exemplary embodiment of a graphical user interface (GUI) display 700 of an inspection system according to the subject matter described herein. In some aspects, the GUI 700 can include an indication of energy consumptions for task related components of various inspection systems provided at a variety of sites. As shown in FIG. 7, the GUI 700 can be configured to display energy usage of a plurality of systems A, B that are performing inspection tasks at a plurality of sites 1, 2, 3. In some aspects, the plurality of systems A, B can include, for example, any of the one or more non-destructive inspection units 110, power supplies 115, miscellaneous devices 120 and/or positioning devices 125. Accordingly, while the energy usage of the plurality of systems A, B that are performing inspection tasks at a plurality of sites 1, 2, 3 are shown in kilowatts, it should be noted that the energy usage can be provided in terms of water usage, air pressure, temperature, or any of the other energy metrics described herein.

[0057] In some aspects, the systems A, B can be components of a larger inspection system (e.g., inspection system 100 of FIG. 1) which is provided at each site 1, 2, 3. Accordingly, while the day-to-day inspection volume may differ from site to site for each inspection system having components A, B, the energy usage data from systems A, B of each inspection system can still be extracted and compared to energy usage data from systems A, B of other similar inspection systems at other sites, as described above. As shown in FIG. 7, the energy usage from systems A, B at each site 1, 2, 3 as they perform specific inspection tasks can be extracted (e.g., using the extraction process 600 of FIG. 6) and compared to one another to determine relative levels of energy efficiency for each system A, B. For example, based on the extracted data displayed in GUI 700, the user can be informed that the energy consumption of system B at site 2 when performing a given inspection task is relatively high when compared to the energy consumption of systems B of sites 1 and 2 when performing a similar or identical inspection task. This can indicate to the user that there may be an issue with the system B at site 2 that warrants further investigation. In some aspects, the tie taken to complete an inspection task can also be displayed to the GUI 700. Accordingly, the systems and methods described herein can be configured to leverage both time taken to complete tasks, and energy consumed during the task to draw more holistic conclusions regarding the efficiency of the inspection system/inspection operation.

[0058] FIG. 8 is a block diagram 800 of a computing system 810 suitable for use in implementing the computerized components described herein. For example, in some aspects, the computing system 810 can be similar to the computing systems 130 and 220 of FIGS. 1 and 2, respectively. In broad overview, the computing system 810 includes at least one processor 850 for performing actions in accordance with instructions, and one or more memory devices 860 and/or 870 for storing instructions and data. The illustrated example computing system 810 includes one or more processors 850 in communication, via a bus 815, with memory 870 and with at least one network interface controller 820 with a network interface 825 for connecting to external devices 830. In some aspects, the external devices 830 can include, for example, the energy sensors 135a-135d of FIG. 1, the energy sensors 205, 210, 215 of FIG. 2 and the servers 230, 350 of FIGS. 2 and 3, respectively. The one or more processors 850 are also in communication, via the bus 815, with each other and with any I/O devices 840 at one or more I/O interfaces 840, and any other devices 880. The processor 850 illustrated incorporates, or is directly connected to, cache memory 860. Generally, a processor will execute instructions received from memory. In some aspects, the computing system 810 can be configured within a cloud computing environment, a virtual or containerized computing environment, and/or a web-based microservices environment.

[0059] In more detail, the processor 850 can be any logic circuitry that processes instructions, e.g., instructions fetched from the memory 870 or cache 860. In many aspects, the processor 850 is an embedded processor, a microprocessor unit or special purpose processor. The computing system 810 can be based on any processor, e.g., suitable digital signal processor (DSP), or set of processors, capable of operating as described herein. In some aspects, the processor 850 can be a single core or multi-core processor. In some aspects, the processor 850 can be composed of multiple processors.

[0060] The memory 870 can be any device suitable for storing computer readable data. The memory 870 can be a device with fixed storage or a device for reading removable storage media. Examples include all forms of non-volatile memory, media and memory devices, semiconductor memory devices (e.g., EPROM, EEPROM, SDRAM, flash memory devices, and all types of solid state memory), magnetic disks, and magneto optical disks. A computing device 810 can have any number of memory devices 870.

[0061] The cache memory 860 is generally a form of high-speed computer memory placed in close proximity to the processor 850 for fast read/write times. In some implementations, the cache memory 860 is part of, or on the same chip as, the processor 850.

[0062] The network interface controller 820 manages data exchanges via the network interface 825. The network interface controller 820 handles the physical, media access control, and data link layers of the Open Systems Interconnect (OSI) model for network communication. In some implementations, some of the network interface controller's tasks are handled by the processor 850. In some implementations, the network interface controller 820 is part of the processor 850. In some implementations, a computing device 810 has multiple network interface controllers 820. In some implementations, the network interface 825 is a connection point for a physical network link, e.g., an RJ 45 connector. In some implementations, the network interface controller 820 supports wireless network connections via network interface port 825. Generally, a computing device 810 exchanges data with other external devices 830, such as another computing devices, network devices, via physical or wireless links to a network interface 825. In some implementations, the network interface controller 820 implements a network protocol such as LTE, TCP/IP Ethernet, IEEE 802.11, IEEE 802.16, or the like.

[0063] The external devices 830 are connected to the computing device 810 via a network interface port 825. The external devices 830 can be a peer computing device, a network device, or any other computing device with network functionality. In some aspects, as described above, the external devices 830 can include a server (e.g., server 230 or 350 of FIGS. 2-3) or a network device such as a hub, a bridge, a switch, or a router, connecting the computing device 810 to a data network such as the Internet. In some aspects, the external devices 830 can further include a server for at least one original equipment manufacturer (OEM) and the computing device 810 can be configured to communicate information described herein (e.g., efficiency metrics and predictive maintenance) directly to the OEM.

[0064] In some uses, the I/O interface 840 supports an input device and/or an output device (not shown). In some uses, the input device and the output device are integrated into the same hardware, e.g., as in a touch screen. In some uses, such as in a server context, there is no I/O interface 840 or the I/O interface 840 is not used. In some uses, additional other components 880 are in communication with the computer system 810, e.g., external devices connected via a universal serial bus (USB).

