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(54) **Title:** A METHOD AND SYSTEM FOR DETERMINING EQUIPMENT SETTINGS OF A BUILDING MANAGEMENT SYSTEM OF A BUILDING

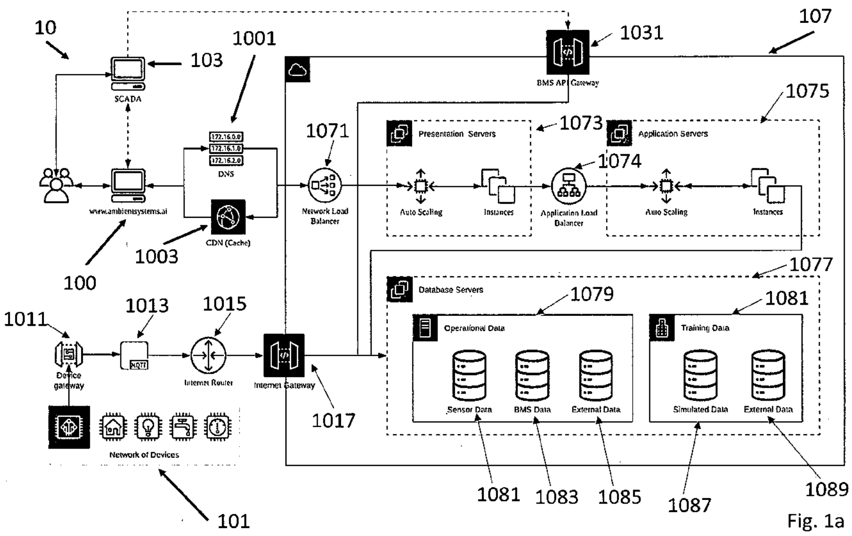

Fig. 1a

(57) **Abstract:** A computer implemented method of determining equipment settings of a building management system 10 of a building, the building including a controlled indoor environment in which crops are cultivated is disclosed herein. In a specific embodiment, the method comprises: receiving equipment settings data 1.3 from the building management system 10, the equipment settings data 1.3 being associated with a plurality of environmental parameters of the controlled indoor environment; and receiving environmental sensor measurements 1.1 for the controlled indoor environment; receiving crop data 1.2b relating to characteristics of the crops. The method further comprises determining a first correlation between the equipment settings data 1.3 and the environmental sensor measurements 1.1; determining a second correlation between the environmental sensor measurements 1.1 and the crop data 1.2b; determining a third correlation between the equipment settings data 1.3 and the crop data 1.2b, based on the determined first and second correlations;

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and determining an adjustment of one or more equipment settings of the building management system 10 to be adjusted based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment. A system 107 for determining equipment settings of a building management system 10 of a building is also disclosed.

A method and system for determining equipment settings of a building management system of a building

Background and Field

The present disclosure relates to methods and systems for management of buildings in which indoor farming facilities are located.

Indoor farm operators rely on conventional building air conditioning and mechanical ventilation (ACMV) equipment to manage the indoor climate. This equipment is often outdated and may not suitable for the climate needs of modern indoor farms. Existing approaches typically rely on pre-determined schedules that run for several months at a time. Farm operators usually do not have the skillset in-house to manage multiple and sometimes competing priorities, such as balancing temperature, humidity, and ventilation requirements, along with complex building standards and guidelines.

It is desirable to provide a method for building automation which addresses at least one of the drawbacks of the prior art and/or to provide the public with a useful choice.

Summary

In a first aspect, there is provided a computer implemented method of determining equipment settings of a building management system of a building, the building including a controlled indoor environment in which crops are cultivated. The method comprises: receiving equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment; receiving environmental sensor measurements for the controlled indoor environment; receiving crop data relating to characteristics of the crops; determining a first correlation between the equipment settings data and the environmental sensor measurements; determining a second correlation between the environmental sensor measurements and the crop data; determining a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations; and determining an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment. By determining a correlation between equipment settings and crop outcomes from a correlation between equipment settings and building climate and a correlation between building climate and crop outcomes, improved responsiveness of automatic equipment setting adjustment to crop outcomes maybe enabled and any building may potentially be employed for indoor farming, without specific adaptation of the building management system. Preferably, determining the first correlation, the second correlation and the third correlation comprises employing multi-output regression.

In a specific embodiment, determining the adjustment of the one or more equipment settings of the building management system based on the determined third correlation further includes determining a time series of the one or more equipment settings. This enables dynamic adjustment of the equipment settings over time to potentially ensure that optimal equipment settings adjust as the needs of the crops change.

Advantageously, predicting crop output based on the determined third correlation comprises predicting a plurality of crop outputs each corresponding to iterative adjustments of the one or more equipment settings; and determining the adjustment of the one or more equipment settings based the predicted plurality of crop outputs. In a specific embodiment, wherein determining the adjustment of the one or more equipment settings based the predicted plurality of predicted crop outputs includes identifying an optimal equipment setting corresponding to an optimal predicted crop output from the predicted plurality of crop outputs; and determining the adjustment of the one or more equipment settings based on the identified optimal equipment setting.

In a second aspect, there is provided system for determining equipment settings of a building management system of a building, the building including a controlled indoor environment in which crops are cultivated. The system comprises: an input configured to: receive equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment, receive environmental sensor measurements for the controlled indoor environment, and receive crop data relating to characteristics of the crops. The system also comprises a processor configured to: determine a first correlation between the equipment settings data and the environmental sensor measurements, determine a second correlation between the climate sensor measurements and the crop data, determine a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations, and determine an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment. Lastly, the system comprises an output configured to output instructions relating to the adjustment to the building management system. The instructions may be configured to cause the one or more equipment settings to be adjusted.

Preferably, the processor is further configured to determine the first correlation, the second correlation and the third correlation by employing multi-output regression.

In a specific embodiment, determining the adjustment of one or more equipment settings of the building management system based on the determined third correlation further includes determining a time series of the one or more equipment settings. The the output may be further configured to output instructions relating to the adjustment to the building management system according to the determined time series.

Advantageously, the processor is further configured to predict crop output based on the determined third correlation and to determine the adjustment of the one or more equipment settings of the building management system based on the predicted crop output. In a specific embodiment, predicting crop output based on the determined third correlation comprises may comprise predicting a plurality of crop outputs each corresponding to iterative adjustments of the one or more equipment settings. The processor may be further configured to determine the adjustment of the one or more equipment settings based the determined plurality of predicted crop outputs.

Preferably, determining the adjustment of the one or more equipment settings based the predicted plurality of predicted crop outputs comprises identifying an optimal selected equipment setting corresponding to an optimal predicted crop output from the predicted plurality of crop outputs. The processor may be configured to determine the adjustment of the one or more equipment settings based on the optimal selected equipment setting.

In a third aspect, there is provided a building management system of a building, the building including a controlled indoor environment in which crops are cultivated. The building management system comprises equipment for controlling the controlled indoor environment; and a system for determining equipment settings of the building management system of the building. The system for determining equipment settings of the building management system of the building comprises: an input configured to: receive equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment, receive environmental sensor measurements for the controlled indoor environment, and receive crop data relating to characteristics of the crops. The system also comprises a processor configured to: determine a first correlation between the equipment settings data and the environmental sensor measurements, determine a second correlation between the climate sensor measurements and the crop data, determine a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations, and determine an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment. Lastly, the system comprises an output configured to output instructions relating to the adjustment to the building management system.

In a fourth aspect, there is provided a building including a controlled indoor environment in which crops are cultivated and comprising a building management system. The building management system comprises equipment for controlling the controlled indoor environment; and a system for determining equipment settings of the building management system of the building. The system for determining equipment settings of the building management system of the building comprises: an input configured to: receive equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment, receive environmental sensor measurements for the controlled indoor environment, and receive crop data relating to characteristics of the crops. The system also comprises a processor configured to: determine a first correlation between the equipment settings data and the environmental sensor measurements, determine a second correlation between the climate sensor measurements and the crop data, determine a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations, and determine an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment. Lastly, the system comprises an output configured to output instructions relating to the adjustment to the building management system.

In a fifth aspect, there is provided a computer readable medium storing instructions which, when executed by a processor, cause the processor to receive equipment settings data from a building management system of a building, the building including a controlled indoor environment in which crops are cultivated, the equipment settings data being associated with a plurality of environmental parameters of a controlled indoor environment; receiving environmental sensor measurements for the controlled indoor environment; receiving crop data relating to characteristics of the crops; determining a first correlation between the equipment settings data and the environmental sensor measurements; determining a second correlation between the environmental sensor measurements and the crop data; determining a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations; and determining an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment. The computer readable medium may be transitory or non-transitory.

In a sixth aspect, there is provided a computer implemented method of adjusting equipment settings of a building management system of a building, the building including a controlled indoor environment in which crops are cultivated. The method comprises: receiving equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment; receiving environmental sensor measurements for the controlled indoor environment; receiving crop data relating to characteristics of the crops; determining a first correlation between the equipment settings data and the environmental sensor measurements; determining a second correlation between the environmental sensor measurements and the crop data; determining a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations; and adjusting one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment.

In a seventh aspect, there is provided a system for adjusting equipment settings of a building management system of a building, the building including a controlled indoor environment in which crops are cultivated. The system comprises: an input configured to: receive equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment, receive environmental sensor measurements for the controlled indoor environment, and receive crop data relating to characteristics of the crops; a processor configured to: determine a first correlation between the equipment settings data and the environmental sensor measurements, determine a second correlation between the climate sensor measurements and the crop data, determine a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations, and determine an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment; and
an output configured to output instructions relating to the adjustment to the building management system.

It should be appreciated that features relevant to one aspect may also be relevant to the other aspects.

Brief Description of Figures

An exemplary embodiment will now be described with reference to the accompanying drawings, in which:

Fig. 1a shows the architecture of a building management system according to a preferred embodiment, including an environment optimization module;

Fig. 1b illustrates a computer system included in the building management system of Fig. 1a;

Fig. 1c illustrates a Supervisory Control and Data Acquisition (SCADA) system of the building management system of Fig. 1a;

Fig. 1d illustrates an exemplary wireless smart sensor of a network of devices included in the building management system of Fig. 1a;

Fig. 1e illustrates an exemplary edge node of a network of devices included in the building management system of Fig. 1a;

Fig. 2 illustrates the outline of a method performed by the environment optimization module of Fig. 1a, comprising three phases;

Fig. 3 illustrates the first, data collection, phase of the method of Fig. 2;

Fig. 4 illustrates the second, data preparation, phase of the method of Fig. 2;

Fig. 5 schematically illustrates a division of training data performed during the second phase illustrated in Fig. 4;

Fig. 6a illustrates the third, training, phase of the method of Fig. 2;

Fig. 6b illustrates an exemplary neural network;

Fig. 6c illustrates a generalised method of training a neural network;

Fig. 7a and 7b illustrate a training method performed during the third phase illustrated in Fig. 6; and

Fig. 8 illustrates a method of predicting crop outcomes performed by an environment optimization module of the climate management system of Fig. 1.

Detailed Description of Preferred Embodiment

An exemplary architecture of a building management system (BMS) 10 of a building in which crops are cultivated, i.e. a building which has indoor farming facilities, is shown in Fig. 1a.

Specifically, the building management system 10 is in the form of a climate management system for controlling the indoor environment in which the crops are cultivated.

The building management system 10 includes a network of devices 101 including climate control equipment for directly controlling the indoor environment of the building (e.g. ACMV and lighting equipment), a central control unit in the form of a Supervisory Control and Data Acquisition (SCADA) system 103, a user terminal in the form of computer 100 and a system for determining equipment settings of the building management system (i.e. the equipment of the network of devices 101) in the form of an environment optimization module 107 which, in the described embodiment, is implemented collectively in servers in a cloud computing environment.

The network of devices 101, the computer 100 and the SCADA system 103 are all in communicative connection with the environment optimization module 107 via respective inputs. Both the computer 100 and SCADA system 103 are operable to receive user input.

It should be appreciated that the cloud computing environment of environment optimization module 107 comprises dynamically scalable computing resources that collaborate to perform tasks. Specifically, the environment optimization module 107 includes computing resources partitioned into three groups of servers 1073, 1075, 1077, namely: presentation servers 1073, application servers 1075 and database servers 1077.

The functionality of the three groups of servers 1073, 1075, 1077 may be provided by one or more computer systems such as that illustrated in Fig. 1b.

The exemplary computer system 380 includes a processor 382 (which may be referred to as a central processor unit or CPU) that is in communication with memory devices including secondary storage 384, read only memory (ROM) 386, random access memory (RAM) 388, input/output (I/O) devices 390, and network connectivity devices 392. The processor 382 may be implemented as one or more CPU chips. Although a general description of each of these components is described below, it will be appreciated that components may vary depending on the role of the specific computer system 380 in the cloud computing environment of the environment optimization module 107, including the complete omission of one or more of the below described components. For example, components may be varied depending on for which of the three groups of servers 1073, 1075, 1077 the computer system 380 provides functionality.

