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ITU-T Y.4495 (11/2023)

SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

Internet of things and smart cities and communities – Frameworks, architectures and protocols

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Requirements and a reference model of data for smart greenhouse service

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Recommendation ITU-T Y.4495

Requirements and a reference model of data for smart greenhouse service

Summary

For data interoperability, Recommendation ITU-T Y.4495 defines requirements and a reference model of data for smart greenhouse service.

Smart greenhouses have improved productivity by controlling the growing environment of crops. The demand for data-based smart greenhouse services has been increasing, as the importance of converged agricultural services (autonomous farm control, pest control, etc.) based on big data is emphasized. Accordingly, the data generated and consumed by IoT devices in the smart greenhouse have been increasing continuously.

In order to efficiently manage and analyse vast amounts of data and create various services based on the analysed data, a standardized data model for data collection and management system is required. In particular, compatibility of data generated and consumed by heterogeneous devices must be guaranteed to ensure interoperability between devices of heterogeneous vendors.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
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Keywords

Data model, reference model, smart greenhouse service.

* To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

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Requirements and a reference model of data for smart greenhouse service

1 Scope

This Recommendation addresses requirements and a reference model of data for smart greenhouse service including the following:

– Overview of crop-growth related data for smart greenhouse service;

– Requirements of crop-growth related data for smart greenhouse service;

– Reference model of data for smart greenhouse service;

– Use cases of the data model for interoperability.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

None.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 data model [b-ITU-T J.380.8]: A data model is a formal view of the data items contained in an information store to which an information service implementing this standard will provide access and is specified for purposes of formulating and executing queries against the information store's data. This standard specifies one data model that may be used for querying a logical service's information store with this standard's "basic query" interface. More complex data models may be specified independently of this standard and may be queried with this standard's "advanced query" interface. In this latter case, the mechanisms by which a consumer incorporates a data model specification so that meaningful queries may be issued against it are outside the scope of this standard.

3.1.2 greenhouse [b-ITU-T Y.4466]: A facility that can control a crop-growth environment (i.e., light, temperature, humidity, etc.).

3.1.3 smart farm [b-ITU-T Y.4466]: A group of smart greenhouses under the management of an administrator.

3.1.4 smart greenhouse [b-ITU-T Y.4466]: A facility that can control the environment of a greenhouse with minimum human intervention using Internet of things (IoT) technologies.

3.1.5 smart greenhouse service [b-ITU-T Y.4466]: A service that enables precision farming based on a smart greenhouse.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CO_2 Carbon Dioxide

CCW Counterclockwise

CW Clockwise

DMS Data Management System

EC Electrical Conductivity

GNSS Global Navigation Satellite System

pH potential of Hydrogen

ppm parts per million

RPM Resolution Per Minute

SG Smart Greenhouse

5 Conventions

The following conventions are used in this Recommendation:

– The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted, if conformance to this Recommendation is to be claimed.

– The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

6 Overview

Smart greenhouses have improved productivity by controlling the growing environment of crops. The demand for data-based smart greenhouse (SG) services has been increasing, as the importance of converged agricultural services (autonomous farm control, pest control, etc.) based on big data is emphasized. Accordingly, the data generated and consumed by IoT devices in the smart greenhouse have been increasing continuously.

Figure 1 shows a general conceptual diagram of the data flow generated and consumed for the smart greenhouse service. In the smart greenhouse, a controller collects data from various sensors of environmental conditions such as temperature, humidity, and CO_2 level as well as crop-growth status indicators like crop height, stem thickness, leaf size, number of flowers, and fruit status. And according to the analysis result of the collected measurement data, the controller controls various actuators to adjust the environmental conditions suitable for the crop-growth.

In addition to the measurement data, the smart greenhouse service also requires configuration data which the user configures on greenhouse or farm facilities such as installation location, structure, scale, as well as specification data like the use, form, model number, and manufacturer of various devices installed in the greenhouse. The configuration data also includes user data such as the information on the user of the farm, smart greenhouses, and data managed for the smart greenhouse service.

Business data which a user may provide, related to resource input plans for farming, production plans from sowing to harvest, production, etc. are also necessary as configuration data in order to increase income. Moreover, a user may provide user data describing the information of the user.

The measurement data and configuration data are managed by a data management system (DMS) installed for the smart greenhouse, collects and manages all the data collected and can transmit the data to the smart greenhouse service provider for more in-depth analysis. The smart greenhouse service provider analyses the delivered various and vast big data and establishes the optimal operation model for the smart greenhouse and the optimal growth model for crops based on the analysis results.

In order to provide smart greenhouse services provided by service providers to users as described above, the collection and analysis of various data must be performed efficiently. This Recommendation presents requirements and reference models for measurement data and configuration data for the smart greenhouse service.

NOTE – Data related to crop growth status, operation model, growth model, and business for smart greenhouse or smart farm management are not under the scope of this Recommendation.