[0065] The other devices 880 can include an I/O interface 840, external serial device ports, and any additional co-processors. For example, a computing system 810 can include an interface (e.g., a universal serial bus (USB) interface, or the like) for connecting input devices (e.g., a keyboard, microphone, mouse, or other pointing device), output devices (e.g., video display, speaker, refreshable Braille terminal, or printer), or additional memory devices (e.g., portable flash drive or external media drive). In some implementations an I/O device is incorporated into the computing system 810, e.g., a touch screen on a tablet device. In some implementations, a computing device 810 includes an additional device 880 such as a co-processor, e.g., a math co-processor that can assist the processor 850 with high precision or complex calculations.

[0066] Certain exemplary aspects have been described to provide an overall understanding of the principles of the structure, function, manufacture, and use of the systems, devices, and methods disclosed herein. One or more examples of these aspects have been illustrated in the accompanying drawings. Those skilled in the art will understand that the systems, devices, and methods specifically described herein and illustrated in the accompanying drawings are non-limiting exemplary aspects and that the scope of the present invention is defined solely by the claims. The features illustrated or described in connection with one exemplary embodiment may be combined with the features of other aspects. Such modifications and variations are intended to be included within the scope of the present invention. Further, in the present disclosure, like-named components of the aspects generally have similar features, and thus within a particular embodiment each feature of each like-named component is not necessarily fully elaborated upon.

[0067] The subject matter described herein can be implemented in analog electronic circuitry, digital electronic circuitry, and/or in computer software, firmware, or hardware, including the structural means disclosed in this specification and structural equivalents thereof, or in combinations of them. The subject matter described herein can be implemented as one or more computer program products, such as one or more computer programs tangibly embodied in an information carrier (e.g., in a machine-readable storage device), or embodied in a propagated signal, for execution by, or to control the operation of, data processing apparatus (e.g., a programmable processor, a computer, or multiple computers). A computer program (also known as a program, software, software application, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file. A program can be stored in a portion of a file that holds other programs or data, in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub-programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

[0068] The processes and logic flows described in this specification, including the method steps of the subject matter described herein, can be performed by one or more programmable processors executing one or more computer programs to perform functions of the subject matter described herein by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus of the subject matter described herein can be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application-specific integrated circuit).

[0069] Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processor of any kind of digital computer. Generally, a processor will receive instructions and data from a read-only memory or a random access memory or both. The essential elements of a computer are a processor for executing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto-optical disks, or optical disks. Information carriers suitable for embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, (e.g., EPROM, EEPROM, and flash memory devices); magnetic disks, (e.g., internal hard disks or removable disks); magneto-optical disks; and optical disks (e.g., CD and DVD disks). The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0070] To provide for interaction with a user, the subject matter described herein can be implemented on a computer having a display device, e.g., a touch-screen display, a cathode ray tube (CRT) or liquid crystal display (LCD) monitor, for receiving inputs and for displaying information to the user and a keyboard and a pointing device, (e.g., a mouse or a trackball), by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well. For example, feedback provided to the user can be any form of sensory feedback, (e.g., visual feedback, auditory feedback, or tactile feedback), and input from the user can be received in any form, including acoustic, speech, or tactile input. For example, in some aspects, the display device can be configured to display the GUI 700 of FIG. 7, or similar GUIs.

[0071] The techniques described herein can be implemented using one or more modules. As used herein, the term “module” refers to computing software, firmware, hardware, and/or various combinations thereof. At a minimum, however, modules are not to be interpreted as software that is not implemented on hardware, firmware, or recorded on a non-transitory processor readable recordable storage medium (i.e., modules are not software *per se*). Indeed “module” is to be interpreted to always include at least some physical, non-transitory hardware such as a part of a processor or computer. Two different modules can share the same physical hardware (e.g., two different modules can use the same processor and network interface). The modules described herein can be combined, integrated, separated, and/or duplicated to support various applications. Also, a function described herein as being performed at a particular module can be performed at one or more other modules and/or by one or more other devices instead of or in addition to the function performed at the particular module. Further, the modules can be implemented across multiple devices and/or other components local or remote to one another. Additionally, the modules can be moved from one device and added to another device, and/or can be included in both devices.

[0072] The subject matter described herein can be implemented in a computing system that includes a back-end component (e.g., a data server), a middleware component (e.g., an application server), or a front-end component (e.g., a client computer having a graphical user interface or a web browser through which a user can interact with an implementation of the subject matter described herein), or any combination of such back-end, middleware, and front-end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network ("LAN") and a wide area network ("WAN"), e.g., the Internet.

[0073] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about," "approximately," and "substantially," are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Here and throughout the specification and claims, range limitations may be combined and/or interchanged, such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise.

[0074] One skilled in the art will appreciate further features and advantages of the invention based on the above-described aspects. Accordingly, the present application is not to be limited by what has been particularly shown and described, except as indicated by the appended claims. All publications and references cited herein are expressly incorporated by reference in their entirety.

CLAIMS

1. An inspection system configured to perform an inspection of an asset, wherein the inspection includes a plurality of inspection tasks, the inspection system comprising:

a plurality of sensors configured to acquire a plurality of energy measurements characterizing an energy consumption of each of the plurality of inspection tasks;

a server system storing historical data characterizing energy consumption of each of the plurality of inspection tasks performed by the inspection system or one or more other inspection systems similar to the inspection system; and

a computing system communicatively coupled to the inspection system and the server system, the computing system including at least one data processor and a memory storing computer-readable instructions which, when executed by the at least one processor, cause the at least one processor to perform operations including:

receiving the plurality of energy measurements from the plurality of sensors,

comparing the plurality of energy measurements to the historical data,

determining, based on the comparing, a level of energy efficiency of the inspection system, and

providing the level of energy efficiency.

2. The inspection system of claim 1, further comprising:

one or more non-destructive inspection units configured perform one or more of the plurality of inspection tasks over the course of the inspection; and

one or more power supplies configured to power the inspection system over the course of the inspection,

wherein the plurality of sensors comprise one or more first sensors configured to acquire a first plurality of energy measurements characterizing an energy consumption of each of the one or more non-destructive inspection units, and

one or more second sensors configured to acquire a second plurality of energy measurements characterizing an energy consumption of each of the one or more power supplies.

3. The inspection system of claim 2, wherein the one or more non-destructive inspection units are configured to use one or more of water, oil, and air conditioning and compressed air and the first plurality of energy measurements include data characterizing one or more of a

water usage, an oil temperature, an oil pressure and an air pressure and the second plurality of energy measurements further comprise data characterizing a battery storage capacity of the one or more power supplies.

4. The inspection system of claim 1, wherein the level of energy efficiency is provided as a level relative to the one or more other inspection systems.