It is understood that by programming and/or loading executable instructions onto the computer system 380, at least one of the CPU 382, the RAM 388, and the ROM 386 are changed, transforming the computer system 380 in part into a particular machine or apparatus having the novel functionality taught by the present disclosure. It is fundamental to the electrical engineering and software engineering arts that functionality that can be implemented by loading executable software into a computer can be converted to a hardware implementation by well-known design rules. Decisions between implementing a concept in software versus hardware typically hinge on considerations of stability of the design and numbers of units to be produced rather than any issues involved in translating from the software domain to the hardware domain. Generally, a design that is still subject to frequent change may be preferred to be implemented in software, because re-spinning a hardware implementation is more expensive than re-spinning a software design. Generally, a design that is stable that will be produced in large volume may be preferred to be implemented in hardware, for example in an application specific integrated circuit (ASIC), because for large production runs the hardware implementation may be less expensive than the software implementation. Often a design may be developed and tested in a software form and later transformed, by well-known design rules, to an equivalent hardware implementation in an application specific integrated circuit that hardwires the instructions of the software. In the same manner as a machine controlled by a new ASIC is a particular machine or apparatus, likewise a computer that has been programmed and/or loaded with executable instructions may be viewed as a particular machine or apparatus.

Additionally, after the system 380 is turned on or booted, the CPU 382 may execute a computer program or application. For example, the CPU 382 may execute software or firmware stored in the ROM 386 or stored in the RAM 388. In some cases, on boot and/or when the application is initiated, the CPU 382 may copy the application or portions of the application from the secondary storage 384 to the RAM 388 or to memory space within the CPU 382 itself, and the CPU 382 may then execute instructions that the application is comprised of. In some cases, the CPU 382 may copy the application or portions of the application from memory accessed via the network connectivity devices 392 or via the I/O devices 390 to the RAM 388 or to memory space within the CPU 382, and the CPU 382 may then execute instructions that the application is comprised of. During execution, an application may load instructions into the CPU 382, for example load some of the instructions of the application into a cache of the CPU 382. In some contexts, an application that is executed may be said to configure the CPU 382 to do something, e.g., to configure the CPU 382 to perform the function or functions promoted by the subject application. When the CPU 382 is configured in this way by the application, the CPU 382 becomes a specific purpose computer or a specific purpose machine.

The secondary storage 384 is typically comprised of one or more disk drives or tape drives and is used for non-volatile storage of data and as an over-flow data storage device if RAM 388 is not large enough to hold all working data. Secondary storage 384 may be used to store programs which are loaded into RAM 388 when such programs are selected for execution. The ROM 386 is used to store instructions and perhaps data which are read during program execution. ROM 386 is a non-volatile memory device which typically has a small memory capacity relative to the larger memory capacity of secondary storage 384. The RAM 388 is used to store volatile data and perhaps to store instructions. Access to both ROM 386 and RAM 388 is typically faster than to secondary storage 384. The secondary storage 384, the RAM 388, and/or the ROM 386 may be referred to in some contexts as computer readable storage media and/or non-transitory computer readable media.

I/O devices 390 may include printers, video monitors, liquid crystal displays (LCDs), plasma displays, touch screen displays, keyboards, keypads, switches, dials, mice, track balls, voice recognizers, card readers, paper tape readers, or other well-known input devices.

The network connectivity devices 392 may take the form of modems, modem banks, Ethernet cards, universal serial bus (USB) interface cards, serial interfaces, token ring cards, fiber distributed data interface (FDDI) cards, wireless local area network (WLAN) cards, radio transceiver cards that promote radio communications using protocols such as code division multiple access (CDMA), global system for mobile communications (GSM), long-term evolution (LTE), worldwide interoperability for microwave access (WiMAX), near field communications (NFC), radio frequency identity (RFID), and/or other air interface protocol radio transceiver cards, and other well-known network devices. These network connectivity devices 392 may enable the processor 382 to communicate with the Internet or one or more intranets. With such a network connection, it is contemplated that the processor 382 might receive information from the network, including from other computer systems 380 in the cloud computing environment or might output information to the network in the course of performing the herein described method steps. Such information, which is often represented as a sequence of instructions to be executed using processor 382, may be received from and outputted to the network, for example, in the form of a computer data signal embodied in a carrier wave.

Such information, which may include data or instructions to be executed using processor 382 for example, may be received from and outputted to the network, for example, in the form of a computer data baseband signal or signal embodied in a carrier wave. The baseband signal or signal embedded in the carrier wave, or other types of signals currently used or hereafter developed, may be generated according to several methods well-known to one skilled in the art. The baseband signal and/or signal embedded in the carrier wave may be referred to in some contexts as a transitory signal.

The processor 382 executes instructions, codes, computer programs, scripts which it accesses from hard disk, floppy disk, optical disk (these various disk based systems may all be considered secondary storage 384), flash drive, ROM 386, RAM 388, or the network connectivity devices 392. While only one processor 382 is shown, multiple processors may be present. Thus, while instructions may be discussed as executed by a processor, the instructions may be executed simultaneously, serially, or otherwise executed by one or multiple processors. Instructions, codes, computer programs, scripts, and/or data that may be accessed from the secondary storage 384, for example, hard drives, floppy disks, optical disks, and/or other device, the ROM 386, and/or the RAM 388 may be referred to in some contexts as non-transitory instructions and/or non-transitory information.

In an embodiment, some or all of the functionality disclosed herein may be provided as a computer program product. The computer program product may comprise one or more computer readable storage medium having computer usable program code embodied therein to implement the functionality disclosed herein. The computer program product may comprise data structures, executable instructions, and other computer usable program code. The computer program product may be embodied in removable computer storage media and/or non-removable computer storage media. The removable computer readable storage medium may comprise, without limitation, a paper tape, a magnetic tape, magnetic disk, an optical disk, a solid state memory chip, for example analog magnetic tape, compact disk read only memory (CD-ROM) disks, floppy disks, jump drives, digital cards, multimedia cards, and others. The computer program product may be suitable for loading, by the computer system 380, at least portions of the contents of the computer program product to the secondary storage 384, to the ROM 386, to the RAM 388, and/or to other non-volatile memory and volatile memory of the computer system 380. The processor 382 may process the executable instructions and/or data structures in part by directly accessing the computer program product, for example by reading from a CD-ROM disk inserted into a disk drive peripheral of the computer system 380. Alternatively, the processor 382 may process the executable instructions and/or data structures by remotely accessing the computer program product, for example by downloading the executable instructions and/or data structures from a remote server through the network connectivity devices 392. The computer program product may comprise instructions that promote the loading and/or copying of data, data structures, files, and/or executable instructions to the secondary storage 384, to the ROM 386, to the RAM 388, and/or to other non-volatile memory and volatile memory of the computer system 380.

In some contexts, the secondary storage 384, the ROM 386, and the RAM 388 may be referred to as a non-transitory computer readable medium or a computer readable storage media. A dynamic RAM embodiment of the RAM 388, likewise, may be referred to as a non-transitory computer readable medium in that while the dynamic RAM receives electrical power and is operated in accordance with its design, for example during a period of time during which the computer system 380 is turned on and operational, the dynamic RAM stores information that is written to it. Similarly, the processor 382 may comprise an internal RAM, an internal ROM, a cache memory, and/or other internal non-transitory storage blocks, sections, or components that may be referred to in some contexts as non-transitory computer readable media or computer readable storage media.

In an embodiment, the computer system 380 may comprise two or more computers in communication with each other that collaborate to perform a task. For example, but not by way of limitation, an application may be partitioned in such a way as to permit concurrent and/or parallel processing of the instructions of the application. Alternatively, the data processed by the application may be partitioned in such a way as to permit concurrent and/or parallel processing of different portions of a data set by the two or more computers.

In an embodiment, virtualization software may be employed by the computer system 380 to provide the functionality of a number of servers of the three groups of servers 1073, 1075, 1077 that is not directly bound to the number of computers in the computer system 380. For example, virtualization software may provide twenty virtual servers on four physical computers.

Returning now to Fig. 1a, the environment optimization module 107 further includes a network load balancer 1071 via which user input data from the computer 100 is routed as balanced traffic to the presentation servers 1073. As will become apparent from the below, user input data may include crop data and climate control equipment data. The presentation servers 1073 may also output data to the computer 100, for example, instructions for the calibration, or adjustment of climate control equipment in the network of devices 101, for example for manual approval by the user.

As illustrated in Fig. 1a, in the described embodiment, the presentation servers 1073 are configured to perform autoscaling and are capable of multi-instance execution of software.

The environment optimization module 107 also includes an application load balancer 1074 via which data is routed as balanced traffic from the presentation servers 1073 to the application servers 1075 which execute software to implement specific functionality of the environment optimization module 107 which will be described in detail below. In common with the presentation servers 1073, in the described embodiment, the application servers 1075 are configured to perform autoscaling and are capable of multi-instance execution of software.

The application servers 1075 are in communicative connection with the database servers 1077 which are configured to store data for use by the environment optimization module 107, including data for use by the application servers 1075 in executing software to implement the specific functionality of the environment optimization module 107 described below. The database servers 1077 themselves include operational data servers 1079 in the form of sensor data servers 1081, BMS data servers 1083 and external data servers 1085; and training data servers 1081 in the form of simulated data servers 1087 and external data servers 1089. As will be explained below, these servers together store a database that may combine heterogonous data from network of devices and external data, including but not limited to, farm operator inputs, outdoor weather, energy (electricity) pricing, water availability, Air-Conditioning and Mechanical Ventilation (ACMV) equipment capabilities, historical data from previous farm harvests, and produce market requirements (yield, quality, and timing).

The environment optimization module 107 further includes an input for receiving data from the network of devices 101 in the form of an internet gateway 1017 specifically for the transfer of data between the database servers 1077 and devices of the network of devices 101 to enable data collection and control. As will become apparent from the below, the data received at the input includes equipment settings data, environmental sensor measurements and may include crop data. As will be explained in detail below, this connection is controlled by the SCADA system 103. The environment optimization module 107 also includes a communication channel to the SCADA system 103 in the form of a Building Management System Application Programming Interface (BMS API) gateway 1031 via which the SCADA system 103 is also in communicative connection with the database servers 1079. As will be explained in more detail below, this communication channel functions as an output for instructions from the environment optimization module 107 to the SCADA system 103 for the calibration, or adjustment of equipment in the network of devices 101.

The SCADA system 103 according to the described embodiment is illustrated in Fig. 1c. The SCADA system 103 includes a transceiver 301 configured to provide communicative connection with individual devices of the network of devices 101, for example, using the IEEE 802 family of standards for wireless communications for data collection and control of the devices, a processor module 303, a local memory 305 and a gateway module 307. The processor module 303 is configured to receive data from the network of devices 101 via the transceiver 301 and format it and store it on local memory 305 which may reduce space and energy requirements for packet communication within the network. The gateway module 307 is configured to transmit data received at the processor 303 from the network of devices 101 with the internet, whereby the data may be transmitted to the environment optimization module 107 via the internet gateway 1017. Components 1011, 1013, 1015 of the gateway module 307 are illustrated in Fig. 1a. Note that, although shown separately in Fig. 1a, they are envisaged to form part of the SCADA system 103. Specifically, in the described embodiment the gateway module 307 includes a device gateway 1101 configured to receive information from each device of the network of devices 101; an MQTT broker 1013 configured to receive information from the device gateway 1011; and an internet router 1015 configured to receive information from the MQTT broker 1013 and transmit data via the internet.

As noted above, the network of devices 101 includes equipment for directly controlling the indoor environment of the building (e.g. ACMV and lighting equipment) itself. In addition, the network of devices 101 also includes edge nodes for monitoring and controlling the equipment, environmental sensors in the form of wireless smart sensors, and further auxiliary devices, for example cameras for acquiring images from crops.

An exemplary wireless smart sensor 200 of the network of devices 101 is illustrated in Fig. 1d. The wireless smart sensor 200 includes an analogue sensor 201, an analogue-to-digital converter (ADC) 203, a processor 205, a transceiver 207 and a memory and data storage module 209. The analogue sensor 201 is configured to perform an ambient, or equivalently an environmental measurement. Examples include measurements of temperature, relative humidity, CO_2, light intensity, volatile organic compounds (VoCs) pressure, and other parameters specific to the farm type. Suitable analogue sensors are widely available. The ADC 203 receives sensor readings from the analogue sensor 201 and transforms them into digital signals before passing the digital data signals to the processor 205 which is configured to manage data processing at the wireless smart sensor 200. The processor 205 is also configured to cause the data to be transmitted using the transceiver 207 to other devices within the control network, the transceiver 207 (a combination of a transmitter and receiver) being operable as a wireless radio to exchange data between the wireless smart sensor 200 and one or more devices controlled by the SCADA system 103 including the SCADA system 103 itself.