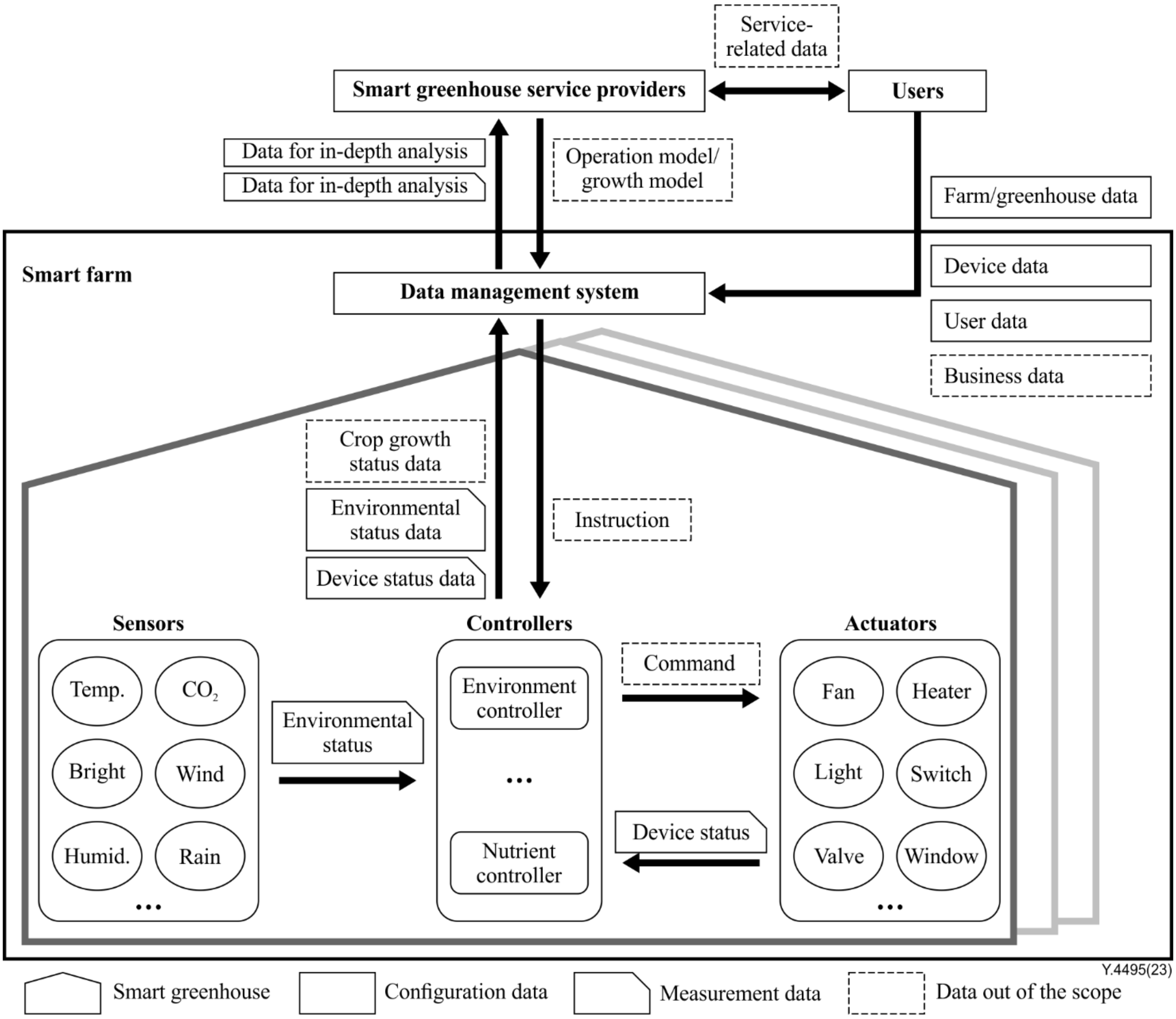

Figure 1 – Conceptual diagram of data flow for smart greenhouse service

NOTE – This Recommendation is not applicable to the data with dashed boxes in Figure 1.

7 Requirements of crop-growth related data for smart greenhouse service

Crop-growth related data used in smart greenhouses can be classified into two categories, which are configuration data and measurement data. Configuration data are used to identify a farm, smart greenhouses in the farm, and devices or equipment used in the smart greenhouses and specify their characteristics. The configuration data are set by a data administrator. Measurement data are used to collect and analyse the environmental status of smart greenhouses and the status of devices installed in the smart greenhouses. The measurement data can either be collected by sensors in the smart greenhouse or provided by external data providers.

7.1 General requirements

To properly utilize the crop-growth related data, two categories of data need to have a relationship. For example, the configuration data including the shape of the greenhouse and device installation information, and the measurement data including environmental status information are considered together for the status of the smart greenhouse during a specific period in the past. Thus, each data needs to have information showing the relationship with other data, and it needs to be distinguishable. The crop-growth related data also need to have temporal and spatial information for precise analytics. The temporal information provides the time value such as the time when a specific configuration is set or when a sensor reports the sensing value. The spatial information provides the value indicating the location of the entities including a smart greenhouse, device or sensor installed in the smart greenhouse. The crop-growth related data can be used by various users such as administrators, farmers, data analysts, etc, and each user needs a different type of authority. As an example, an administrator can create and update configuration data, while a farmer can retrieve part of the data. Thus, each crop-growth related data needs to have authority information regarding the user type.

Crop-growth related data used in smart greenhouses have the following general requirements:

– Crop-growth related data are required to be stored and managed by a data management system (DMS) supporting create, retrieve, update, and delete operations;
– Crop-growth related data are required to include temporal and spatial information;
– The temporal information is required to be presented by the time in year, month, date, hour, minute, second, and subsecond (if supported);
– The temporal information is required to be presented by supporting various resolutions;
– The temporal information is required to be presented in a specific format such as yyyy/mm/dd/hh/mm/s;
– The temporal information is recommended to conform to the time notation which DMS uses;
– The spatial information is required to be composed of absolute position information and relative position information;
– The spatial information is required to represent the position in a 2-dimensional space and 3-dimensional space;
– The spatial information is recommended to include absolute position measured by equipment such as global navigation satellite system (GNSS) and relative position set representing relative direction and distance from the reference position set by the administrator;
– Crop-growth related data are required to have an identifier which may conform [b-ITU-T X.667];
– Crop-growth related data are required to have the authority information to access, use, and administer the data.

7.2 Requirements of configuration data

Configuration data provide information about smart greenhouse configuration and it is set and used by a data administrator such as an owner of the smart greenhouse. Configuration data are merely changed after initial configuration. Configuration data are composed of farm data, greenhouse data, device data, device installation data, and user data.

7.2.1 General requirements

Configuration data have the following general requirement:

– Configuration data are required to have relevant information such as a version that the history of changes including creation, update, and deletion can be manageable.

7.2.2 Farm data

Farm data provide the information of a farm. A farm needs to be identifiable using information such as an identifier, a name, and an address. Especially, the location of a farm is important to identify the farm because geographical location is closely related to climate conditions affecting crop growth.

Farm data have the following requirements:

– Farm data are required to include an identifier, a name, and an address;

– Farm data are recommended to include a geographical location represented by absolute position and relative position;

– Farm data are recommended to include area meaning the size of the farm.

7.2.3 Greenhouse data

Greenhouse data provide the information of a smart greenhouse. A smart greenhouse needs to be identifiable using information showing the characteristics of the smart greenhouse.

Greenhouse data have the following requirements:

– Greenhouse data are required to include an identifier, a name, and a type of greenhouse, width, length, height, type of medium, type of irrigation, type of heating system, type of crop, description of cropping season, and utilization status;

– Greenhouse data are recommended to include a geographical location represented by absolute position and relative position.

7.2.4 Device data

Device data provide the information of a device that can be installed in a smart greenhouse. Each device has its own life cycle from installation to failure and it needs to be replaced before its failure. To manage the devices and find a proper compatible device, device data needs to show the characteristics of the device.

Device data have the following requirements:

– Device data are required to include a device code, name, device type, model name, model code, and the manufacturer name;

– Device data are required to be managed based on the information provided by the manufacturer.

7.2.5 Device installation data

Device installation data provide information about devices installed and operated in a smart greenhouse. A device can be installed at various locations in a smart greenhouse to help with crop growth or collecting environmental status. To control the device or utilize data from the device, it is important to be aware of the information about installation.

Device installation data have the following requirement:

– Device installation data are required to include an identifier, a name, installation date, and installation location.

7.2.6 User data

User data provides information about the user of crop-growth related data.

User data have the following requirement:

– User data are required to include an identifier, a name, and information of a group indicating the authority of the user.

7.3 Requirements of measurement data

Measurement data are the data measured by devices installed in a smart greenhouse or the data obtained by simple processing such as changing data units like converting Fahrenheit to Celsius, and the measured data. Any error that occurs during the measurement introduces useless data and thus a valid range is set for every measured data in order to check whether the measured value is valid. Measuring devices may have different levels of capabilities such as resolution or sensitivity, and the difference may introduce some difference among the measured values. However, the difference among measured values can be ignored, if the difference is within the error range.

Measurement data are composed of environmental status data and device status data.