5. The inspection system of claim 2, further comprising:

one or more positioning devices configured to position the inspection system for the inspection,

wherein the plurality of sensors further comprise one or more third sensors configured to acquire a third plurality of energy measurements characterizing an energy consumption of each of the one or more positioning devices.

6. The inspection system of claim 1, wherein the historical data further comprises one or more of time data characterizing an amount of time required to complete each of the plurality of inspection tasks performed by the inspection system or the one or more other inspection systems and a number of inspections performed by the inspection system.

7. The inspection system of claim 6, wherein the operations performed by the at least one processor further comprise:

determining an amount of time required to complete each of the plurality of inspection tasks;

comparing the amount of time required to complete each of the plurality of inspection tasks to the historical data; and

determining, based on the comparing, the level of energy efficiency for the inspection system.

8. The inspection system of claim 7, wherein the operations performed by the at least one processor further comprise:

comparing one or more energy measurements of the plurality of energy measurements acquired for a first task of the plurality of inspection tasks or a first amount of time required to complete the first task to the historical data;

determining, based on the comparing, a level of energy efficiency for the first task; and providing the level of energy efficiency for the first task.

9. The inspection system of claim 1, wherein the plurality of inspection tasks comprise one or more of a validation/calibration task, a positioning task, an evaluation task, a standby task and a re-validation task.

10. The inspection system of claim 1, wherein the inspection system is configured to perform the inspection of the asset on-demand.

11. A method of performing an inspection of an asset by an inspection system, wherein the inspection includes a plurality of inspection tasks performed by the inspection system, the method comprising;

acquiring plurality of energy measurements characterizing an energy consumption of each of the plurality of inspection tasks by a plurality of sensors operatively coupled to the inspection system;

receiving, by at least one data processor of a computing system comprising a memory storing computer-readable instructions to be executed by the at least one processor, the plurality of energy measurements from the plurality of sensors;

comparing, by the at least one data processor, the plurality of energy measurements to historical data stored within a server system, the historical data characterizing energy consumption of each of the plurality of inspection tasks performed by the inspection system or one or more other inspection systems similar to the inspection system;

determining, by the at least one data processor, a level of energy efficiency for the inspection system, and

providing, by the at least one data processor, the level of energy efficiency.

12. The method of claim 11, wherein the inspection system further comprises one or more non-destructive inspection units configured perform one or more of the plurality of inspection tasks over the course of the inspection and one or more power supplies configured to power the inspection system over the course of the inspection, the method further comprising:

acquiring a first plurality of energy measurements characterizing an energy consumption of each of the one or more non-destructive inspection units, by one or more first sensors operatively coupled to the one or more non-destructive inspection units; and acquiring a second plurality of energy measurements characterizing an energy consumption of each of the one or more power supplies, by one or more second sensors operatively coupled to the one or more power supplies.

13. The method of claim 12, wherein the one or more non-destructive inspection units are configured to use one or more of water, oil, and air conditioning and compressed air and the first plurality of energy measurements include data characterizing one or more of a water usage, an oil temperature, an oil pressure and an air pressure over the course of the inspection and the second plurality of energy measurements further comprise data characterizing a battery storage capacity of the one or more power supplies.

14. The method of claim 11, wherein the level of energy efficiency is provided as a level relative to the one or more other inspection systems.

15. The method of claim 12, wherein the inspection system further comprises one or more positioning devices, the method further comprising:

positioning, by the one or more positioning devices, the inspection system for one or more inspection tasks of the plurality of inspection tasks; and

acquiring a third plurality of energy measurements characterizing an energy consumption of each of the one or more positioning devices, by one or more third sensors operatively coupled to the one or more positioning devices.

16. The method of claim 11, wherein the historical data further comprises one or more of time data characterizing an amount of time required to complete each of the plurality of inspection tasks performed by the inspection system or the one or more other inspection systems and a number of inspections performed by the inspection system.

17. The method of claim 16, further comprising:

determining, by the at least one data processor, an amount of time required to complete each of the plurality of inspection tasks;

comparing, by the at least one data processor, the amount of time required to complete each of the plurality of inspection tasks to the historical data; and

determining, by the at least one data processor, the level of energy efficiency for the inspection based on the comparing.

18. The method of claim 17, further comprising:

comparing, by the at least one data processor, one or more energy measurements of the plurality of energy measurements acquired for a first task of the plurality of inspection tasks or a first amount of time required to complete the first task to the historical data;

determining, based on the comparing, a level of energy efficiency for the first task; and

providing the level of energy efficiency for the first task.

19. The method of claim 11, wherein the plurality of inspection tasks comprise one or more of a validation/calibration task, a positioning task, an evaluation task, a standby task and a re-validation task.