An exemplary edge node 400 of the network of devices 101 for controlling and monitoring equipment is illustrated in Fig. 1e. The edge node 400 includes an electro-mechanical probe 401 for monitoring a component of, for example, ACMV equipment for the building. Examples of ACMV equipment included in the network of device 101 may include (but is not limited to) dampers, Variable air volume (VAV), Variable Frequency Drive (VFD), lighting, mixing valves, and pumps. The electromechanical probe 401 is controlled by a programmable logic controller (PLC) 403. The programmable logic controller 403 has, for example, the same structure as the computer system 380 including an I/O device 390 in the form of a connection to the electro-mechanical probe 401. The PLC 403 is configured to store and execute Software-Defined Hardware algorithms that manage a corresponding component of ACMV equipment. Network devices 392 of the PLC 403 include a transceiver 407 for communication with the equipment itself for control instructions to be transmitted from the edge node to the corresponding equipment. For example, the software-Defined Hardware algorithms may control settings the ACMV equipment according to the BACnet protocol for Building Automation based on ASHREA, ANSI, and the ISO 16484-5 standard. The transceiver may also enable communication with the SCADA system 103 and other devices of the network of devices 101.

In the described embodiment, the computer 100 has the structure of the exemplary computer system 380. The building management system 10 further includes a Domain Name System (DNS) server 1001 via which data from the computer 100 is routed to the environment optimization module 107 and vice versa, specifically via the network load balancer 1071 comprised within the environment optimization module 107. In the described embodiment, the building management system 10 further includes a Content Delivery Network (CDN) cache 1003 networked with the DNS server 1001 and via which data passing between the network load balancer 1071 and the computer 100 may be routed. The computer 100 may be configured to display a user Interface (UI), for example comprising a web-based suite of technologies that may display the data to the user in a potentially intuitive, fast, and actionable manner.

It should be appreciated that optional functionality in addition to that described above may be performed by components shown in the architecture of Fig. 1a and/or discussed above, or performed by additional components not shown. This optional functionality includes but is not limited to:

- Network communication module that uses protocols from IEEE 802 family of standards for wireless communications.
- User Interface (UI) comprising live camera feeds from the facility to ensure site security.
- Facility Analytics module that visually displays floor plan and facility layout, along with the locations of the network of devices.
- Device Network feature that comprises data about all devices in the network, such as, but not limited to, device image, name, location, power level, date of installation, and activity.
- Climatic Conditions feature that comprises data readings from the network of devices 101 displayed in a graphical and configurable manner.

- Equipment Status feature that comprises the energy consumption of the devices under the control by edge nodes in the network of devices 101 such as the exemplary edge node 400 described above.
- Live Camera feed that combines the video feeds from various cameras at the facility and delivers it to the user at the computer 100 in a secure and efficient manner.

An overview of a method of adjusting equipment settings of the building performed by the building management system 10 of Fig. 1a according to the described embodiment is illustrated in Fig. 2. The system works to optimize the environment through the following three phases and accompanying sub steps: Phase 1, comprising data collection; Phase 2, comprising Data Preparation; and Phase 3 comprising training.

The sub steps of Phase 1: data collection are shown in detail in Fig. 3.

This Phase includes the collection of three categories of data:

- Climate Data 1.1;
- Crop Data 1.2a, 1.2b (consisting of inputs and outputs, respectively); and
- Equipment Data 1.3.

The four categories of data 1.1, 1.2a, 1.2b, 1.3 are collected by sensors 200 and edge nodes 400 forming part of the network of devices 101 and also may in part be manually input at the computer 100 and then transferred to and received by the environment optimization module 107 where it is held on the database servers 1077 for use in phases 2 and 3 of the method of Fig. 2.

The Climate Data 1.1 includes but is not limited to environmental sensor data 500 collected by wireless smart sensors in the network of devices 101 (such as the exemplary wireless smart sensor 200 described above), for example: temperature, relative humidity, CO2, light intensity, and other parameters which may be relevant to a specific crop type.

The Crop Data 1.2 includes but is not limited to output data 1.2b comprising information regarding crop quantity 519 and crop quality 517. The output data 1.2b may further include images of the plant that allow image recognition to identify crop type, quality, and stage of the growing cycle. As such, the database servers 1077 may store image recognition software which when executed by the environment optimization module 107 may enable output data 1.2b to be extracted from images.

Optionally, the Crop Data 1.2 may further include input data 1.2a comprising the nutrient schedule 501, the water schedule 503, the pH level 505, and growing substrate information 507.

It should be appreciated that at least some of the crop data 1.2 may be input by a user at the computer 100, for example, the information regarding the crop quality and/or the nutrient and water schedule information.

Equipment Data 1.3 includes equipment settings data received from the edge nodes 400 (i.e. obtained by respective electromechanical probes 401 and/or equipment setting information stored by the PLC 403) and includes ACMV equipment setpoint data 509, lighting system data 511, auxiliary device data 515 and ACMV equipment sensor data 515 in the network of devices 101. Examples of the equipment data may include (but is not limited to) the following:

- Thermostat: Supply Air Temperature, Supply Air Temperature Setpoint, Outdoor Air Temperature, Mixed Air Temperature, Return Air Temperature
- Fan: Supply Air Fan Status, Return Air Fan Status, Supply Air Fan Speed Control Signal, Return Air Fan Speed Control Signal
- Dampers: Outdoor Air Damper Control Signal, Return Air Damper Control Signal
- Cooling: Cooling Coil Valve Control Signal

- Heating: Heating Coil Valve Control Signal
- Pressure: Supply Air Duct Static Pressure Set Point
- Lighting System: Light Wavelength (electromagnetic spectrum), Light Intensity, Duration, distance from the crops.

Once received by the environment optimization module 107, software is executed in the environment optimization module 107 to automatically check the data collected for formatting to meet subsequent requirements regarding data quality. If conditions are not met, the data is evaluated and 'cleaned' to meet the requirements. Evaluation of the collected data may include: validity, accuracy, completeness, uniformity, range, type, syntax, and other checks. It will be appreciated that many such techniques are employed in conventional machine learning models.

In the described embodiment, the received data is also labelled in the following manner:

- Climate data 1.1 from environmental sensor readings are labelled based on location
- Equipment data 1.3 are labelled according to location
- Crop data (outputs) 1.2b are optionally labelled according to location of the reading, plant type, and other metrics.

The received data are then stored in database servers 1077 of the environment optimization module 107 for use in subsequent phases of the method of Fig.2.

The method then moves on to Phase 2: Data Preparation. The steps of this phase are illustrated in Fig. 4. It will be appreciated that these steps are performed by executing software on one or more processors of the environment optimization module 107.

In step 2.1 the following matrices are generated from each of the three categories of collected data 1.1, 1.2, 1.3:

- X1: equipment settings data 1.3
- Y1: climate data 1.1
- X2: climate data 1.1
- Y2: crop data output 1.2b

In step 2.2, bias terms are added to the X1 and X2 matrices – these will function as coefficients for training. Specifically, the X1 and X2 matrices are altered as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1d} \\ x_{21} & x_{22} & \cdots & x_{2d} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nd} \end{bmatrix} \Rightarrow X = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1d} \\ 1 & x_{21} & x_{22} & \cdots & x_{2d} \\ 1 & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nd} \end{bmatrix}$$

In step 2.3, feature selection is performed for all four matrices X1, Y1, X2, Y2. This comprises automated feature selection that sets up a training process which examines which features should be used for training the machine learning model – dimensionality reduction is applied to all four matrices X1, Y1, X2, Y2 to remove redundant or unnecessary features. It should be appreciated that a range of automated feature selection approaches could be employed.

In step 2.4, normalization is performed. In this step, values of each matrix are normalized using min-max feature scaling technique:

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

In step 2.5, data splitting of each of the matrices X1, Y1, X2 and Y2 is performed. Specifically, the data is split into three groups for pre-training and training modules, specifically training data 1207, testing data 1201, and validation data 1205, which will be explained in more detail below. Step 2.5 is illustrated schematically in Fig. 5 according to the described embodiment.

As will be appreciated from Fig. 5, in an example, 20% of the original data 1200 is first split off as test data 1201. 20% of the remaining data 1203 is further split off as validation data 1205. The final remaining data (i.e. 64% of the original data 1200) is employed as training data 1207.

The method then proceeds to Phase 3: Training. This phase is illustrated in Fig. 6a. The steps of this phase are performed by the one or more processors of the application servers 1075.

In step 3.1, the model is defined. In the described embodiment, the model comprises a multiple-output X1:Y2 regression model implemented by means of two neural networks. Neural networks (neural models) are adaptive models trained by machine learning methods. In general, they comprise sets of algorithms configured to map inputs to outputs. A schematic of the simplest type of neural network is shown in Figure 6b. An exemplary neural network 19 comprises an input layer 1901 where the input data is input into the network, one or more hidden layers 1903 where inputs are combined and an output layer 1905 at which the output is received.

The hidden layer 1903 comprises a series of biased nodes 1909. Each input to each hidden layer is weighted and combined at a node with a non-linear activation function.

The neural network is defined by a series of parameters, including those characterizing the architecture of the neural network (i.e. number of nodes and number of hidden layers), activation functions, weights and biases. The weights and biases are determined during training of the neural network 19. The number of nodes, number of hidden layers and activation functions are typically referred to as hyperparameters and are held constant during training of the weights and biases but may be tuned.

Note that although only one hidden layer is shown in Figure 6b, the neural network may comprise a plurality of hidden layers, according to the architecture employed.

The overall X1:Y2 regression model employed according to the described embodiment is constructed from a multi-output neural network model comprising an X1:Y1 correlation model and a X2:Y2 correlation model. In multi-output regression, two or more outputs are required for each input sample, and the outputs are required simultaneously.

The total number of nodes, *n*, of each of the neural networks is determined in step 3.1 by trial and error based on the specific system configuration.

In step 3.2, the model defined in step 3.1 is fit to the received data, in other words, the model is trained.

In general, in order to train the weights and biases of a neural network, training data in the form of inputs 1107 and corresponding target outputs 1109 is employed as illustrated in Fig. 6c which shows a generalized training approach to a neural network. In step 1103, a neural network error is calculated based on employing the inputs 1107 in the neural network and comparing the outputs produced by the neural network with the target outputs 1109. In step 1105, parameters of the neural network (i.e. weights and biases) are adjusted in order to minimize the difference in the neural network output and the target output 1109. The process then returns to step 1103.

In practice, minimizing the difference in the neural network output and the target output 1109 is done by minimizing a so-called objective, or loss function which characterizes the error in the network. In the described embodiment, in which a regression model is implemented via a neural network, the Root Mean Squared Error (RMSE) is employed, where the loss function L is defined as:

$$
\begin{aligned}
L &= \frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2 \\
&= \frac{1}{n}\sum_{i=1}^{n}(\theta^T x_i - y_i)^2 \\
&= \frac{1}{n}\|X\theta - y\|^2
\end{aligned}
$$

Eqn. (1)

where y_i is an observed value of an output variable, $\hat{y}_i$ is the corresponding predicted value, x_i are the predictor, or input values and θ is the normal equation which depends on the particular regression technique employed.

In the described embodiment, ridge regression is employed for which the normal equation is given as follows:

$$\theta = (X^T X + \lambda I)^{-1} X^T y$$

$$\theta = (X^T X + \lambda \begin{bmatrix} 0 & & & \\ & 1 & & \\ & & \ddots & \\ & & & 1 \end{bmatrix})^{-1} X^T y$$

Eqn. (2)

It should be appreciated that other types of regression techniques and loss functions (including custom ones) may alternatively be employed.

In the described embodiment there are three stages of the regression, or training as summarized in Fig. 3:

- Step 3.3 correlates the equipment data equipment settings (X1) with climate data (Y1), i.e. generates a X1:Y1 model
- Step 3.4 climate data (X2) with crop data output (Y2), i.e. generates a X2:Y2 model; and

- Step 3.5 correlates equipment data equipment settings (X1) crop data output (Y2), i.e. generates a X1:Y2 model based on the correlations determined in the first stage step 3.3 and the second stage step 3.4. In the described embodiment, this is done by combining the correlation models determined in the first and second stages. All three models are trained together.

Figs. 7a and 7b illustrate steps 3.3-3.5 in more detail, with steps 700 to 706 shown in Fig. 7a, and steps 707 to 715 shown in Fig. 7b.

In step 700 the model correlating equipment settings (X1) with climate data (Y1) (X1:Y1 model) and the model correlating climate data (X2) with crop data output (Y2) (X2:Y2 model) are both initialized, in other words initial parameters and architecture of the neural network are chosen. It will be appreciated that a variety of approaches may be employed in order to intialize the models.