7.3.1 General requirements

Environmental status data have the following general requirements:

– Environmental status data are required to include a timestamp as measurement time indicating the time conducting the measurement;
– Environmental status data are required to include the information about the relationship with the device installation data of the measuring device;
– Measurement data, measured value, measurement time, measurement location, and the information of measuring device are recommended to be managed together;
– Environmental status data are required to include a valid range of measured values;
– Environmental status data are required to include the error range of measured value;
– Environmental status data are required to include a data unit of measured value;
– The same data unit of environmental status data is recommended to be applied to all devices installed in smart greenhouses or farms;
– Measurement data managed by a DMS are recommended to use the same unit of each measured value.

Device status data have the following general requirements:

– Device status data are required to include a timestamp as report time indicating the time conducting the measurement;
– Device status data are required to include the information about relationship with device installation data of the device;
– Device status data are required to include a valid range of measured values;
– Device status data managed by a DMS are recommended to use the same unit of each measured value.

7.3.2 Environmental status data

Environmental status data provide the information about internal and external environment of a smart greenhouse and the data can be collected from sensors or obtained from external providers sharing data such as the weather data.

For each smart greenhouse, environmental status data are required to include temperature data, humidity data, carbon dioxide (CO_2) data, insolation data, wind direction data, wind speed data, light quantum data, soil moisture tension data, rain detection data, electrical conductivity (EC) data, and potential of hydrogen (pH) data.

7.3.2.1 Temperature data

Basic environmental conditions affecting crop growth, inappropriate conditions where the temperature is too low or too high reduces crop growth.

To properly manage and utilize the temperature data, the following requirements are defined:

– Temperature data are required to be managed as environmental status data;

– Temperature data are required to have *temperature value* reported from temperature sensor;

– Temperature data are required to specify the *unit* of temperature value, which is either Celsius or Fahrenheit.

7.3.2.2 Humidity data

As another basic environment condition, humidity is directly related to the growth of crops. High humidity may lead to disease and pest injury, while low humidity may incur high transpiration of crops which results in low photosynthesis. Consequently, inappropriate humidity leads to poor growth of crops.

To properly manage and utilize the humidity data, the following requirements are defined:

– Humidity data are required to be managed as environmental status data;

– Humidity data are required to have *humidity value* reported from the humidity sensor;

– Humidity data are required to specify the *unit* of humidity value, which is either g/m^3 for absolute humidity or % for relative humidity.

7.3.2.3 Carbon dioxide

Carbon dioxide (CO_2) is highly related to the photosynthesis of crops since photosynthesis consumes CO_2. Low atmospheric carbon dioxide concentration in smart greenhouses leads to poor growth of crops.

To properly manage and utilize the carbon dioxide data, the following requirements are defined:

– Carbon dioxide data are recommended to be managed as environmental status data;

– Carbon dioxide data are required to have *carbon dioxide value* reported from the carbon dioxide sensor;

– Carbon dioxide data are recommended to have a relationship with insolation data to control the supply of extra carbon dioxide;

– Carbon dioxide data are required to specify the *unit* of carbon dioxide value, which is parts per million (ppm).

7.3.2.4 Insolation

Insolation can be used to presume the amount of the crop's photosynthesis. In a smart greenhouse, insolation is adjustable by controlling the shade of the skylight window.

To properly manage and utilize the insolation data, the following requirements are defined:

– Insolation data are recommended to be managed as environmental status data;

– Insolation data are required to have *insolation value* reported from the insolation sensor;

– Insolation data are recommended to have a relationship with carbon dioxide data;

– Insolation data are required to specify the *unit* of insolation value, which can be W/m^2, $kcal/m^2$, $cal/cm^2/min$ or ly/min.

7.3.2.5 Wind direction

Wind direction is the direction of air blowing in the atmosphere outside of a smart greenhouse, which is measured by the weather station installed outside of the smart greenhouse.

To properly manage and utilize the wind direction data, the following requirements are defined:

– Wind direction data are recommended to be managed as environmental status data;
– Wind direction data are required to have *wind direction value* reported from the weather station;
– Wind direction data are required to specify the *unit* of wind direction value, which is represented by 360 degrees clockwise meaning 360 degrees for north, 90 degrees for east, 180 degrees for south, and 270 degrees for west.

7.3.2.6 Wind speed

As the speed of air blowing in the atmosphere outside of a smart greenhouse, wind speed is considered together with the wind direction, the structure of the greenhouse and the direction of the greenhouse. Wind speed is measured by the weather station installed outside of the smart greenhouse and it affects the degree of atmospheric inflow into the greenhouse when the window is opened and the atmospheric environment in the greenhouse such as temperature, humidity, and atmospheric carbon dioxide concentration. In order to prevent damage to the facilities in a greenhouse, it is important to lower atmospheric pressure in the greenhouse by closing the ventilation when strong wind blows.

To properly manage and utilize the wind speed data, the following requirements are defined:

– Wind speed data are recommended to be managed as environmental status data;
– Wind speed data are required to have *wind speed value* reported from the weather station;
– Wind speed data are required to specify the *unit* of wind speed value, which is either m/s, or knot;
– Wind speed data are recommended to have a relationship with wind direction data and device installation data.

7.3.2.7 Rain detection

Rain detection indicates precipitation events such as rainfall and snowfall and it is used to prevent damage due to precipitation events such as root rot due to excessive standing water around the roots, poor yield due to low temperatures, and pests due to excessive moisture. To prevent such damage, roof windows and sidewall windows will be closed when precipitation events are detected.

To properly manage and utilize the rain detection data, the following requirements are defined:

– Rain detection data are recommended to be managed as environmental status data;
– Rain detection data are required to have *rain detection value* reported from the rain sensor;
– Rain detection data are required to specify *units* of rain detection value, such as ON/OFF, 0/1, or true/false.

7.3.2.8 Soil moisture tension

Soil moisture tension presents the degree of moisture absorption of the soil, and it shows the environmental status around a smart greenhouse. Soil moisture tension data are key data to set irrigation water needs or irrigation scheduling which affects the quality and quantity of crop. Installation of a soil moisture tension sensor is highly related to soil characteristics and thus soil moisture tension data are used with the information on soil moisture tension sensor installation.

To properly manage and utilize the soil moisture tension data, the following requirements are defined:

– Soil moisture tension data are recommended to be managed as environmental status data;
– Soil moisture tension data are required to have *soil moisture tension value* reported from the soil tensiometer;
– Soil moisture tension data are required to specify a *unit* of soil moisture tension value, such as kPA or PA.

7.3.2.9 Electrical conductivity

Electrical conductivity (EC) indicates a measure of a material's ability to carry an electrical current and it is affected by the amount of salinity in soil or water. EC can be used to estimate the concentration of the nutrient solution with different appropriate levels for each type of crop. High EC implies high salinity or overuse of fertilizer which makes crops hard to survive, while low EC implies low nutrients which makes crops hard to grow.

To properly manage and utilize the EC data, the following requirements are defined:

– EC data are recommended to be managed as environmental status data;

– EC data are required to have *EC value* reported from the EC sensor;

– EC data are required to specify *units* of EC value, such as mS/cm or dS/m.

7.3.2.10 Potential of hydrogen

Potential of hydrogen (pH) is a measure of the hydrogen ion concentration in an aqueous solution and it is used for making nutrient solutions. High acidity limits root growth, while high alkalinity incurs imbalanced absorption of nutrients resulting in physiological disorders. Thus, maintaining appropriate pH is important for crop growth, and the appropriate pH differs for each type of crop.