20. The method of claim 11, wherein the inspection is performed on-demand.

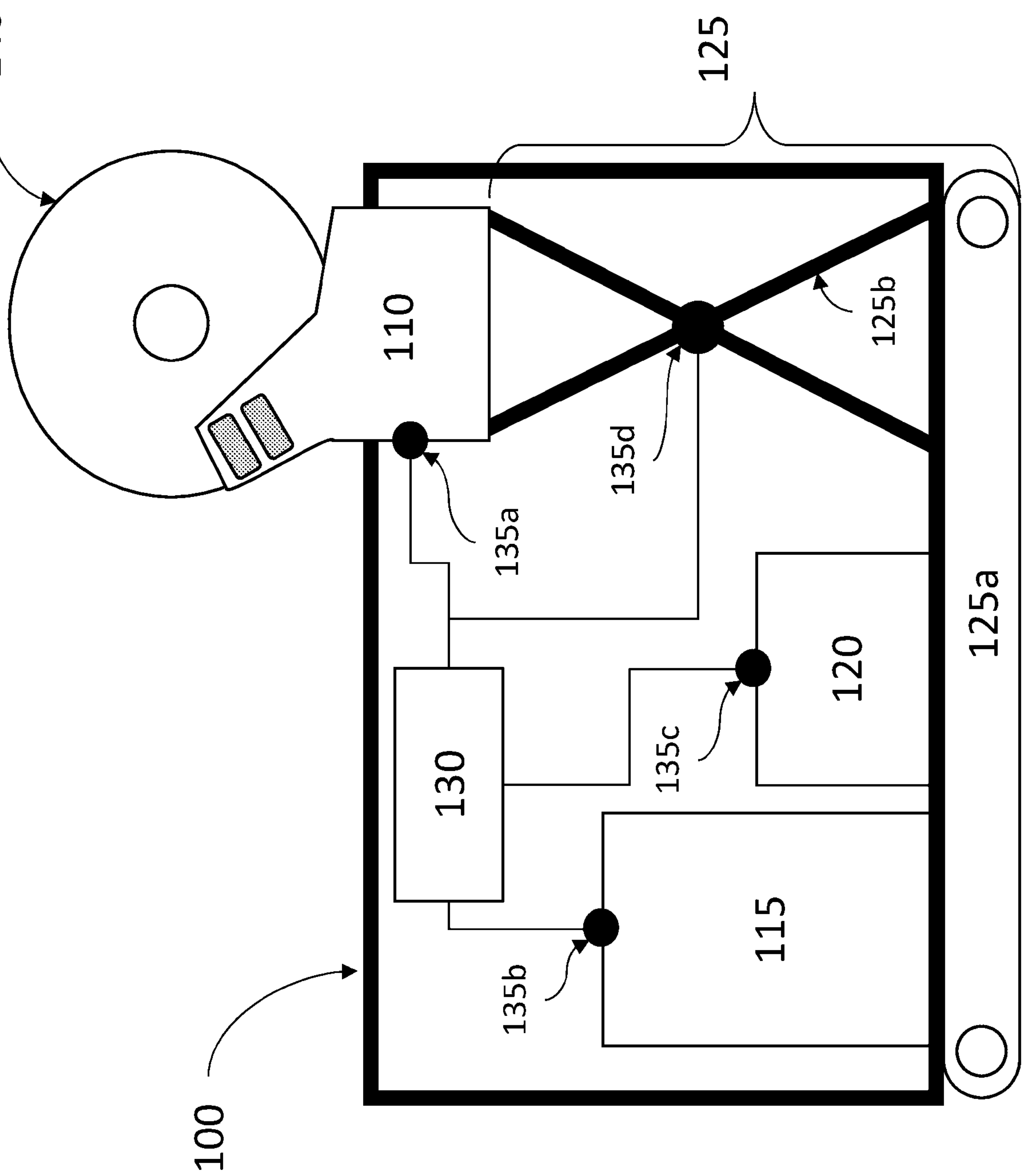


FIG. 1