In step 701 parameters of the neural network model correlating equipment settings (X1) with climate data (Y1) is trained by performing regression using the relevant training data as shown in Fig. 5. For example, the weights and biases of the X1:Y1 model may be adjusted according to the method of Fig. 6c by minimizing the loss function as defined in Eqn. (1) and (2) above, employing corresponding training data 1207 as the input 1107 and target output 1109.

In step 702, validation data values of equipment settings (X1) are input into the trained model and the output is compared with corresponding validation climate data (Y1) and an error is calculated based on the comparison, i.e. the error generated from the model trained using training data is calculated using validation data. For example, the Root Mean Squared Error (RMSE) function may be employed, as embodied in Eqn. (1) and (2) above.

In step 703, if the error calculated in step 702 is below a threshold then the method proceeds to step 704. If the error is greater than the threshold then the architecture (e.g. the number of nodes and hidden layers 1903) of the X1:Y1 correlation model is adjusted and the method returns to step 701 and the parameters of the adjusted X1:Y1 correlation model are retrained using training data.

In step 704, the X1:Y1 correlation model is tested using testing data 1201 obtained as described shown in Fig. 5, i.e. testing data values of equipment settings (X1) are input into the model and the output is compared with corresponding testing climate data (Y1) and an error is calculated based on the comparison. For example, the Root Mean Squared Error (RMSE) function may be employed, as embodied in Eqn. (1) and (2) above.

In step 705, if the error is below a threshold then the method proceeds to step 707 (see Fig. 7b). If the error is greater than the threshold then the method proceeds to step 706.

In step 706, the architecture of the X1:Y1 correlation model is adjusted based on the error calculated in step 705 and the adjusted model is retrained using training data (as in step 701). The method then returns to step 704.

In step 707 (see Fig. 7b), the initialized model correlating climate data (X2) with crop output (Y2) is trained using the X2 and Y2 training data determined as described in relation to Fig. 5. Specifically, the weights and biases of the X2:Y2 model are adjusted according to the method of Fig. 6c by minimizing the loss function as defined in Eqn. (1) and (2) above, employing corresponding training data 1207 as the input 1107 and target output 1109.

In step 708, validation data values of climate data (X2) are input into the initialized model and the output is compared with corresponding validation data crop outputs

(Y2) and an error is calculated based on the comparison, i.e. the error generated from the model trained using training data is calculated using validation data. For example, the Root Mean Squared Error (RMSE) function may be employed, as embodied in Eqn. (1) and (2) above.

In step 709, If the error is below a threshold then the method proceeds to step 710. If the error is greater than the threshold then the architecture of the X2:Y2 correlation model (e.g. the number of nodes and hidden layers 1903) is adjusted and the method returns to step 707 and the parameters of the adjusted X2:Y2 correlation model are retrained using training data.

In step 710, the X2:Y2 correlation model is tested using testing data as shown Fig. 5, i.e. testing data values of climate data (X2) are input into the model and the output is compared with corresponding testing crop output data (Y2) and an error is calculated based on the comparison. For example, the Root Mean Squared Error (RMSE) function may be employed, as embodied in Eqn. (1) and (2) above.

In step 711, if the error is below a threshold then the method proceeds to step 713. If the error is greater than the threshold then the method proceeds to step 712.

In step 712, the architecture of the X2:Y2 correlation model is adjusted and the adjusted model is retrained using training data (as in step 707). The method then returns to step 710.

In step 713, a correlation error between training values of the equipment settings (X1) and corresponding training values of the crop output (Y2) is determined.

The error is calculated by employing the testing values of the equipment settings in the method of Fig. 8 to determine crop output values based on combining the individually trained X1:Y1 and X2:Y2 correlation models to define an overall X1:Y2 correlation model, i.e. a model which correlates equipment settings (X1) to crop outputs (Y2).

In step 801, the equipment settings testing data is input into the X1:Y1 correlation model and climate data is output in step 803.

In step 805, the climate data output in step 803 is input into the X2:Y2 correlation model and crop output data is output in step 807.

Thus, together steps 801 to 807 produce predicted crop output from equipment settings testing data, i.e. steps 801 to 807 define a correlation model 80 between the equipment settings data (X1) and the crop output (Y2).

The crop output data thus determined is compared with crop output testing data (Y2) corresponding to the equipment settings testing data (X1) employed in step 801. For example, the Root Mean Squared Error (RMSE) function may employed in step 713, as embodied in Eqn. (1) and (2) above.

In step 715, it is determined if the calculated error is below a threshold. If the error is below the threshold, then the combination of trained X1:Y1 and X2:Y2 correlation models are output as the final trained X1:Y2 correlation model 80. If the calculated error exceeds the threshold then the method returns to step 701 and the parameters of the individual correlation models are adjusted.

In the described embodiment, hyperparameter tuning using the exhaustive grid search method is done to find optimal coefficients that minimize the error values in steps 702, 704, 708, and 713.

Once the models are built, they are used to predict the expected crop output iteratively based on various potential equipment setting inputs until an optimum point is identified, i.e. various potential equipment settings inputs are employed in the method of Fig. 8 with corresponding predicted crop outputs determined in step 807.

Specifically, potential equipment settings are input into the X1:Y1 correlation model in step 801, and the predicted climate data is output in step 803.

In step 805, the predicted climate data output in step 803 is input into the X2:Y2 correlation model and predicted crop output data is output in step 807.

In practice, iterative adjustments to the equipment settings are employed in order to find the optimal point for the equipment settings (i.e., a point where equipment settings should be in order to create an optimal crop output).

Thus, in the described embodiment, the overall trained X1:Y2 model is then iteratively used to calculate multiple potential outputs. The trained X1:Y2 model outputs results in the time-domain, with the expected crop output given multiple parameter time scheduling scenarios being determined, i.e. the system performs experiments using multiple scenarios until it finds the optimal outcome according to the model. It tries out different parameters settings at different time points, sees the results, then adjusts. Thus, the output of the optimization process using the trained X1:Y2 model is a timeseries dataset of parameter settings optimized to achieve a desired crop outcome. These timeseries outputs can be classified according to the plant type, growing stage, or desired output characteristics of the plant.

Once parameters are determined by the environment optimization module 107, the environment optimization module 107 causes adjustment of the equipment settings of the building management system 10 based on the obtained parameters. Specifically, in the described embodiment, the equipment settings information is communicated by the environment optimization module 107 to the SCADA 103 via the BMS API Gateway 1031 for calibration of devices in the network of devices 101 by the SCADA 103 according to the determined parameter settings. This may be an entirely automated process, i.e. an automated process of assigning equipment setpoints to achieve the desired parameters, i.e. the settings of devices in the network of devices 101 are adjusted in line with the determined equipment setpoints.

Alternatively, or additionally, data may be output to the user terminal in the form of the computer 100 thereby manually notifying the user how to achieve these optimal parameters at the appropriate times. The proposed outputs may be manually approved by a human at the user terminal before calibration is implemented by the SCADA 103.

Thus, the environment optimization module 107 and method of Fig. 2 according to the described embodiment, comprising of machine learning techniques potentially creates an optimal climate for indoor farms by calibrating equipment settings. The method of Fig. 2 correlates equipment settings to the climate, climate to the crop output, and, finally, equipment settings to crop output. This creates a potentially effective feedback loop among the system components, enabling a range of benefits for the farm operator. These include the potential of reduced skilled personnel hours to calibrate the building management system 10 and manage data, increased visibility into farm operators for easier replicability and insurance, optimized energy consumption, enhanced crop health, and better prediction of harvest timing, which can be connected with the farm’s supply chain management system to potentially enhance distribution planning.

Thus, employing the building management system 10 and method of Fig. 2 according to the described embodiment, indoor climate-related data may be considered when optimizing for a farm’s key outputs, namely yield, quality, and harvest predication dates. Moreover, data may be archived or it is stored on-site with visibility by the farm operator. The operator may not need to manually combine readings from various farm sensors before being able to determine optimal environmental conditions. There may also be no need for the farm operator to determine how to program the ACMV equipment to achieve the optimal targets, which would otherwise be demanding, complex, and time consuming. The building management system 10 according to the described embodiment may streamline this process for the farm operator and may provide optimization adjustments using machine learning techniques.

In addition, the environment optimization module 107 described above may enable indoor farms to be integrated into existing buildings with existing building management systems, without requiring any changes to the building management system; the model may be trained based on the available setpoints of the existing building management system in order to optimize crop outcomes.

Further, the system and method described above may enable the provision of a real-time climate monitoring dashboard. Typically, building operators currently review quality of indoor air once or twice a year through engineering audits. Being able to see the data in real-time may enhance climate quality, improve operations, and reduce energy requirements.

Further, typically, building operators run HVAC systems on a pre-determined schedule, revisiting it usually when a problem emerges. Similarly, most solutions available on the market only provide data to operators at the site. Alerting the operator of undesirable changes in the indoor climate, along with remedy recommendations, may help improve building performance while also providing a peace of mind to its owners, operators, and occupants. Methods and systems according to the described embodiment may therefore provide a useful scheduling and alert mechanism

It should be appreciated that the building management system 10 according to the described embodiment has a blended data structure that may leverage efficient and secure Internet of Things (IoT) networks of wireless sensors 200 in addition to operator requirements, equipment capabilities, and, in the case of vertical farming, plant data.

This novel approach to Internet of Things (IoT) networks may pave the way for the Machine Learning (ML) enabled optimization models.

By employing machine Learning (ML)-enabled optimization models, the building management system 10 according to the described embodiment may add an additional layer of intelligence to an existing Building Management (BMS) system or function as a standalone BMS.

The described embodiment should not be construed as limitative.

Although establishing correlations with equipment settings is described above, it is envisaged that additional correlations in addition to crop output may also be established, such as correlations energy expenditure, indoor air quality. In addition, in cases in which the crop input data 1.2a is collected, correlations between the crop input data 1.2a and the crop output data 1.2b may further be established.

Although ridge regression models are described as being employed in the described embodiment, it is envisaged that other regression models or other models capable of correlating variables could be employed, including correlation techniques which do not employ neural networks.

It should be appreciated that a wide variety devices could be employed in the network of devices 101. It is envisaged that any device which either senses data relevant to a building climate or has a potential impact on the climate of a building may be employed according to embodiments. In addition, it is envisaged that a wide variety of crop data (output or input) may be employed and may be adapted to the specific crop which is being cultivated.

Although the environment optimization module 107 is described as being implemented in a cloud computing environment, it is envisaged that all of the functionality of the environment optimization module 107 may be performed without use of a cloud-computing environment, for example locally to the building for which the building management system 10 provides management. Likewise, it is envisaged that environment optimization module 107 could be implemented by an individual processor of a computer or two or more individual computers or processors which are in communication with each other (for example using parallel processing) but not part of a cloud computing environment.

It is envisaged that the central control unit may not be a Supervisory Control and Data Acquisition (SCADA) system 103 as such. For example, the functionality of the central may instead be performed by the computer 100 or another component within the building management system 10.

Although manual approval of equipment settings is described above, it is envisaged that the equipment setting process could be completely automated without any user involvement.

Although the hyperparameter tuning is described as being done in the time-domain and a time-schedule of equipment settings determined, it is envisaged that equipment settings for only a single point in time may be determined.

Although the time-series dataset is described above as being determined automatically by a processor, it is envisaged that it could also be determined manually by a user by inputting equipment setting scenarios into the determined X1:Y2 correlation model.

It should be appreciated that although a specific architecture of the building management system 10 has been described above, alternative components could be employed to achieve the same functionality.

It is envisaged that features of one or more of the variations described above may be combined according to embodiments.

Having now fully described the invention, it should be apparent to one of ordinary skill in the art that many modifications can be made hereto without departing from the scope of the claims of invention listed below.

Claims

1. A computer implemented method of determining equipment settings of a building management system of a building, the building including a controlled indoor environment in which crops are cultivated, the method comprising:

    receiving equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment;

    receiving environmental sensor measurements for the controlled indoor environment;

    receiving crop data relating to characteristics of the crops;

    determining a first correlation between the equipment settings data and the environmental sensor measurements;

    determining a second correlation between the environmental sensor measurements and the crop data;

    determining a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations; and

    determining an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment.

2. A computer implemented method according to claim 1, wherein determining the first correlation, the second correlation and the third correlation comprises employing multi-output regression.

3. A computer implemented method according to claim 1 or 2, wherein determining the adjustment of the one or more equipment settings of the building management system based on the determined third correlation

further includes determining a time series of the one or more equipment settings.

4. A computer implemented method according to any one of the preceding claims, further comprising predicting crop output based on the determined third correlation, and determining the adjustment of the one or more equipment settings based on the predicted crop output.

5. A computer implemented method according to claim 4, wherein predicting crop output based on the determined third correlation comprises predicting a plurality of crop outputs each corresponding to iterative adjustments of the one or more equipment settings; and

and

determining the adjustment of the one or more equipment settings based the predicted plurality of crop outputs.