To properly manage and utilize the pH data, the following requirements are defined:

– pH data are recommended to be managed as environmental status data;

– pH data are required to have *pH value* reported from pH sensor;

– pH data are not required to specify the *unit* of pH value, since the unit is dimensionless.

7.3.3 Device status data

Device status data provide the status of devices for measuring the environmental status of a smart greenhouse and the growth status of crops and for controlling the status.

For each smart greenhouse, device status data are composed of window opener status data, insolation cover status data, fan status data, irrigation pump status data, irrigation valve status data, cooling, and heater status data.

7.3.3.1 Window opener status data

To maintain temperature and humidity appropriately for crop growth, a window opener is used for ventilation of a smart greenhouse by opening and closing roof windows and sidewall windows. Window opener uses a motor for opening and closing windows and thus the window open state can be specified by motor rotation direction and rotation time. The appropriate window open state depends on the environmental status of an internal and external smart greenhouse. Internal environmental status includes temperature, humidity, atmospheric carbon dioxide concentration, and external environmental status includes temperature, humidity, wind direction, wind speed, and rain detection.

To properly manage and utilize the window opener status data, the following requirements are defined:

– Window opener status data are recommended to be managed as device status data;

– Window opener status data are required to have *window open state value* reported from the window opener;

– Window opener status data are required to specify the *unit* of motor rotation direction value, such as clockwise (CW)/counterclockwise (CCW);

– Window opener status data are required to specify the *unit* of motor rotation time value, such as second;

– Window opener status data are recommended to have a relationship with the environmental status data.

7.3.3.2 Insolation cover status data

Insolation cover is used for warming the greenhouse by adjusting the amount of light and heat. Insolation cover is also called as insulation curtain since it is installed inside the greenhouse and folded/unfolded like a curtain. Insolation cover uses a motor for opening and closing the cover and thus the open cover state can be specified by motor rotation direction and rotation time. The appropriate open cover state depends on the environmental status of the internal and external smart greenhouse. Internal environmental status includes temperature and insolation, and external environmental status includes temperature and rain detection.

To properly manage and utilize the insolation cover status data, the following requirements are defined:

– Insolation cover status data are recommended to be managed as device status data;
– Insolation cover status data are required to have *insolation cover state value* reported from the insolation cover;
– Insolation cover status data are required to specify the *unit* of motor rotation direction value, such as clockwise (CW)/counterclockwise (CCW);
– Insolation cover data are required to specify the *unit* of motor rotation time value, such as second;
– Insolation cover data are recommended to have a relationship with the environmental status data.

7.3.3.3 Fan status data

Fan status data indicate the status of fans installed for a smart greenhouse. A fan is classified into a ventilator and a flow fan. Ventilator is installed at the boundary of the inside and outside of the greenhouse in order to adjust atmospheric conditions in the greenhouse by mixing the air inside and outside the greenhouse. Flow fan is installed in the greenhouse in order to maintain a uniform atmospheric condition in the greenhouse. Fan uses a motor for its operation and thus the fan status can be specified by an operation state, motor rotation direction and rotation speed. The appropriate fan status depends on the environmental status of the internal and external smart greenhouse. Internal environmental status includes temperature, humidity, atmospheric carbon dioxide concentration, and external environmental status includes wind direction and wind speed.

To properly manage and utilize the fan status data, the following requirements are defined:

– Fan status data are recommended to be managed as device status data;
– Fan status data are required to have *fan state value* reported from the insolation cover;
– Fan status data are required to specify the *unit* of motor operation state value, such as on/off;
– Fan status data are required to specify the *unit* of motor rotation direction value, such as clockwise (CW)/counterclockwise (CCW);
– Fan status data are required to specify the *unit* of motor rotation speed value, such as resolution per minute (RPM) or %;
– Fan status data are recommended to have a relationship with the environmental status data.

7.3.3.4 Irrigation pump status data

Irrigation pump status indicates the status of the irrigation pump used for watering crops. Irrigation pump uses a motor for its operation and thus the irrigation pump status can be specified by the operation state and operation time. The appropriate irrigation pump status depends on the environmental status of the inside of the smart greenhouse, which is humidity. In addition, the irrigation starting time and amount of irrigation per unit time are also considered for the appropriate irrigation pump status.

To properly manage and utilize the irrigation pump status data, the following requirements are defined:

– Irrigation pump status data are recommended to be managed as device status data;
– Irrigation pump status data are required to have the *irrigation pump state value* reported from the irrigation pump;
– Irrigation pump status data are required to specify the *unit* of motor operation state value, such as on/off;
– Irrigation pump status data are required to specify the *unit* of operation time value, such as second;
– Irrigation pump status data are recommended to have a relationship with the environmental status data.

7.3.3.5 Irrigation valve status data

Irrigation value status indicates the status of the irrigation valve used for controlling irrigation. The irrigation valve is tightly related to the irrigation pump since the irrigation pipe will be damaged if the irrigation pump operates when the irrigation valve is closed. Irrigation valve uses a motor for its operation and thus the irrigation valve status can be specified by the level of opening and opening time.

To properly manage and utilize the irrigation valve status data, the following requirements are defined:

– Irrigation valve status data are recommended to be managed as device status data;
– Irrigation valve status data are required to have *irrigation value state value* reported from the irrigation valve;
– Irrigation valve status data are required to specify the *unit* of motor operation state value, such as on/off;
– Irrigation valve status data are required to specify the *unit* of operation time value, such as second;
– Irrigation valve status data are recommended to have a relationship with the irrigation pump status data.

7.3.3.6 Cooler and heater status data

Cooler and heater status indicates the status of the cooler and heater maintaining the temperature and humidity inside the greenhouse. Cooler and heater are adjusted by comparing the environmental condition in the greenhouse and the appropriate condition of the temperature and humidity. For maintaining the temperature and humidity in the greenhouse, a target temperature value is set and then the cooler and heater operates to achieve the target temperature.

To properly manage and utilize the cooling and heater status data, the following requirements are defined:

– Cooler and heater status data are recommended to be managed as device status data;
– Cooler and heater status data are required to have *cooler and heater state value* reported from the cooler and heater;
– It is required to be capable of managing and adjusting the cooler and heater status;
– Cooler and heater status data are required to specify a *unit* of operation state value, such as on/off;

– Cooler and heater status data are required to specify a *unit* of temperature setting value, such as Fahrenheit or Celsius;

– Cooler and heater status data are required to specify a *unit* of operation level value, such as %;

– Cooler and heater status data are required to specify a *unit* of operation time value, such as minute or second.

8 Reference data model for smart greenhouse service

8.1 Conceptual data model

Smart greenhouse service supports the creation and management of data for the type of crop and device, operation environment, and the purpose of the service. For integrated management of the data collected from various types of devices and services and generation of valuable data by processing the collected data, it is required to define the types of common data to be managed in the smart greenhouse service and the relationship between each data. The defined types and relationships enable the interoperability between different services and different devices. Figure 2 shows a conceptual data model presenting the data entities and their relationship.