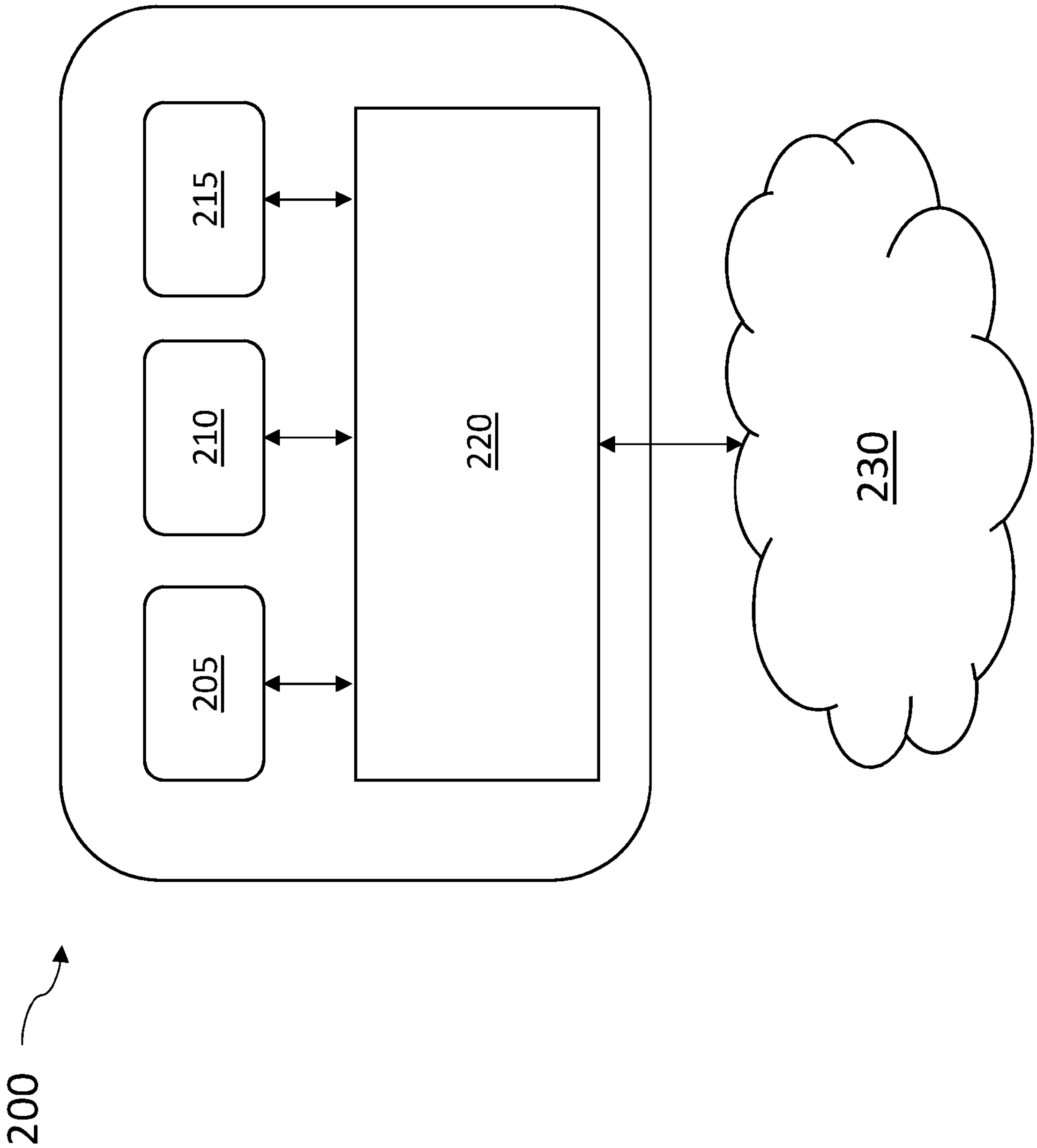


FIG. 2

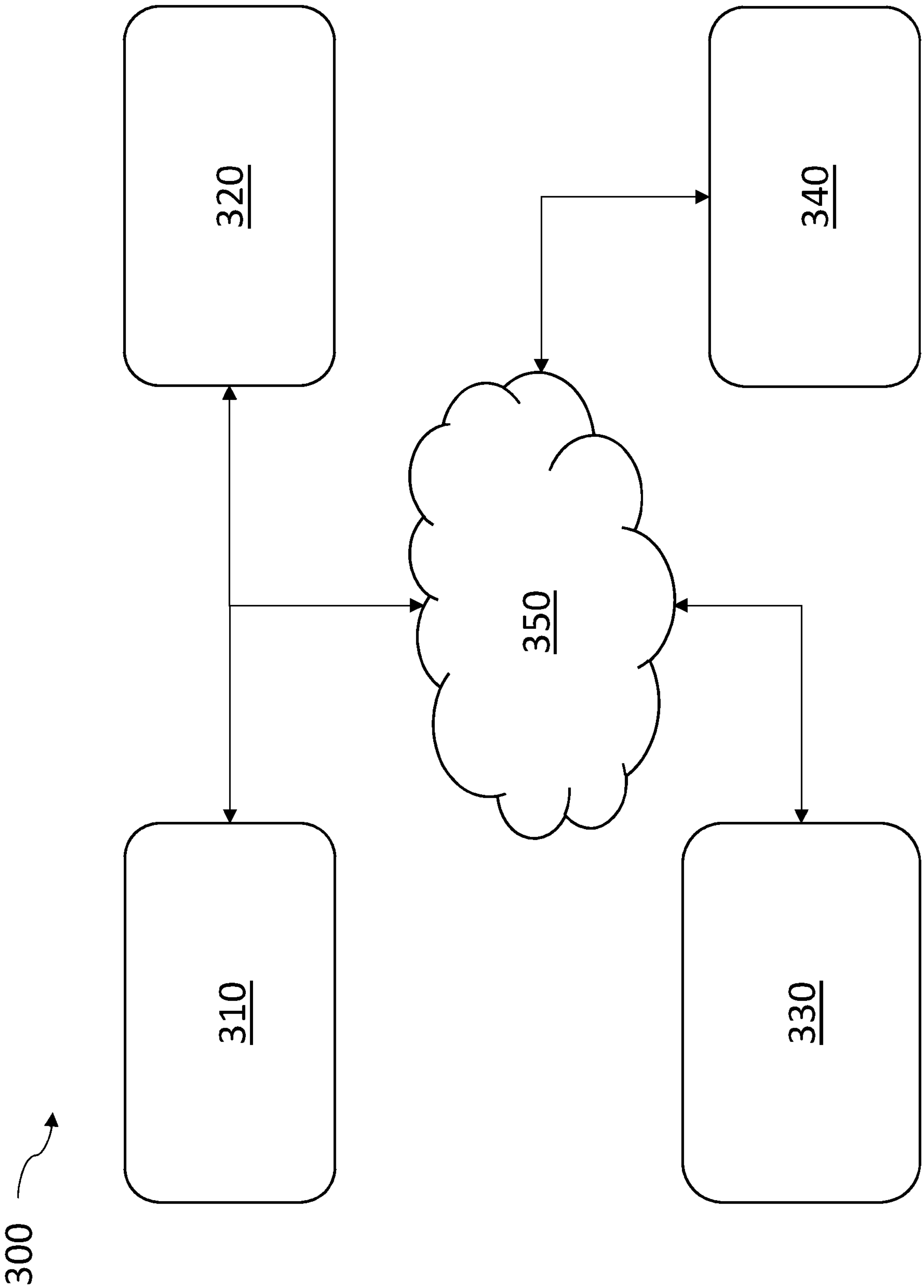
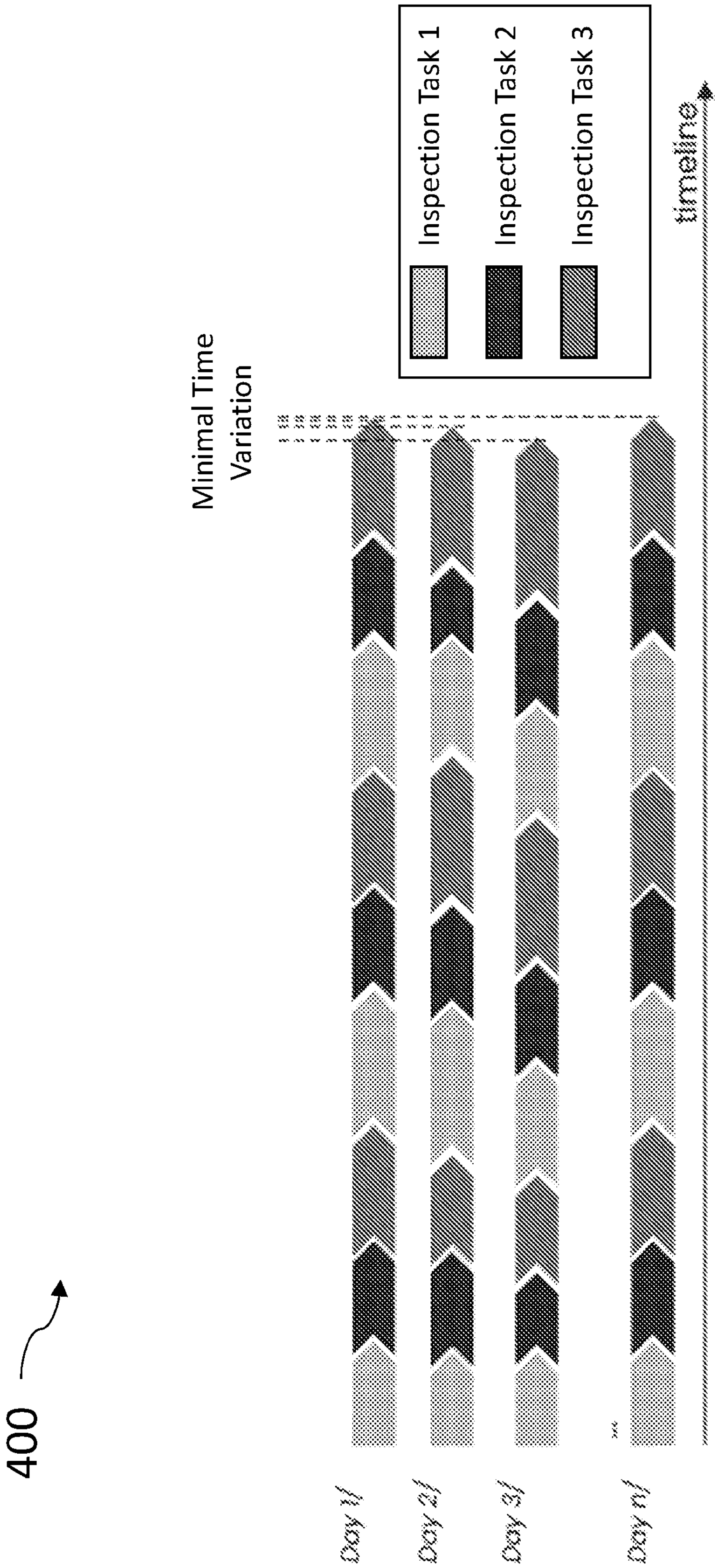