6. A computer implemented method according to claim 5, wherein determining the adjustment of the one or more equipment settings based the predicted plurality of predicted crop outputs includes identifying an optimal equipment setting corresponding to an optimal predicted crop output from the predicted plurality of crop outputs; and determining the adjustment of the one or more equipment settings based on the identified optimal equipment setting.

7. A computer implemented method according to any one of claims 1 to 6, further comprising, causing the one or more equipment settings to be adjusted according to the determined adjustment.

8. A system for determining equipment settings of a building management system of a building, the building including a controlled indoor environment in which crops are cultivated, the system comprising:

an input configured to:

receive equipment settings data from the building management system, the equipment settings data being associated with a plurality of environmental parameters of the controlled indoor environment,

receive environmental sensor measurements for the controlled indoor environment, and

receive crop data relating to characteristics of the crops;

a processor configured to:

determine a first correlation between the equipment settings data and the environmental sensor measurements,

determine a second correlation between the climate sensor measurements and the crop data,

determine a third correlation between the equipment settings data and the crop data, based on the determined first and second correlations, and

determine an adjustment of one or more equipment settings of the building management system based on the determined third correlation to control at least one of the plurality of environmental parameters of the controlled indoor environment; and

an output configured to output instructions relating to the adjustment to the building management system.

9. A system for determining equipment settings of a building management system of a building according to claim 8, wherein the processor is further configured to determine the first correlation, the second correlation and the third correlation by employing multi-output regression.

10. A system for determining equipment settings of a building management system of a building according to claim 8 or 9, wherein determining the adjustment of one or more equipment settings of the building management system based on the determined third correlation further includes determining

a time series of the one or more equipment settings, and wherein the output is further configured to output instructions relating to the adjustment to the building management system according to the determined time series.

11. A system for determining equipment settings of a building management system of a building according to any one of claims 8 to 10, wherein the processor is further configured to predict crop output based on the determined third correlation and to determine the adjustment of the one or more equipment settings of the building management system based on the predicted crop output.

12. A system for determining equipment settings of a building management system of a building according to claim 11, wherein predicting crop output based on the determined third correlation comprises predicting a plurality of crop outputs each corresponding to iterative adjustments of the one or more equipment settings, and wherein the processor is further configured to determine the adjustment of the one or more equipment settings based the determined plurality of predicted crop outputs.

13. A system for determining equipment settings of a building management system of a building according to claim 12, wherein determining the adjustment of the one or more equipment settings based the predicted plurality of predicted crop outputs comprises identifying an optimal selected equipment setting corresponding to an optimal predicted crop output from the predicted plurality of crop outputs, and wherein the processor is configured to determine the adjustment of the one or more equipment settings based on the optimal selected equipment setting.

14. A system for determining equipment settings of a building management system of a building according to any one of claims 8 to 13, wherein the instructions

are configured to cause the one or more equipment settings to be adjusted according to the determined adjustment.

15. A building management system of a building, the building including a controlled indoor environment in which crops are cultivated, the building management system comprising:
a system for determining equipment settings of the building management system of the building according to any one of claims 8 to 14.

16. A building including a controlled indoor environment in which crops are cultivated and comprising the building management system of claim 15.

17. A computer readable medium storing instructions which, when executed by a processor, cause the processor to perform the method of any one of claims 1 to 7.

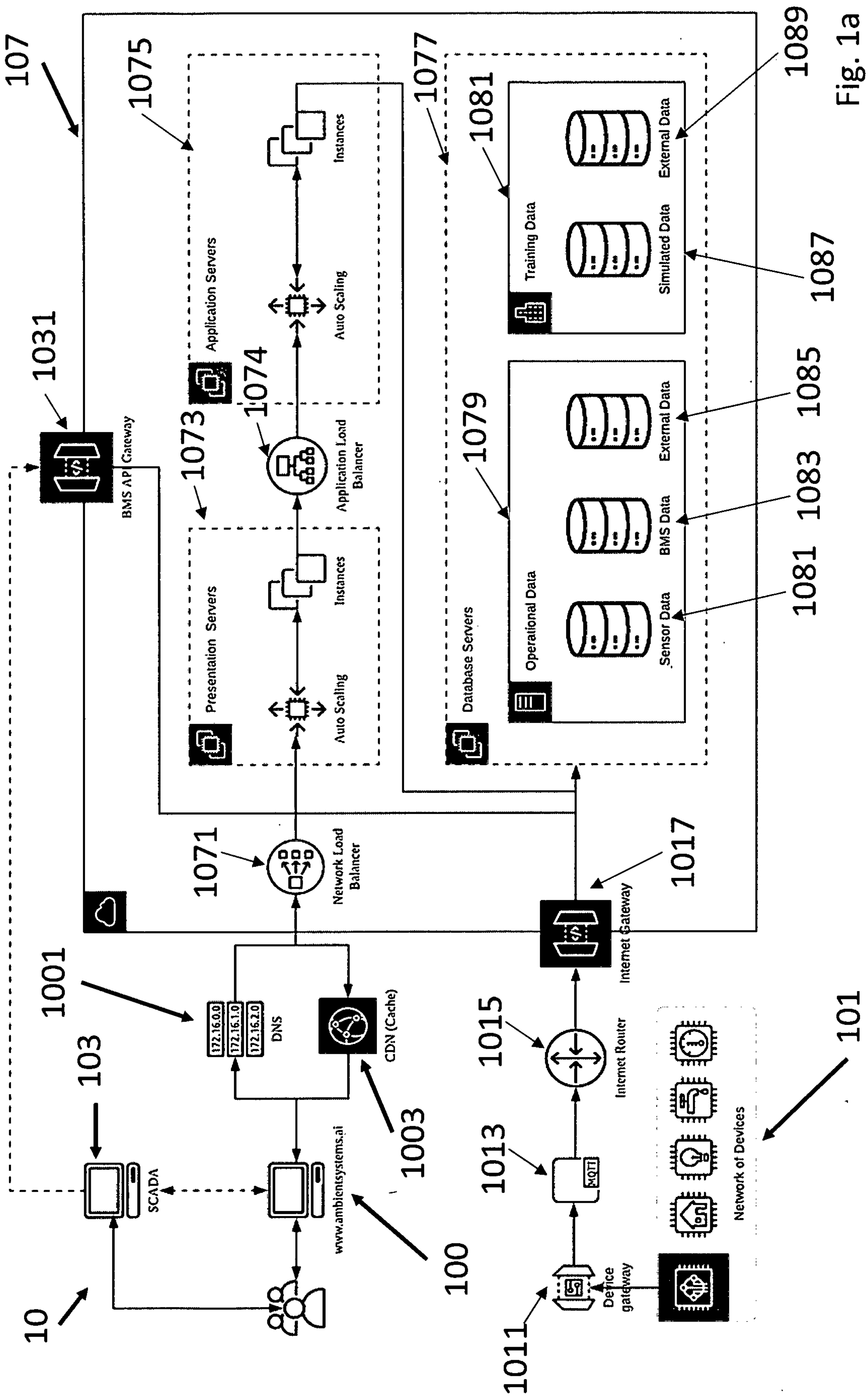

10
100
www.ambientsystems.ai
103
SCADA
1001
DNS
172.16.0.0
172.16.1.0
172.16.2.0
1003
CDN (Cache)
107
1031
BMS API Gateway
1071
Network Load Balancer
1073
Presentation Servers
Auto Scaling
Instances
1074
Application Load Balancer
1075
Application Servers
Auto Scaling
Instances
1077
Database Servers
1079
Operational Data
Sensor Data
BMS Data
External Data
1081
Training Data
Simulated Data
External Data
1083
1085
1087
1089
1017
Internet Gateway
1015
Internet Router
1013
MQTT
1011
Device gateway
101
Network of Devices