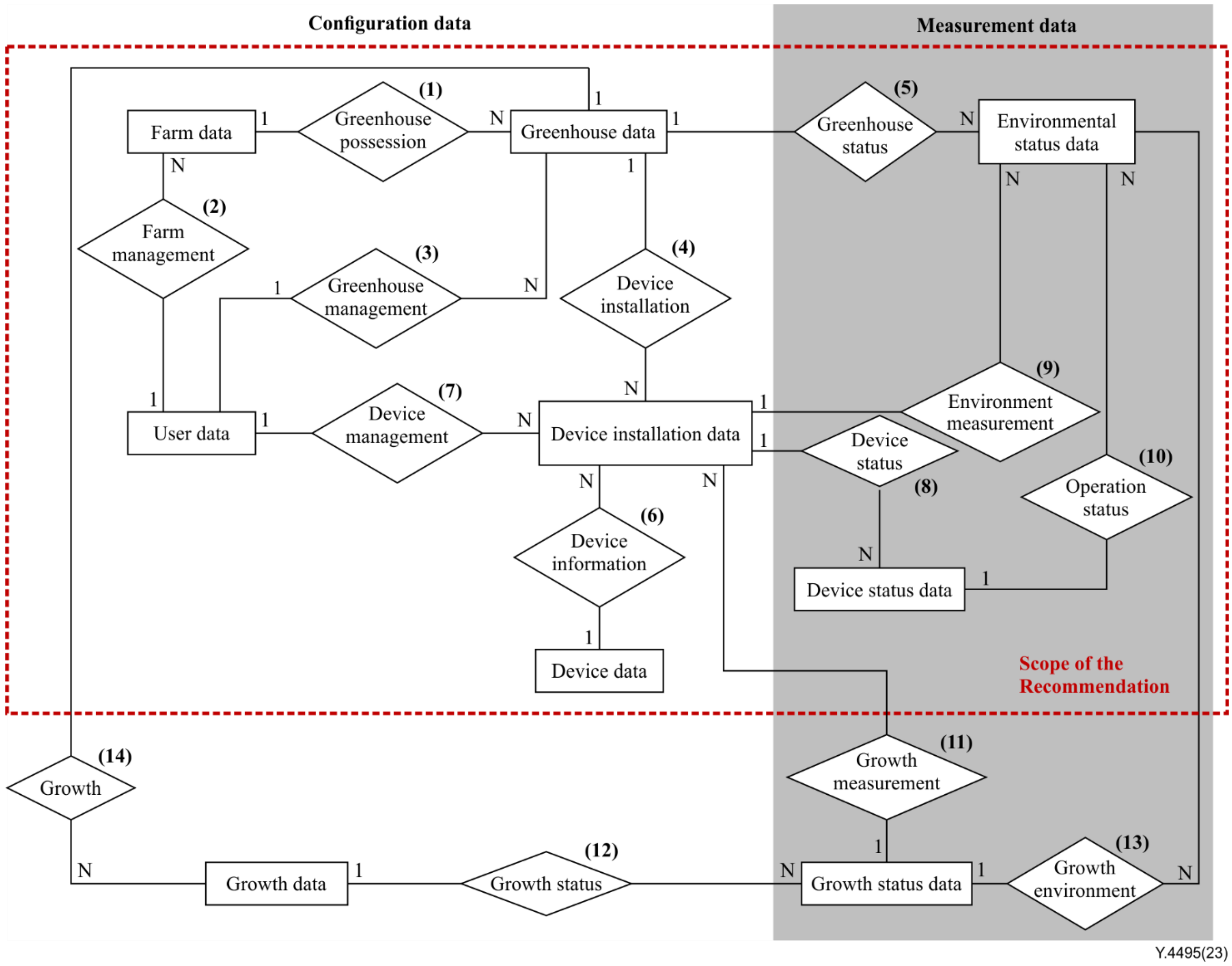

Figure 2 – Conceptual data model of crop-growth related data for smart greenhouse service

The description about each numbered relationship in Figure 2 is as follows:

(1) A farm may have multiple greenhouses and a certain greenhouse belongs to a farm. Thus, farm data have "1:N" greenhouse possession relationship with multiple greenhouse data;

(2) A user can manage multiple farms. Thus, user data have "1:N" farm management relationship with the farm data;

(3) A user can manage multiple greenhouses. Thus, user data have "1:N" greenhouse management relationship with the greenhouse data;

(4) A greenhouse may have multiple devices installed, and a device is installed in a greenhouse. Thus, greenhouse data have "1:N" device installation relationship with the device installation data;

(5) A greenhouse has various types of environmental status. Thus, greenhouse data have "1:N" greenhouse status relationship with the environmental status data;

(6) A type of device can be installed in various locations. Thus, device data have "1:N" device information relationship with the device installation data;

(7) A user can manage multiple devices installed, and an installed device is managed by a user. Thus, user data have "1:N" device management relationship with the device installation data;

(8) An installed device may have multiple status. Thus, device installation data have "1:N" device status relationship with the device status data;

(9) An installed device may measure multiple types of environmental conditions. Thus, device installation data have "1:N" environment measurement relationship with the environmental status data;

(10) An installed device may operate under various environmental conditions. Thus, device status data have "1:N" operation status relationship with the environmental status data;

(11) Crop growth status may be measured by multiple devices measuring different types of status. Thus, growth status data have "1:N" growth measurement relationship with the device installation data;

(12) A crop growth status can be cumulative for proper analysis. Thus, growth data have "1:N" growth status relationship with growth status data which consists of one latest status and a cumulative historical status;

(13) A group growth status can be presented with various environmental conditions. Thus, growth status data have "1:N" growth environment relationship with the environmental status data;

(14) A greenhouse can have multiple types of crops and a crop belongs to a greenhouse. Thus, greenhouse data have "1:N" growth relationship with growth data.

NOTE – The relationships from (11) to (14) are not under the scope of this Recommendation as shown in Figure 2.

8.2 Logical data models

This clause addresses the three types of logical data models of crop-growth related data for smart greenhouse services. The logical data model of configuration data shows the entities of configuration data and their relationships, while the logical data model of measurement data shows the entities of measurement data and their relationships. The logical data of the relationship between configuration data and measurement data shows the relationship between them.

8.2.1 Logical data model of configuration data

This clause addresses the logical data model of configuration data including the five types of configuration data entities and the six types of data entities showing the relationship among the configuration data entities. Figure 3 shows the logical data model of configuration data.