FIG. 3



400
Minimal Time Variation
Inspection Task 1
Inspection Task 2
Inspection Task 3
timeline
Day 1
Day 2
Day 3
Day n

FIG. 4

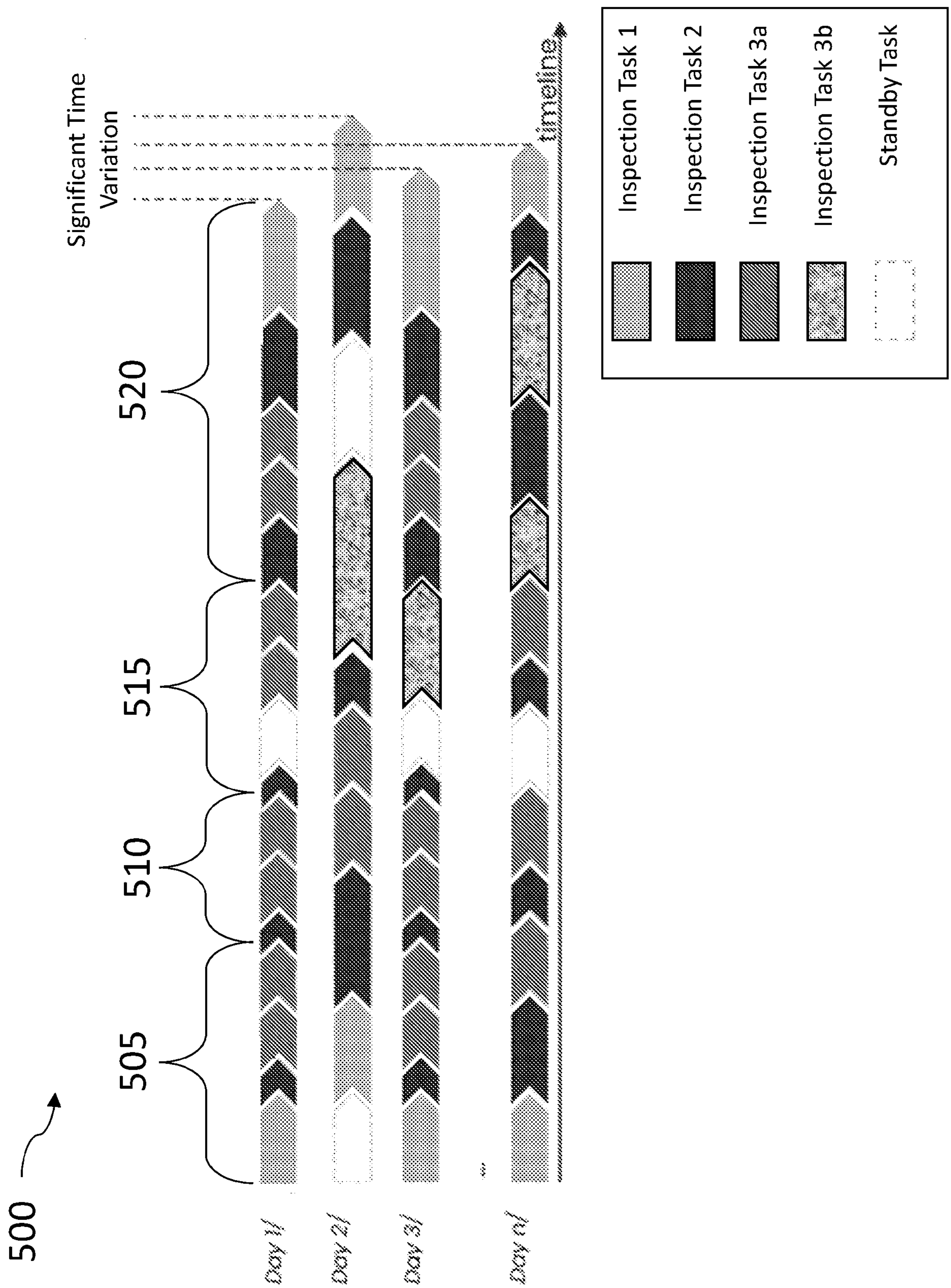

500
505
510
515
520
Significant Time Variation
Day 1
Day 2
Day 3
Day n
timeline
Inspection Task 1
Inspection Task 2
Inspection Task 3a
Inspection Task 3b
Standby Task