Fig. 1a

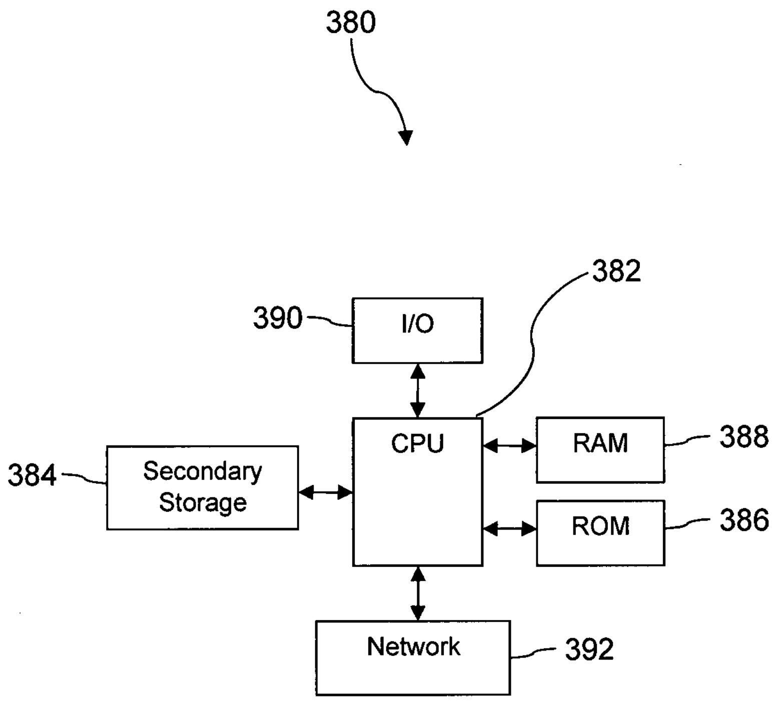

380
382
390
I/O
CPU
RAM
388
384
Secondary Storage
ROM
386
Network
392

Fig. 1b

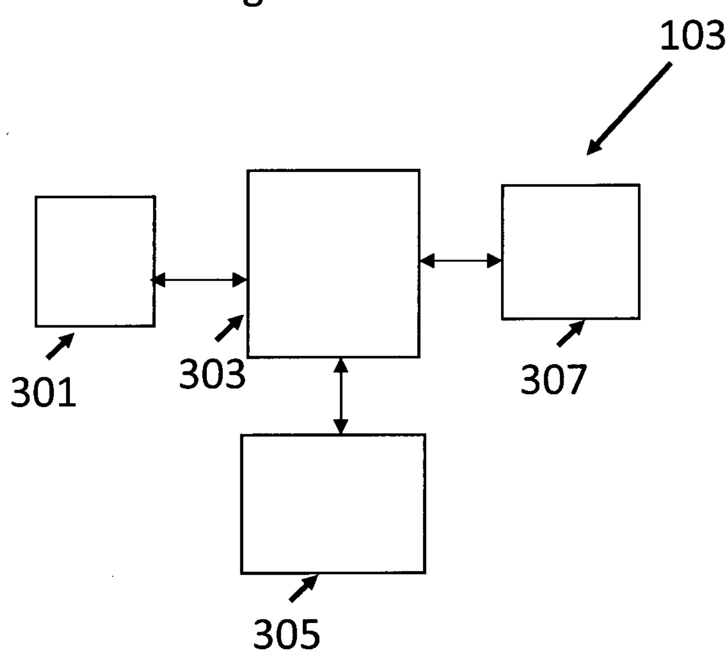

103
301
303
307
305

Fig. 1c

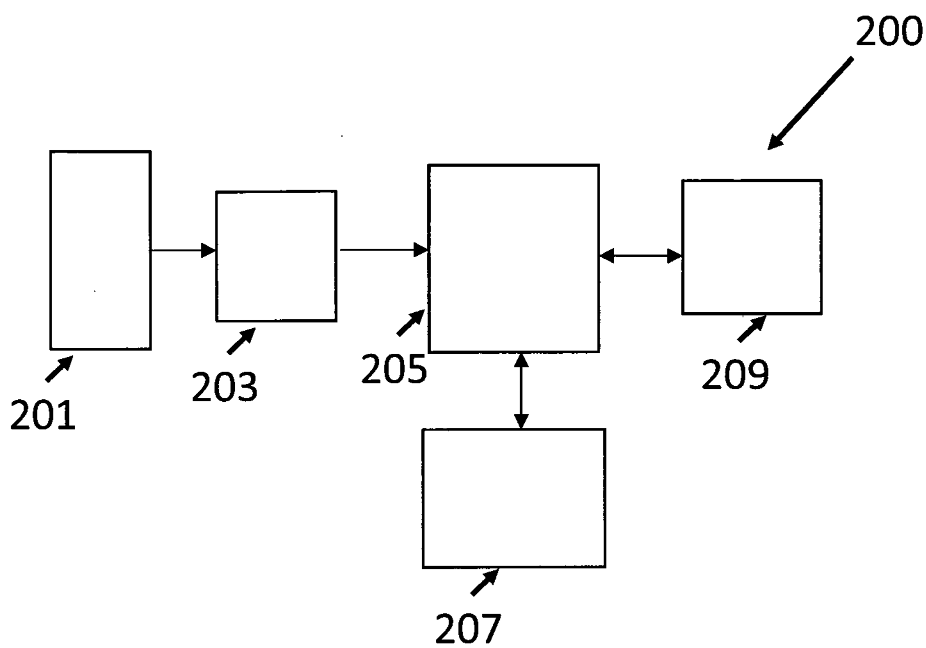


Fig. 1d

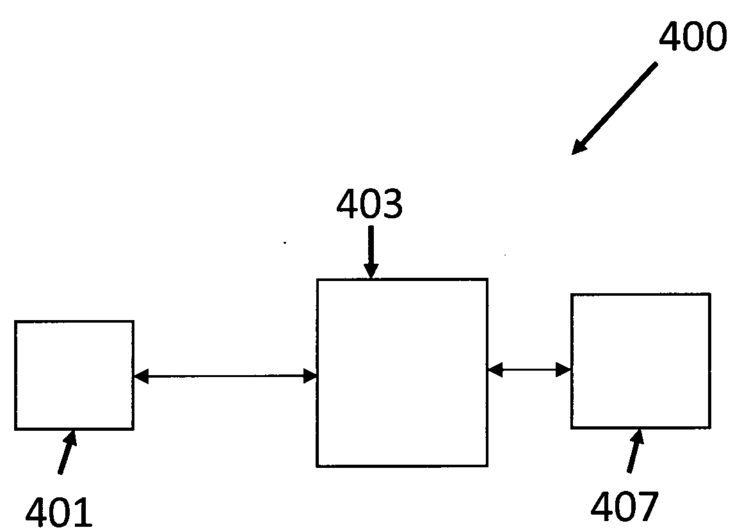


Fig. 1e

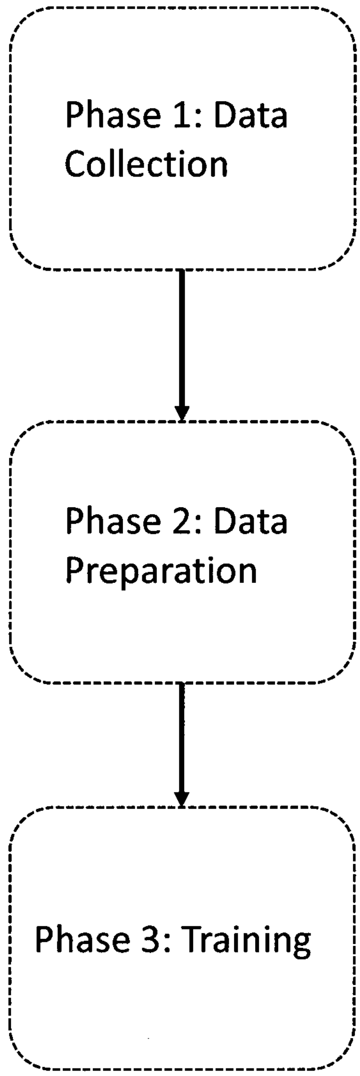

Phase 1: Data Collection
Phase 2: Data Preparation
Phase 3: Training

Fig. 2

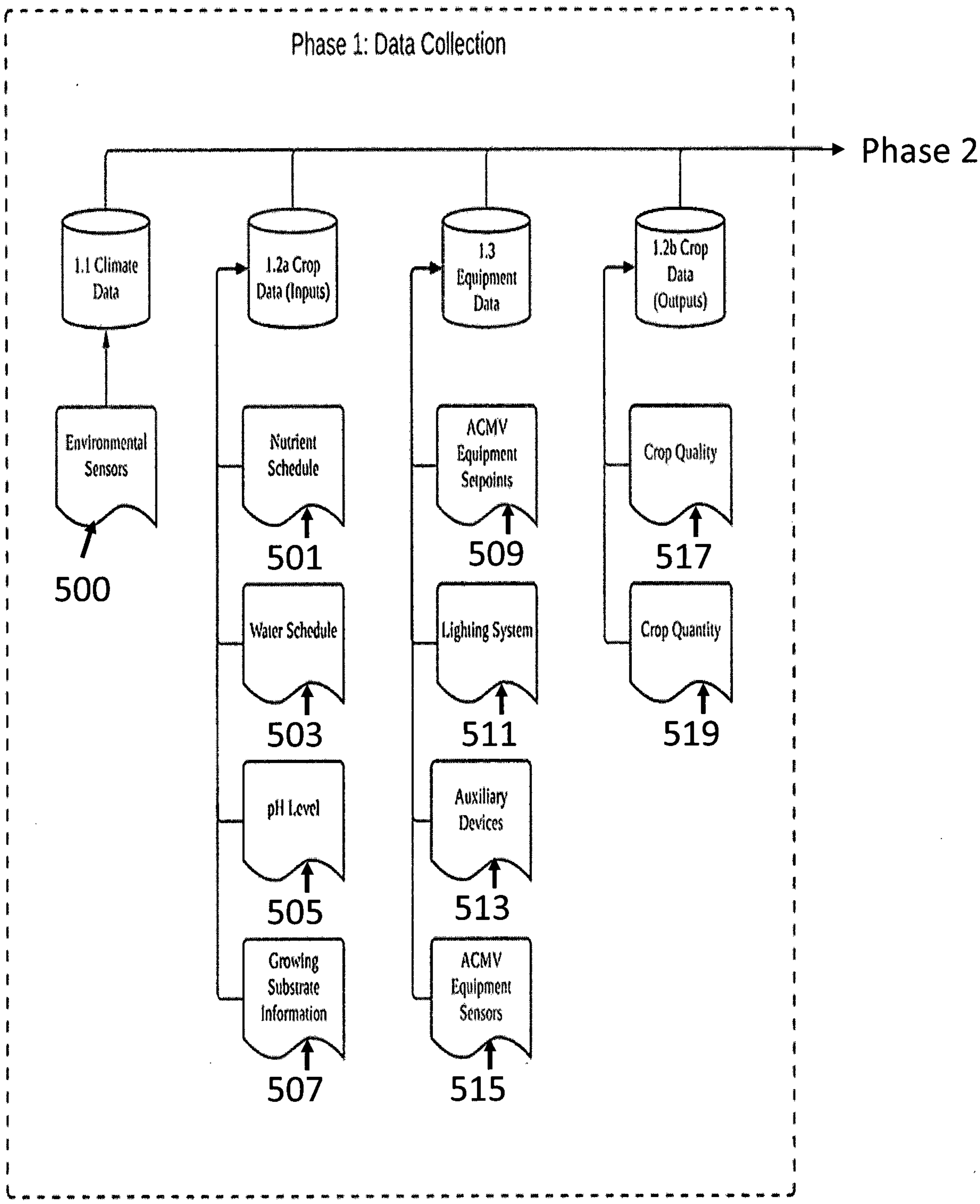

Phase 1: Data Collection
Phase 2
1.1 Climate Data
1.2a Crop Data (Inputs)
1.3 Equipment Data
1.2b Crop Data (Outputs)
Environmental Sensors
500
Nutrient Schedule
501
Water Schedule
503
pH Level
505
Growing Substrate Information
507
ACMV Equipment Setpoints
509
Lighting System
511
Auxiliary Devices
513
ACMV Equipment Sensors
515
Crop Quality
517
Crop Quantity
519

Fig. 3

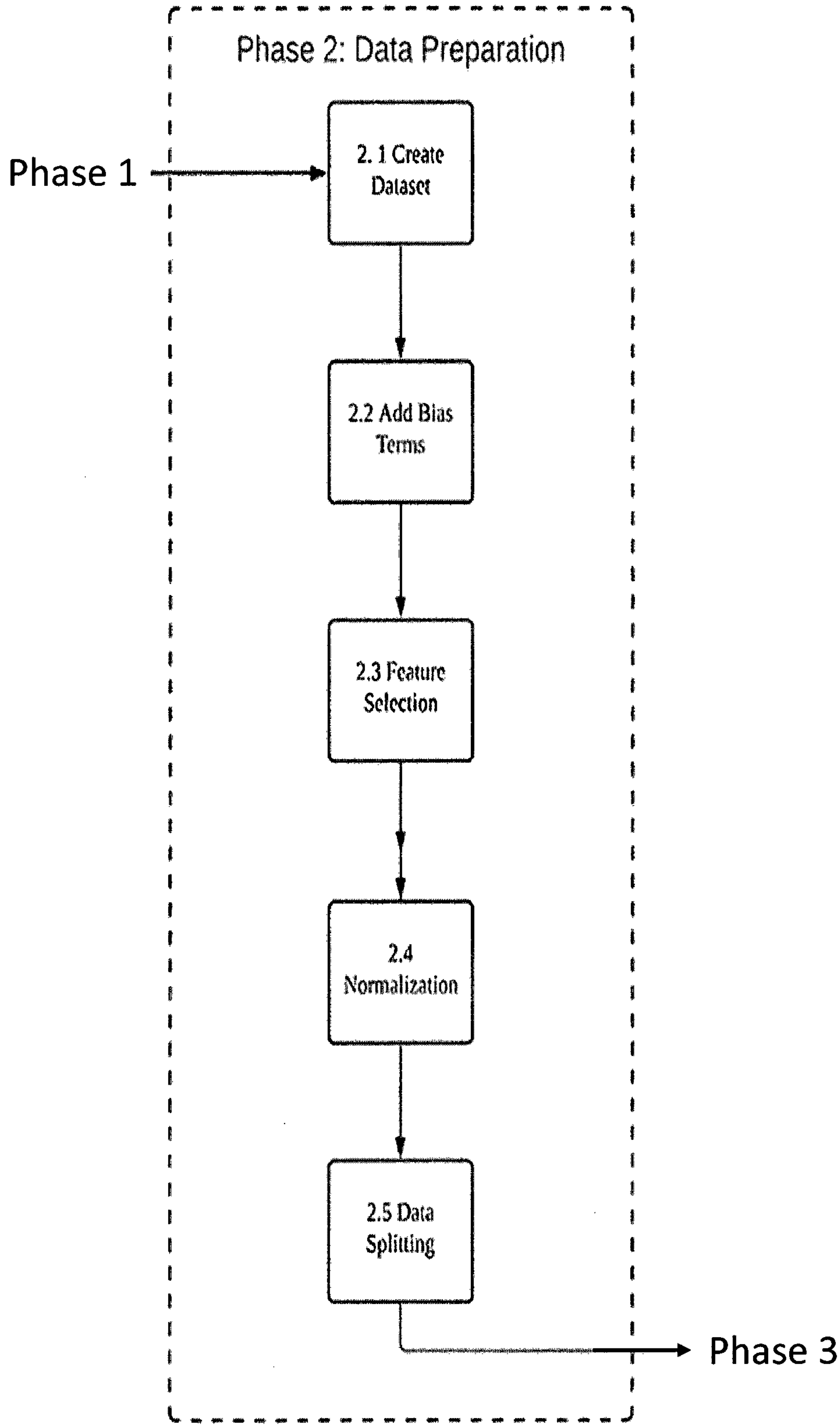

Phase 2: Data Preparation
Phase 1
2. 1 Create Dataset
2.2 Add Bias Terms
2.3 Feature Selection
2.4 Normalization
2.5 Data Splitting
Phase 3