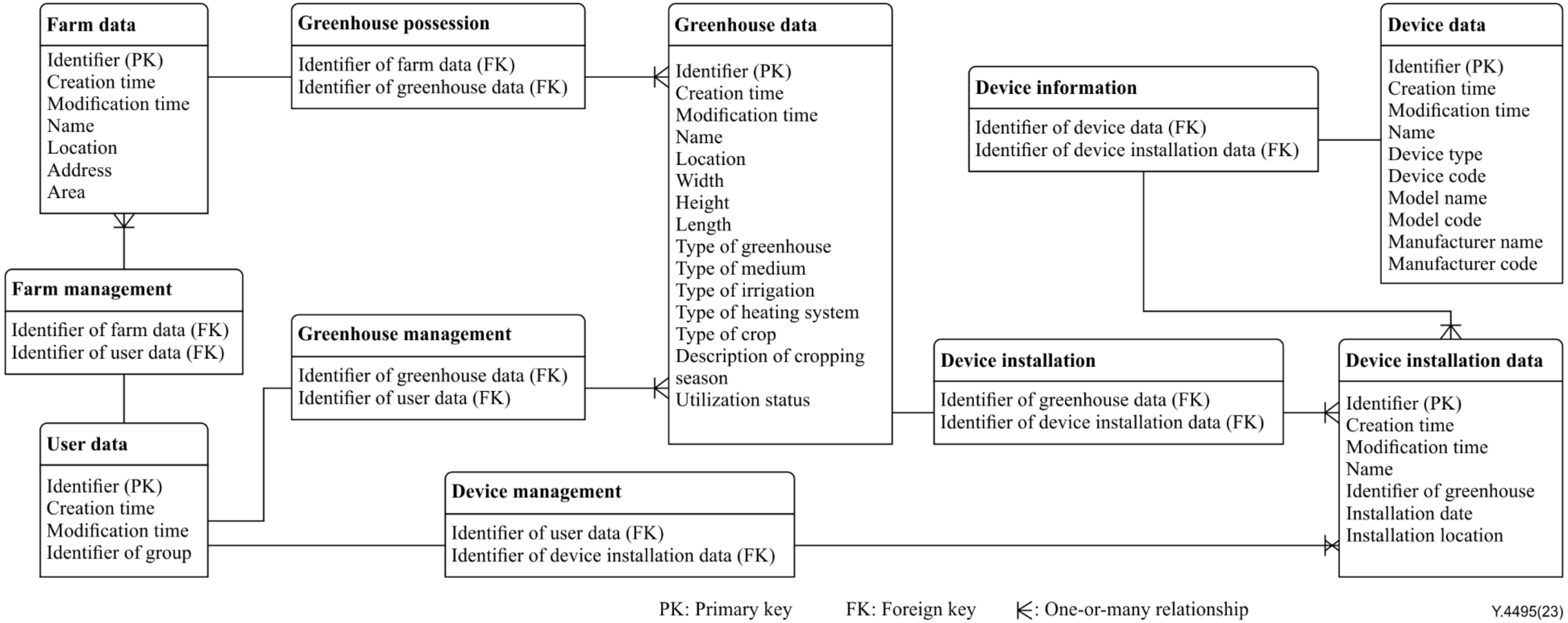

Figure 3 – Logical data model of configuration data

8.2.1.1 Farm data

Farm data shows the information of a farm and have the following attributes:

– Identifier is the information to represent a farm and shall not be modified throughout its lifecycle;
– Creation time is the time when the farm data are created by registering a farm with a smart greenhouse service and shall not be modified throughout its lifecycle;
– Modification time is the time when the farm data are modified and shall be automatically updated;
– Name is a human-readable name for easily identifying the farm, and multiple farm data can have the same name. Name can be modified by the authorised user;
– Location shows the location of the farm represented by various types of values such as global navigation satellite system (GNSS) coordinates and shall include the type of value and unit. Location can be modified by the authorised user;
– Address is human-readable location information for easily identifying the location of the farm. Address can be modified by the authorised user;
– Area is the area of the farm represented by various types of values such as an acre or square metre (m^2) and shall include value, unit, and error range. Area can be modified by the authorised user.

8.2.1.2 Greenhouse data

Greenhouse data shows the information of a greenhouse and have the following attributes:

– Identifier is the information to represent a greenhouse and shall not be modified throughout its lifecycle;
– Creation time is the time when the greenhouse data are created by registering a greenhouse with a smart greenhouse service and shall not be modified throughout its lifecycle;
– Modification time is the time when the greenhouse data are modified and shall be automatically updated;
– Name is a human-readable name for easily identifying the greenhouse, and multiple greenhouse data can have the same name. Name can be modified by the authorised user;
– Location shows the location of the farm represented by various types of values such as GNSS coordinates or an appropriate exchange format regarding the GNSS coordinates and shall include the type of value and unit. Location can be modified by the authorised user;
– Width, height, and length are the width, height, and length of the greenhouse represented by various types of value such as yard (yd) or metre (m) and shall include value, unit, and error range. Width, height, and length can be modified by the authorised user;
– Type of greenhouse, medium, irrigation, heating system, crop, description of cropping season, and utilization status are human-readable information for easily identifying the characteristics of a greenhouse. The attributes can be modified by the authorised user.

8.2.1.3 Device data

Device data shows the information of a device and have the following attributes:

– Identifier is the information to represent a device and shall not be modified throughout its lifecycle;
– Creation time is the time when the device data are created by registering a device with a smart greenhouse service and shall not be modified throughout its lifecycle;

– Modification time is the time when the device data are modified and shall be automatically updated;

– Name is a human-readable name for easily identifying the device, and multiple device data can have the same name. Name can be modified by the authorised user;

– Device type is the information to represent the usage of the device, and multiple device data can have the same type. Device type can be modified by the authorised user;

– Model name is the information to represent a device and multiple device data can have the same model name. Model name shall not be modified throughout its lifecycle;

– Model code is the information to represent compatibility and multiple device data can have the same model code, meaning that they are compatible. Model code shall not be modified throughout its lifecycle;

– Manufacturer name is a human-readable name for easily identifying the manufacturer of the device and includes name, an address of the Internet website, etc. Manufacturers can be modified by the authorised user.

8.2.1.4 Device installation data

Device installation data shows the information of a device installed and have the following attributes:

– Identifier is the information to represent a device and shall not be modified throughout its lifecycle;

– Creation time is the time when the device installation data are created by registering the installation of a device with a smart greenhouse service and shall not be modified throughout its lifecycle;

– Modification time is the time when the device installation data are modified and shall be automatically updated;

– Name is a human-readable name for easily identifying the device installed, and multiple device installation data can have the same name. Name can be modified by the authorised user;

– Installation date shows the date of device installation;

– Installation location shows the location of the installed device represented by various types of values such as GNSS coordinates or an appropriate exchange format regarding GNSS coordinates and shall include the type of value and unit. Location can be modified by the authorised user.

8.2.1.5 User data

User data shows the information of a user and have the following attributes:

– Identifier is the information for identifying each user that cannot be modified throughout its lifecycle and it shall not be exploitable for tracking the user;

NOTE – Identifier shall be made by the mechanism guaranteeing that the user of the identifier cannot be trackable through the identifier, which is out of the scope of this Recommendation.

– Creation time is the time when the user is created by registering a user with a smart greenhouse service and shall not be modified throughout its lifecycle;

– Modification time is the time when the user data are modified and shall be automatically updated;

– Group is the information to represent the group to which the user belongs and includes an identifier of the group, authority of the group, etc. Group can be modified by the authorised user.

8.2.1.6 Farm management

Farm management shows the relationship between farm data and user data.

– Identifier of farm data is the foreign key of farm data which has the farm management relationship with user the data;
– Identifier of user data is the foreign key of user data which has the farm management relationship with the farm data.