FIG. 5

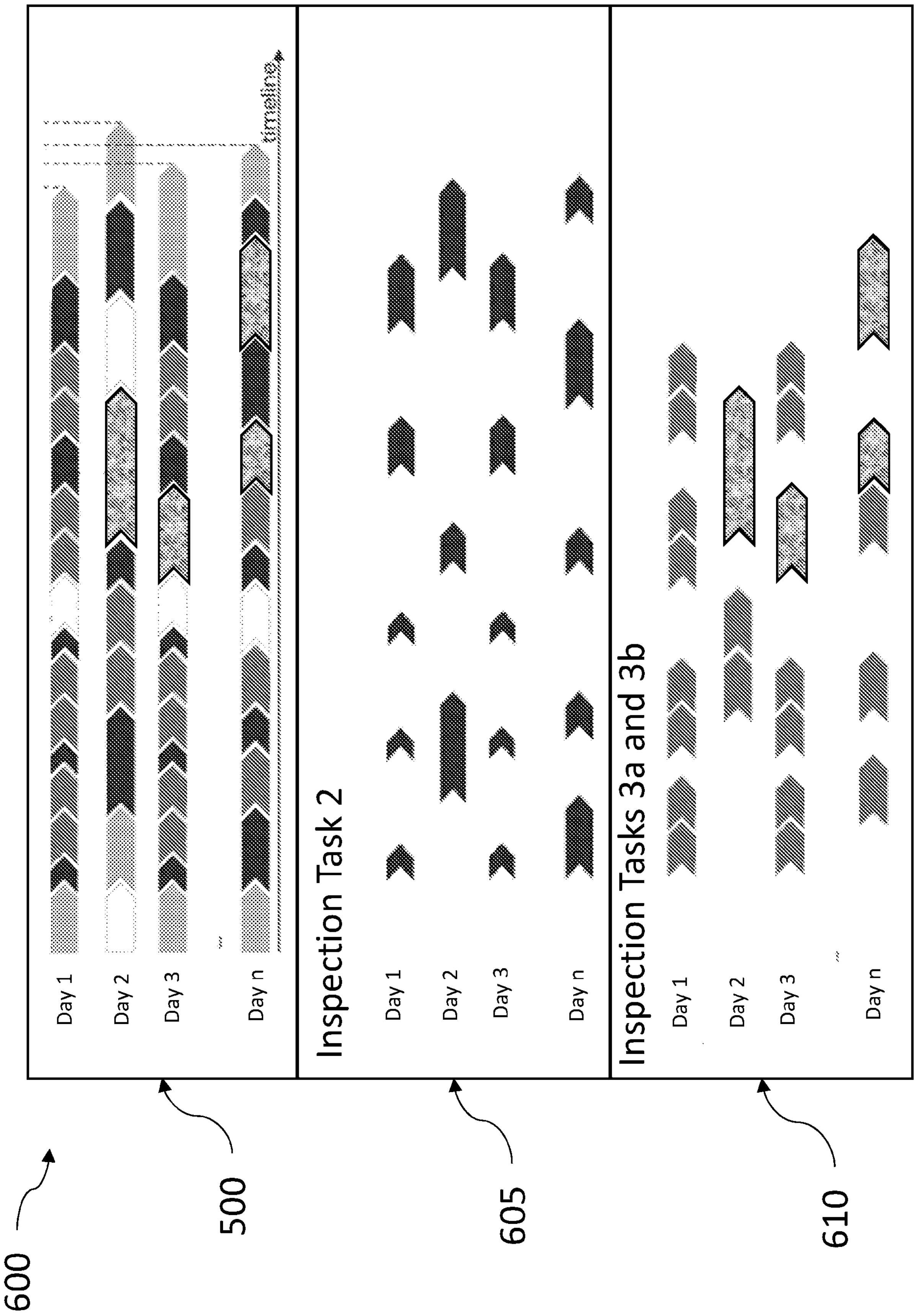

600
500
605
610
Day 1
Day 2
Day 3
Day n
timeline
Inspection Task 2
Inspection Tasks 3a and 3b

FIG. 6

700

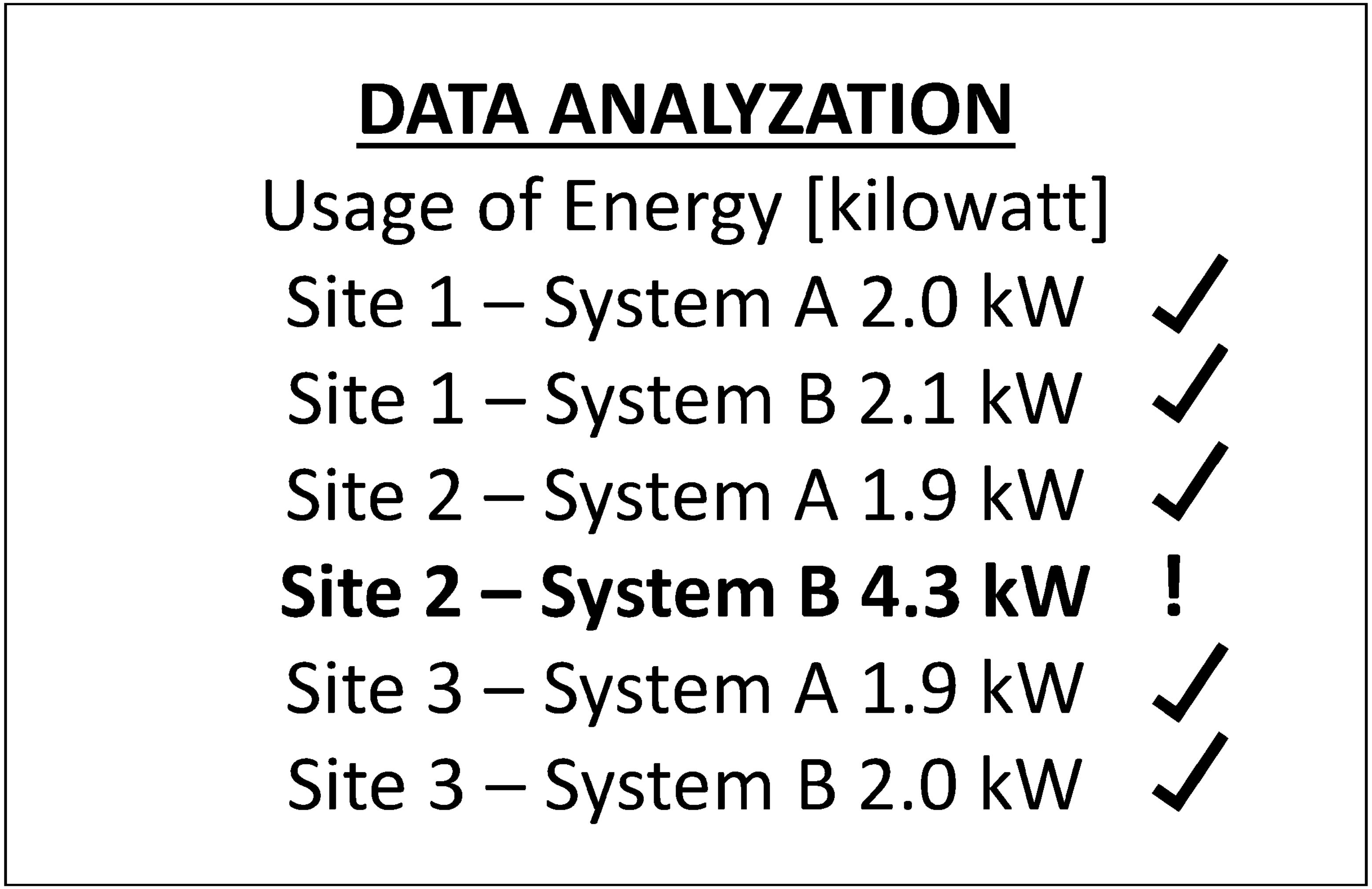

DATA ANALYZATION
Usage of Energy [kilowatt]
Site 1 – System A 2.0 kW ✓
Site 1 – System B 2.1 kW ✓
Site 2 – System A 1.9 kW ✓
Site 2 – System B 4.3 kW !
Site 3 – System A 1.9 kW ✓
Site 3 – System B 2.0 kW ✓