Fig. 4

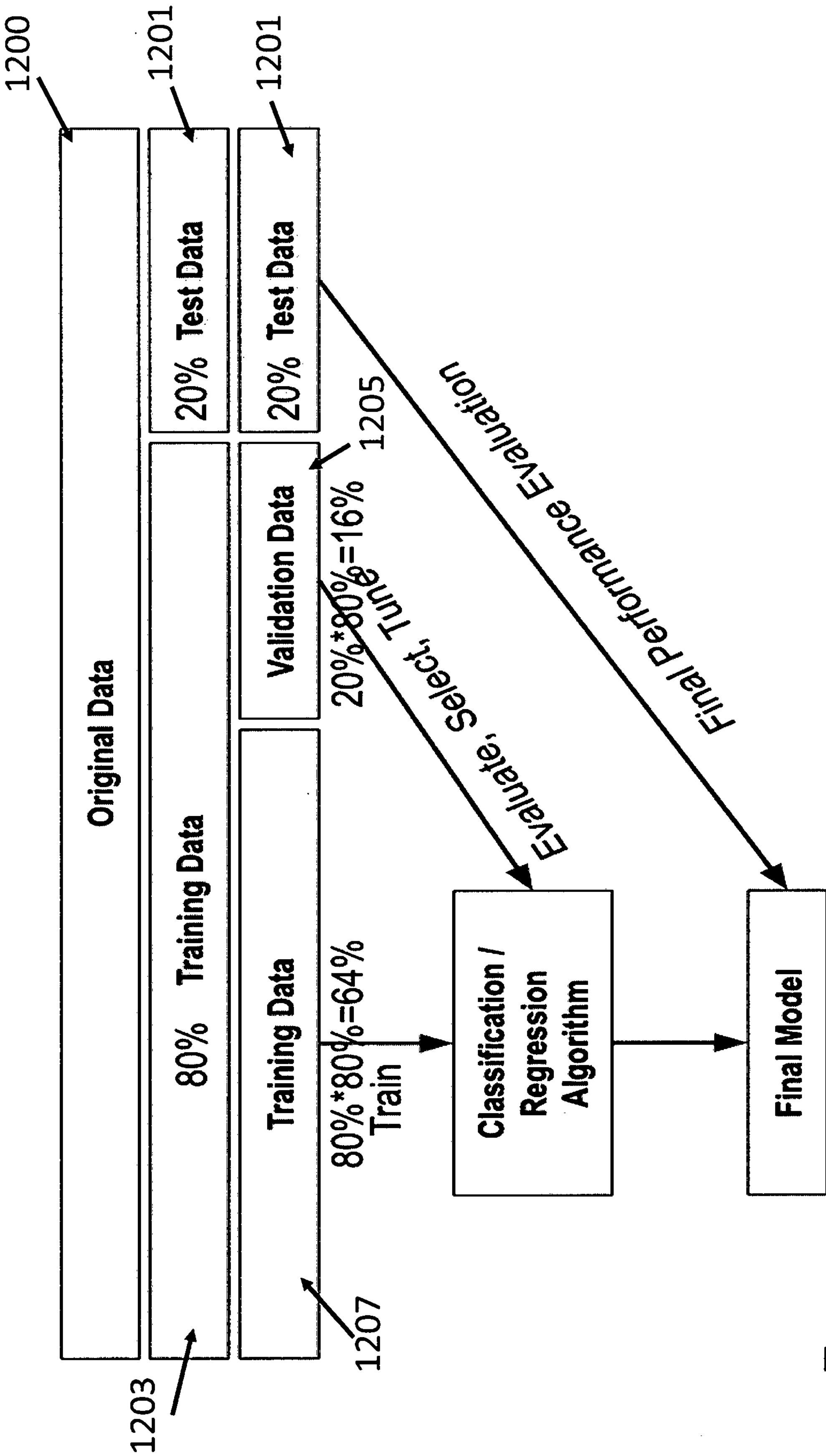

1200
1201
1201
Original Data
20% Test Data
80% Training Data
20% Test Data
Validation Data
Training Data
1205
20%*80%=16%
Evaluate, Select, Tune
Final Performance Evaluation
80%*80%=64%
Train
Classification / Regression Algorithm
Final Model
1203
1207

Fig. 5

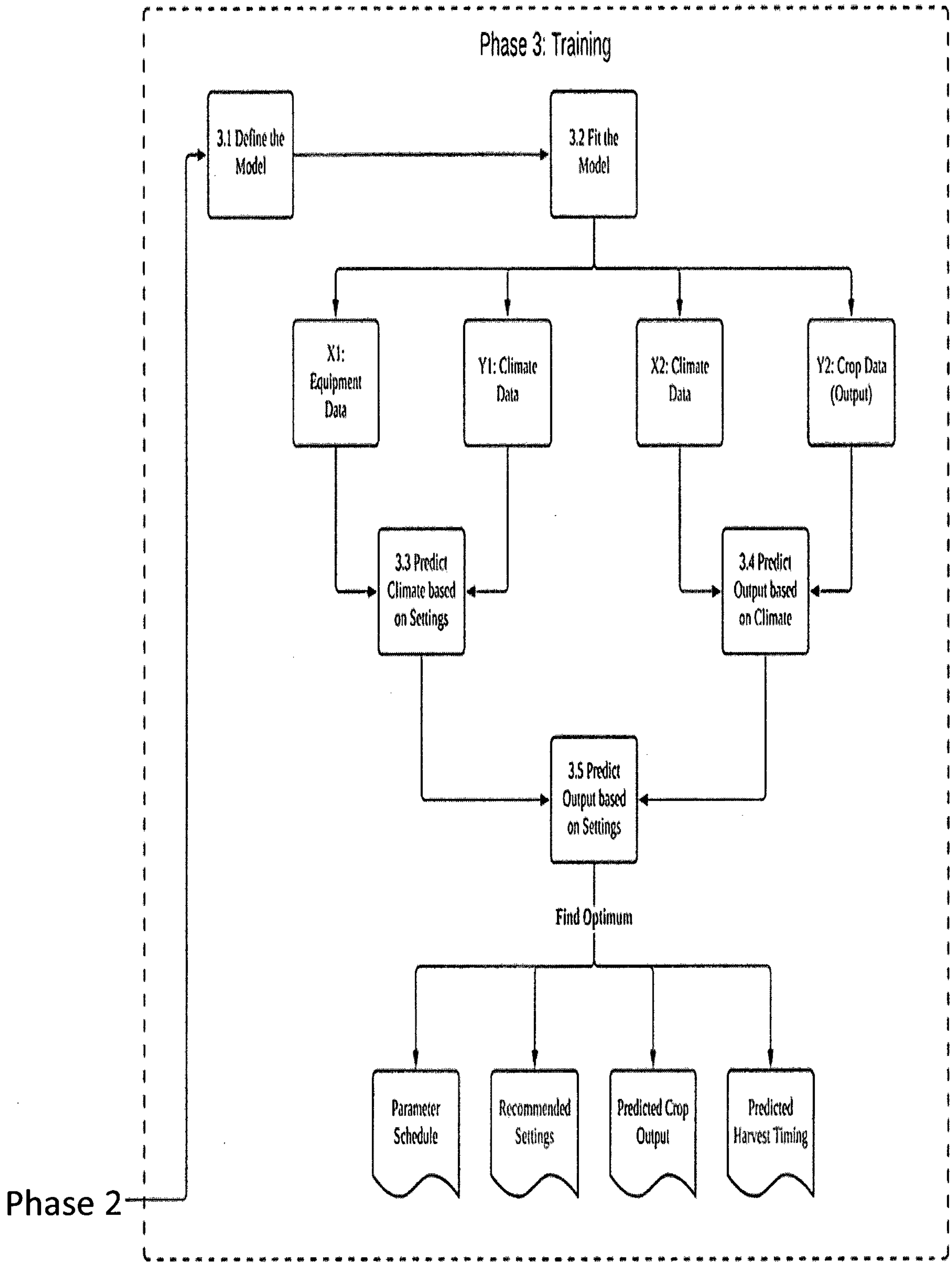

Phase 3: Training
3.1 Define the Model
3.2 Fit the Model
X1: Equipment Data
Y1: Climate Data
X2: Climate Data
Y2: Crop Data (Output)
3.3 Predict Climate based on Settings
3.4 Predict Output based on Climate
3.5 Predict Output based on Settings
Find Optimum
Parameter Schedule
Recommended Settings
Predicted Crop Output
Predicted Harvest Timing
Phase 2

Fig. 6a

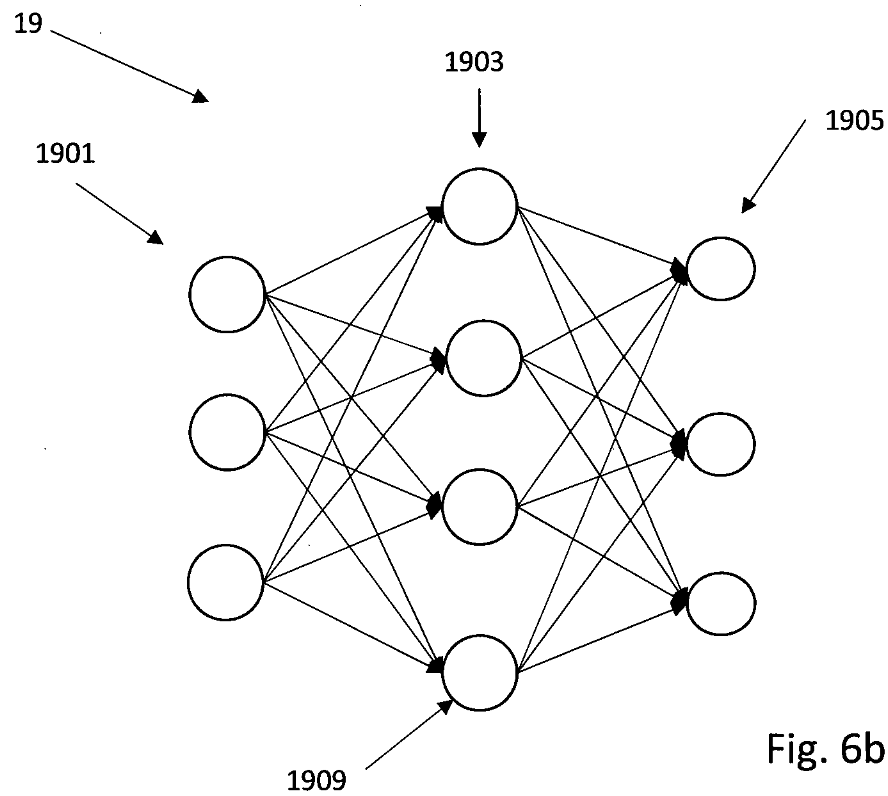

19
1901
1903
1905
1909

Fig. 6b

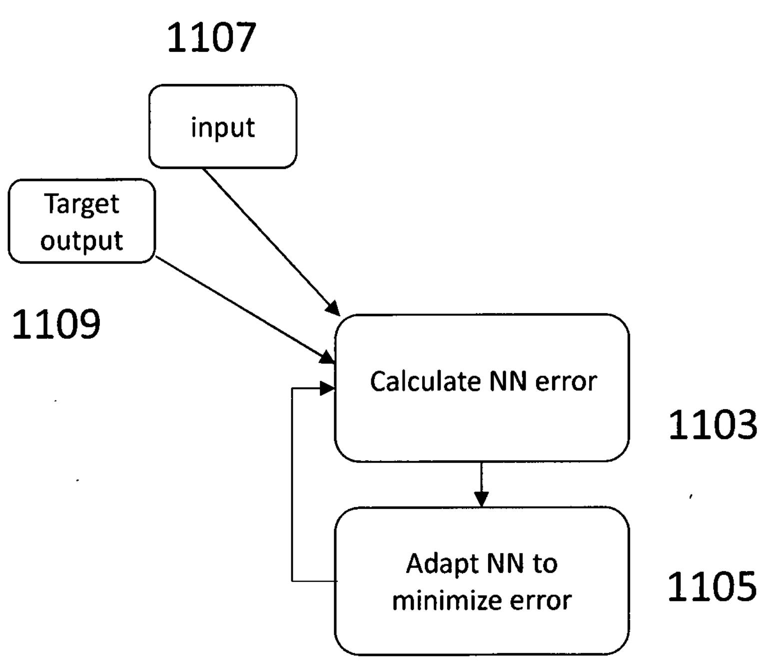
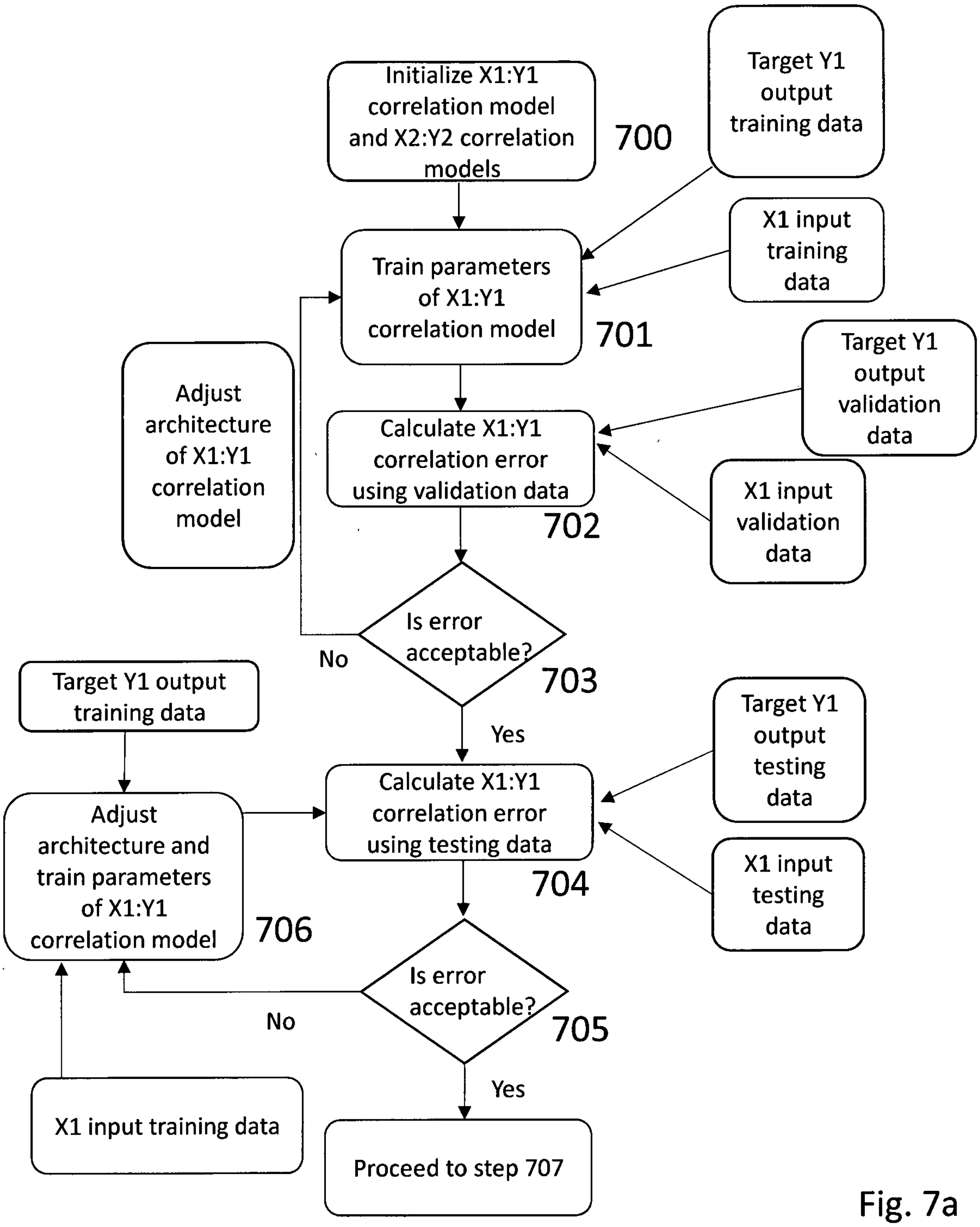