8.2.1.7 Greenhouse possession

Greenhouse possession shows the relationship between farm data and greenhouse data.

– Identifier of farm data is the foreign key of farm data which has the greenhouse possession relationship with the greenhouse data;
– Identifier of greenhouse data is the foreign key of greenhouse data which has the greenhouse possession relationship with the farm data.

8.2.1.8 Greenhouse management

Greenhouse management shows the relationship between user data and greenhouse data.

– Identifier of user data is the foreign key of user data which has the greenhouse management relationship with the greenhouse data;
– Identifier of greenhouse data is the foreign key of greenhouse data which has the greenhouse management relationship with the user data.

8.2.1.9 Device installation

Device installation shows the relationship between device installation data and greenhouse data.

– Identifier of device installation data is the foreign key of device installation data which has the device installation relationship with the greenhouse data;
– Identifier of greenhouse data is the foreign key of greenhouse data which has the device installation relationship with the device installation data.

8.2.1.10 Device management

Device management shows the relationship between device installation data and user data.

– Identifier of device installation data is the foreign key of device installation data which has the device management relationship with the user data;
– Identifier of user data is the foreign key of user data which has the device management relationship with the device installation data.

8.2.1.11 Device information

Device information shows the relationship between device installation data and device data.

– Identifier of device installation data is the foreign key of device installation data which has the device information relationship with the device data;
– Identifier of device data is the foreign key of user data which has the device information relationship with the device installation data.

8.2.2 Logical data model of measurement data

This clause addresses the logical data model of measurement data showing the two types of measurement data and a type of data showing the relationship among the measurement data. Figure 4 shows the logical data model of measurement data.

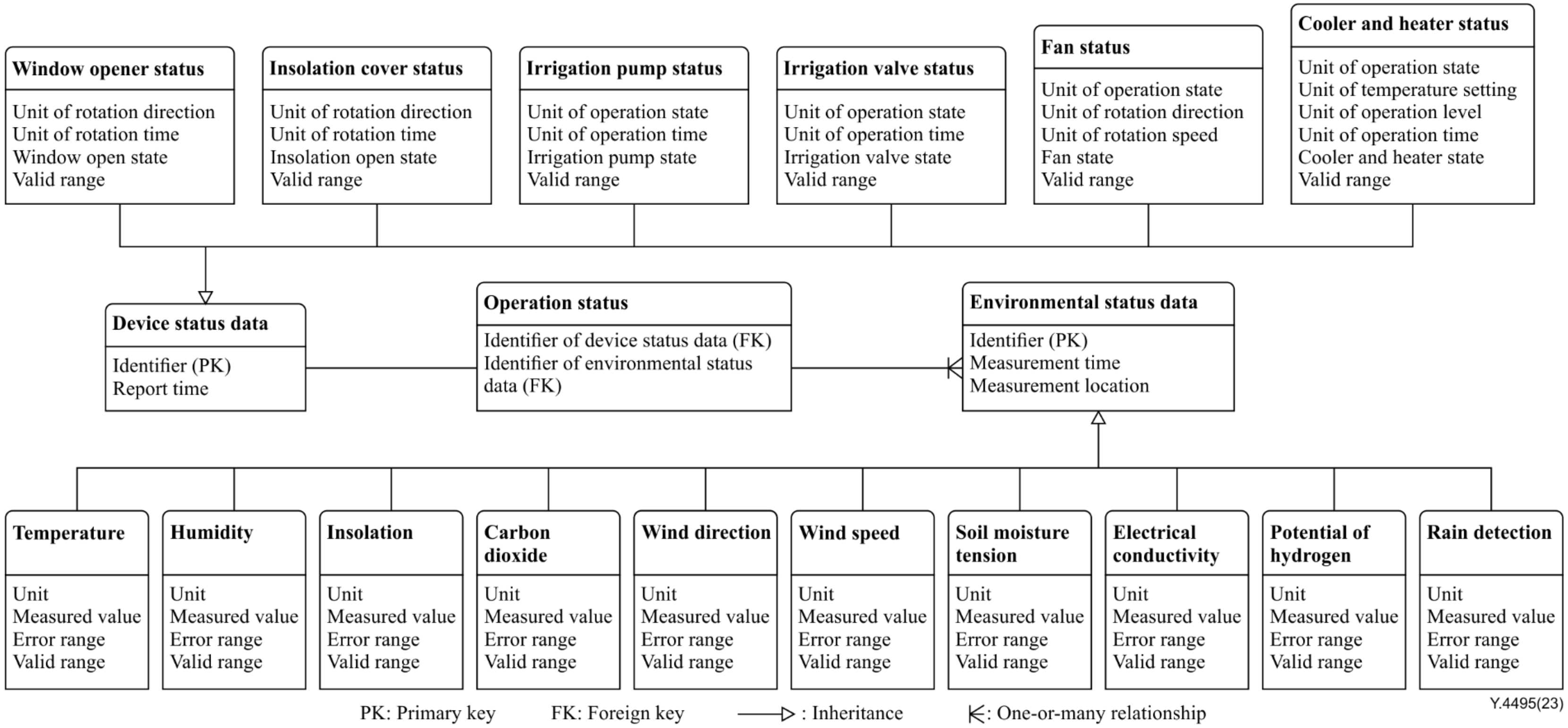

Figure 4 – Logical data model of measurement data

8.2.2.1 Environmental status data

Environmental status data shows the environmental status of a greenhouse, and it is a generalization of the environmental status data described under clause 7.3.2. Environmental status data have the following attributes:

– Identifier is the information to represent the environmental status data and shall not be modified throughout its lifecycle;

– Measurement time is the time when the environmental status is measured and shall not be modified throughout its lifecycle;

– Measurement location is the location where the environmental status is measured, and it is set as same as the installation location attribute of device installation data described in clause 8.2.1.4.

NOTE – The entities inheriting the environmental status data entity inherits all attributes of the environmental status data entity.

8.2.2.2 Device status data

Device status data shows the status of a device and it is a generalization of the device status data described under clause 7.3.3. Device status data have the following attributes:

– Identifier is the information to represent the device status data and shall not be modified throughout its lifecycle;

– Report time is the time when the environmental status is reported and shall not be modified throughout its lifecycle.

NOTE – The entities inheriting the device status data entity inherits all attributes of the device status data entity.

8.2.2.3 Operation status

Operation status shows the relationship between device status data and environmental status data.

– Identifier of device status data is the foreign key of device status data which has the operation status relationship with the environmental status data;

– Identifier of environmental status data is the foreign key of environmental status data which has the operation status relationship with the device status data.

8.2.3 Logical data model of the relationships between configuration data and measurement data

This clause addresses the logical data model of relationships between configuration data and measurement data. Figure 5 shows the logical data model of the relationships between configuration data and measurement data.

NOTE – Details of entities of device installation data, greenhouse data, device status data, and environmental status data are described in clauses 8.2.1 and 8.2.2.