FIG. 7

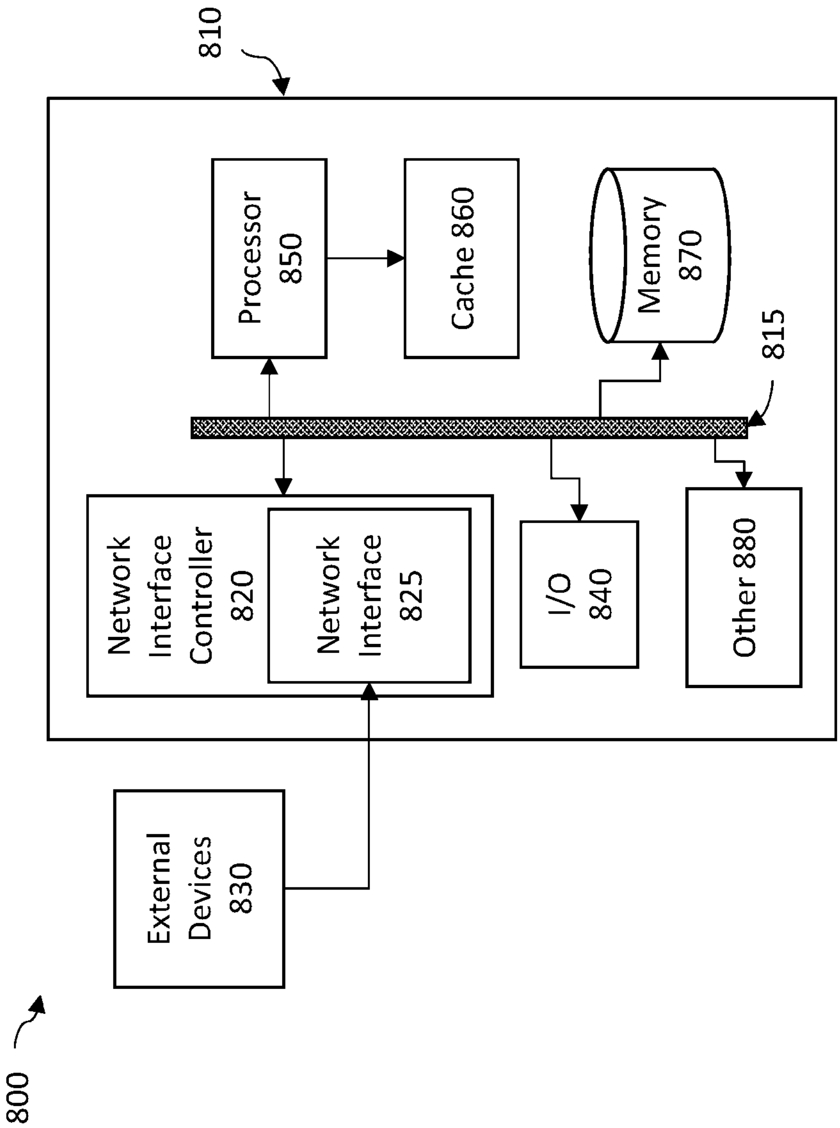

800
810
815
Processor 850
Cache 860
Memory 870
Network Interface Controller 820
Network Interface 825
I/O 840
Other 880
External Devices 830

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2024/033200

A. CLASSIFICATION OF SUBJECT MATTER

G01N 27/90(2006.01)i; **G01N 29/04**(2006.01)i; **G01N 23/083**(2006.01)i; **G01N 21/88**(2006.01)i

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)

G01N 27/90(2006.01); G01H 1/00(2006.01); G01N 29/04(2006.01); G01N 29/22(2006.01); G05B 13/02(2006.01); G06F 7/24(2006.01); G06N 3/08(2006.01); G06Q 30/00(2006.01); G06Q 50/06(2012.01); G06Q 50/26(2012.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: inspection system, inspection task, sensor, server, computing system, energy measurement, energy efficiency, power supply, positioning device

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2017-0052060 A1 (ALSTOM TRANSPORT TECHNOLOGIES et al.) 23 February 2017 (2017-02-23) paragraph [0051], claim 12, and figure 1	1-5,9-15,19,20 6-8,16-18
Y	US 2009-0012654 A1 (CULP et al.) 08 January 2009 (2009-01-08) paragraphs [0019]-[0044], claims 1, 2, and figures 1-3	1-5,9-15,19,20
Y	US 2019-0017970 A1 (ASTEC, INC.) 17 January 2019 (2019-01-17) paragraphs [0048]-[0052] and figures 5-9	2,3,5,12,13,15
A	US 2022-0383334 A1 (CASE WESTERN RESERVE UNIVERSITY) 01 December 2022 (2022-12-01) paragraphs [0060]-[0113] and figures 1-4	1-20
A	KR 10-2021-0084771 A (CHOI, YOU LIM) 08 July 2021 (2021-07-08) paragraphs [0028]-[0094] and figures 1-5	1-20

☐ 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
"D" document cited by the applicant in the international application
"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
13 September 2024	**13 September 2024**
Name and mailing address of the ISA/KR **Korean Intellectual Property Office** **189 Cheongsa-ro, Seo-gu, Daejeon** **35208, Republic of Korea** Facsimile No. **+82-42-481-8578**	Authorized officer **PARK, Tae Wook** Telephone No. **+82-42-481-3405**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2024/033200

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				ES	2549652	A1	30 October 2015
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				US	7962536	B2	14 June 2011
US	2019-0017970	A1	17 January 2019	US	10908128	B2	02 February 2021
				US	2016-0274584	A1	22 September 2016
				US	2017-0146992	A1	25 May 2017
US	2022-0383334	A1	01 December 2022	US	11403647	B2	02 August 2022
				US	2019-0347670	A1	14 November 2019
KR	10-2021-0084771	A	08 July 2021	None			