1107
input
Target output
1109
Calculate NN error
1103
Adapt NN to minimize error
1105

Fig. 6c



Initialize X1:Y1 correlation model and X2:Y2 correlation models
700
Target Y1 output training data
Train parameters of X1:Y1 correlation model
X1 input training data
701
Adjust architecture of X1:Y1 correlation model
Target Y1 output validation data
Calculate X1:Y1 correlation error using validation data
702
X1 input validation data
Is error acceptable?
No
703
Yes
Target Y1 output training data
Target Y1 output testing data
Adjust architecture and train parameters of X1:Y1 correlation model
706
Calculate X1:Y1 correlation error using testing data
704
X1 input testing data
Is error acceptable?
No
705
Yes
X1 input training data
Proceed to step 707

Fig. 7a

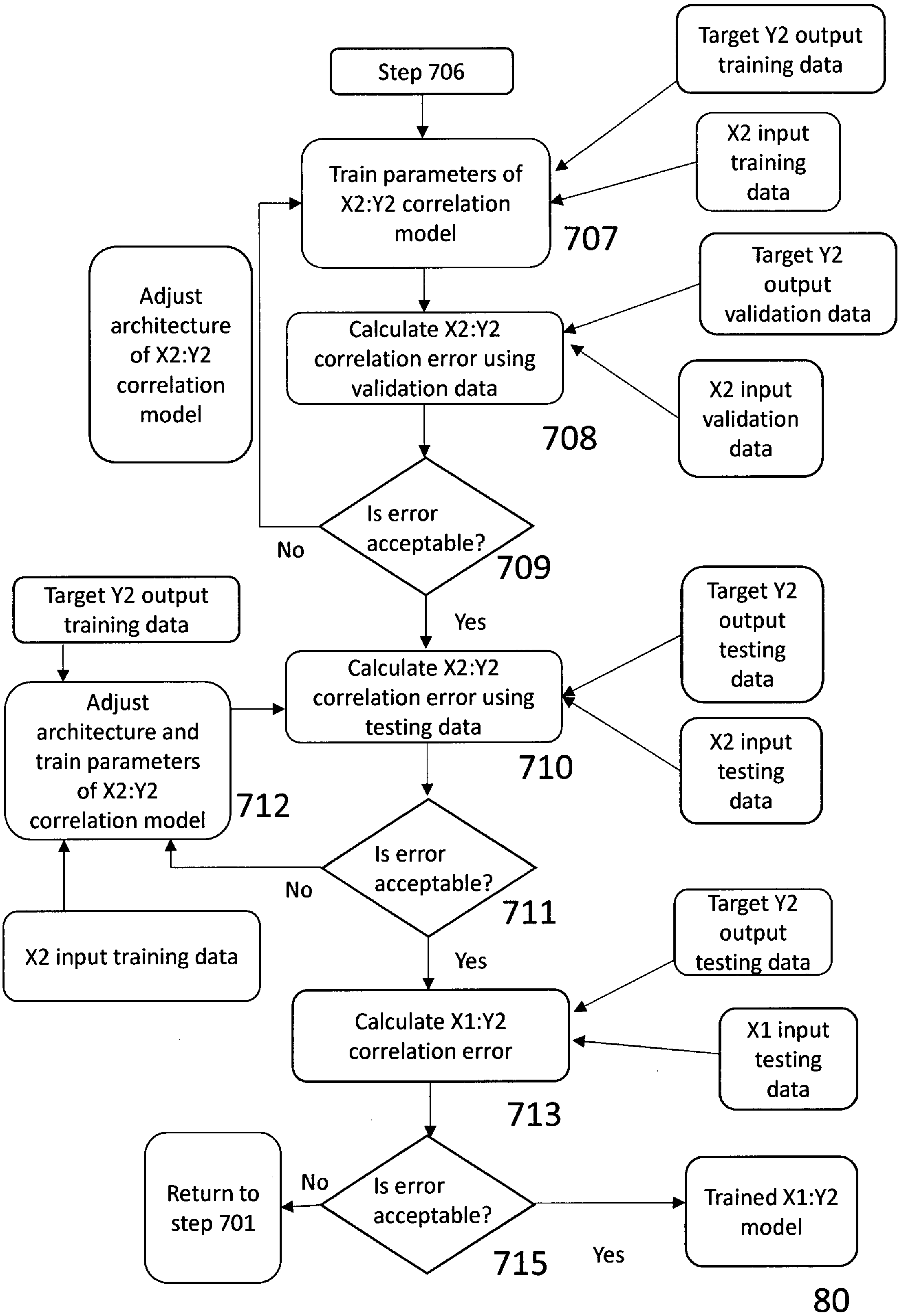

Step 706
Target Y2 output training data
X2 input training data
Train parameters of X2:Y2 correlation model
707
Adjust architecture of X2:Y2 correlation model
Target Y2 output validation data
Calculate X2:Y2 correlation error using validation data
X2 input validation data
708
Is error acceptable?
No
709
Yes
Target Y2 output training data
Adjust architecture and train parameters of X2:Y2 correlation model
712
Calculate X2:Y2 correlation error using testing data
Target Y2 output testing data
X2 input testing data
710
Is error acceptable?
No
711
Yes
X2 input training data
Target Y2 output testing data
Calculate X1:Y2 correlation error
X1 input testing data
713
Return to step 701
No
Is error acceptable?
715
Yes
Trained X1:Y2 model
80

Fig. 7b

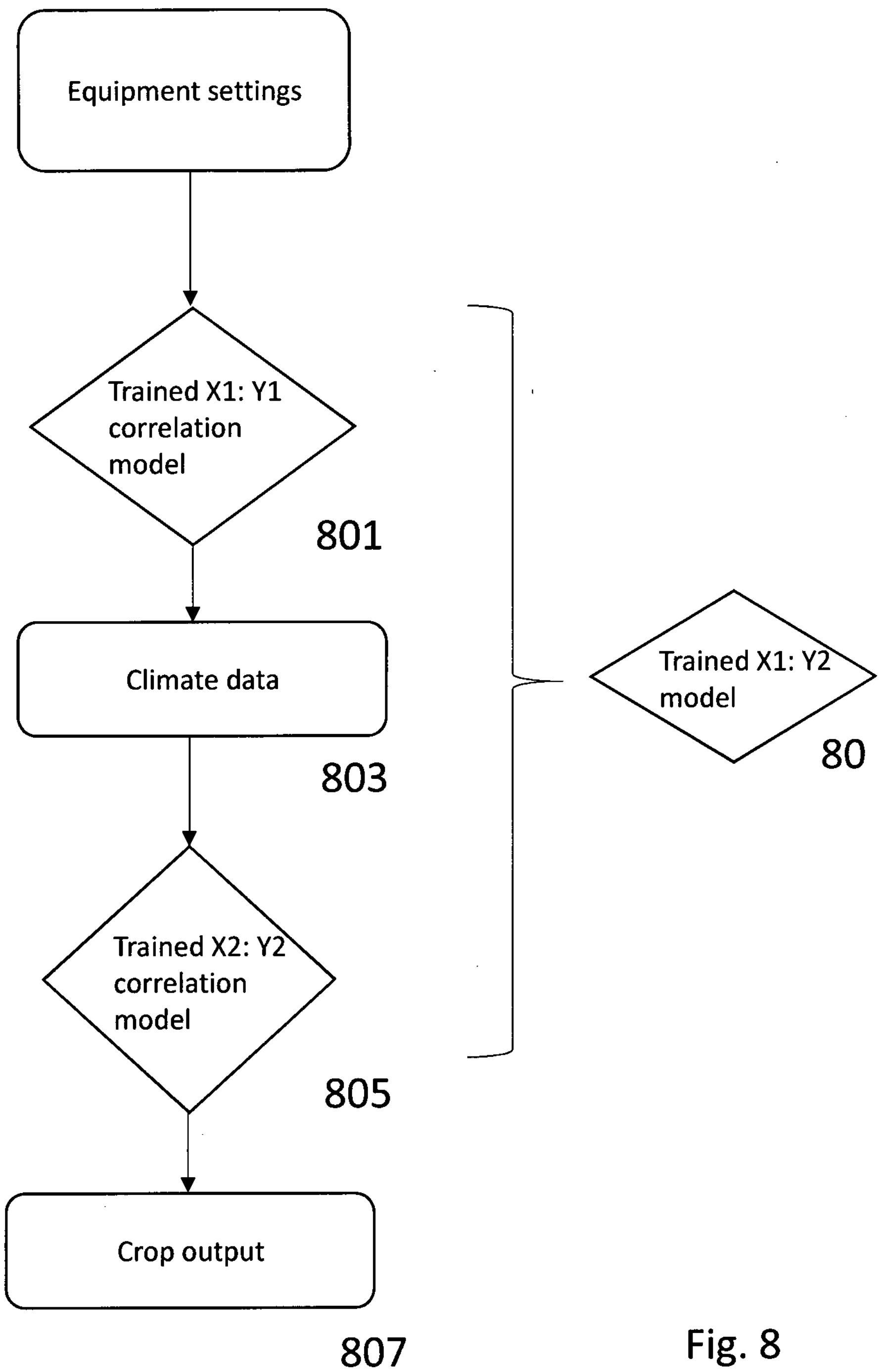

Equipment settings
Trained X1: Y1 correlation model
801
Climate data
803
Trained X2: Y2 correlation model
805
Crop output
807
Trained X1: Y2 model
80

Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2022/050319

A. CLASSIFICATION OF SUBJECT MATTER

See Supplemental Box

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F24F, G06N, G06Q, G16Y

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)

Database: FAMPAT, CNKI, Google Scholar

Keywords: building, greenhouse, management, automation, crops, equipment, ventilation, fan, environment, temperature, humidity, harvest, correlation, optimization, 建造, 温室, 管理, 自动化, 农作物, 设备, 通风, 扇子, 环境, 温度, 湿度, 收获, 相关性, 优化 and other related terms

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 110262435 A (HOHAI UNIVERSITY) 20 September 2019 pages 3, 6-8 of the machine translation	
A	US 2017/0127622 A1 (HONG X.) 11 May 2017 the whole document especially paragraph [0021]	
A	CN 106912325 A (SHANDONG AGRICULTURAL UNIVERSITY) 4 July 2017 the whole document of the machine translation especially page 4	
A	US 2021/0027057 A1 (GENTY N.R. ET AL.) 28 January 2021 the whole document	

☐ 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
26/09/2022 *(day/month/year)*	28/09/2022 *(day/month/year)*

Name and mailing address of the ISA/SG	Authorized officer
Intellectual Property Office of Singapore 1 Paya Lebar Link, #11-03 PLQ 1, Paya Lebar Quarter Singapore 408533	Danny Yap Ming Ann (Mr)
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International application No.
PCT/SG2022/050319

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CN 110262435 A	20/09/2019	NONE	
US 2017/0127622 A1	11/05/2017	NONE	
CN 106912325 A	04/07/2017	NONE	
US 2021/0027057 A1	28/01/2021	US 2019/0377946 A1 US 2022/0245940 A1	12/12/2019 04/08/2022

International application No.
PCT/SG2022/050319

Supplemental Box
(Classification of Subject Matter)

Int. Cl.
F24F 11/30 (2018.01)
G06N 3/02 (2006.01)
G06Q 50/02 (2012.01)
F24F 11/58 (2018.01)
F24F 11/63 (2018.01)
G06Q 10/04 (2023.01)
G16Y 40/35 (2020.01)