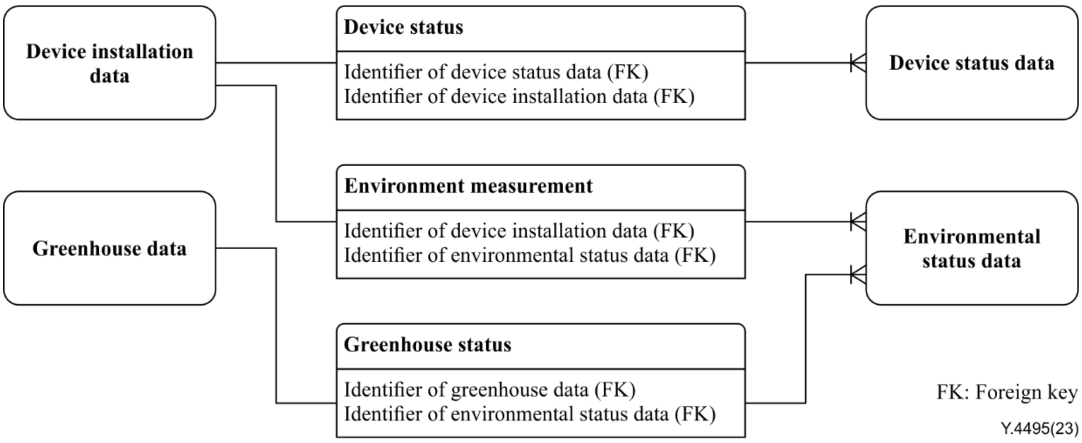

Figure 5 – Logical data model of the relationships between configuration data and measurement data

8.2.3.1 Device status

Device status shows the relationship between device installation data and device status data.

– Identifier of device status data is the foreign key of device status data which has the device status relationship with the device installation data;

– Identifier of device installation data is the foreign key of device installation data which has the device status relationship with the device status data.

8.2.3.2 Environment measurement

Environment measurement shows the relationship between device installation data and environmental status data.

– Identifier of device installation data is the foreign key of device installation data which has the environment measurement relationship with the environmental status data;

– Identifier of environmental status data is the foreign key of environmental status data which has the environment measurement relationship with the device installation data.

8.2.3.3 Greenhouse status

Greenhouse status shows the relationship between greenhouse status data and environmental status data.

– Identifier of greenhouse status data is the foreign key of greenhouse status data which has the greenhouse status relationship with the environmental status data;

– Identifier of environmental status data is the foreign key of environmental status data which has the greenhouse status relationship with the greenhouse status data.

Appendix I

Use case – Data conversion for integrated data analysis

(This appendix does not form an integral part of this Recommendation.)

The growth of crops in a smart greenhouse is highly dependent on the environment within the greenhouse, and different types of crops require different environmental conditions for optimal growth. As a result, smart greenhouse services require vast amounts of consistent data to be systematically collected and accumulated to configure the best possible environmental conditions for crop growth. Figure I.1 shows the cycling process of developing a growth model to be used for configuring environmental conditions suitable for the growth of crops in smart greenhouse services.

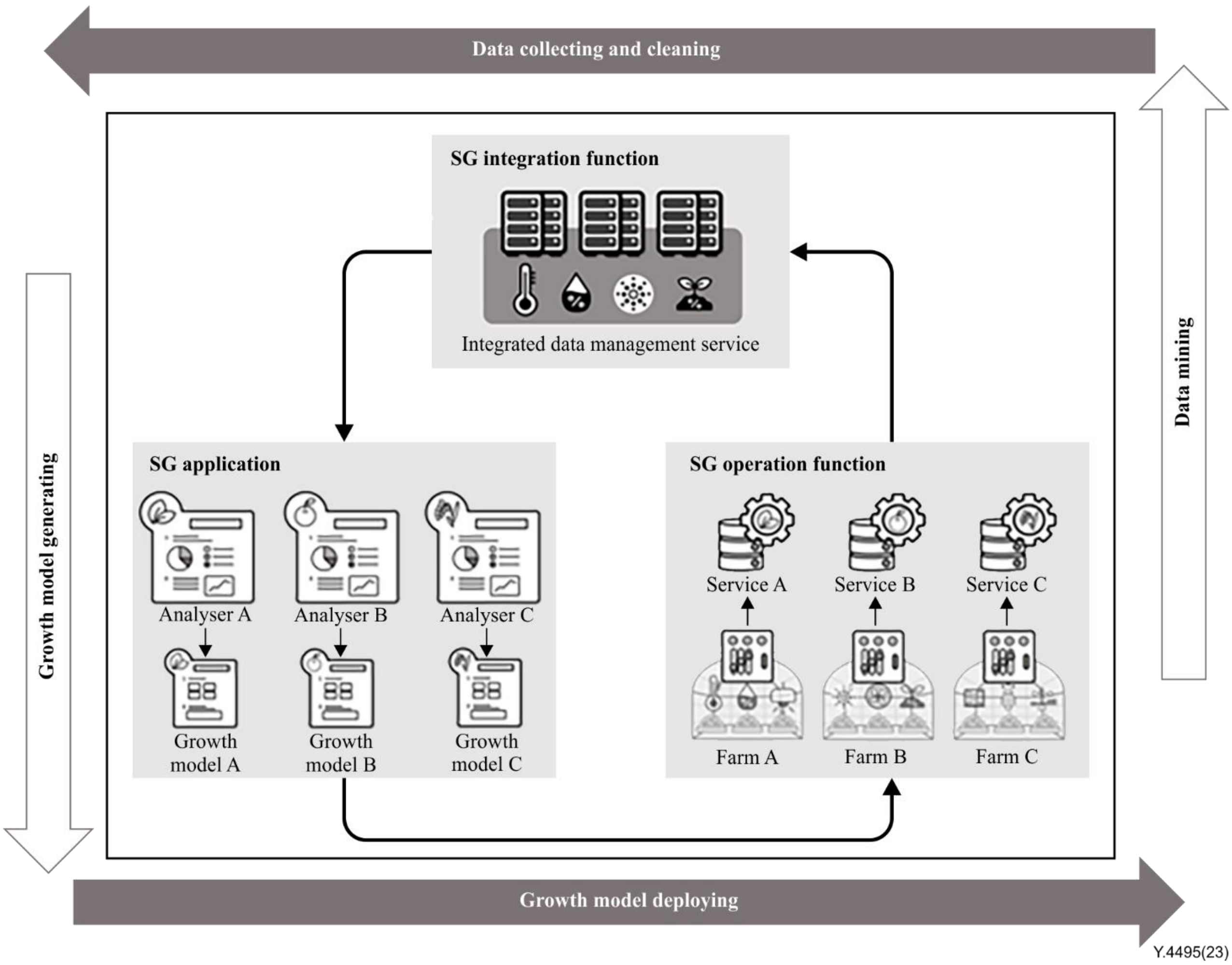

Figure I.1 – Cycling process for developing growth model for smart greenhouse service

The cycling process involves several steps. First, data are collected from the smart greenhouse (SG) operation function (data mining) and aggregated by an SG integration function provided by an integrated data management service. The aggregated data are then subjected to data cleaning to remove any errors or inconsistencies. Next, the cleaned data are analysed and processed by an SG application to develop an optimal growth model for each crop. The growth model generated by the SG application considers the unique requirements of each crop, as well as the specific environmental conditions within the smart greenhouse. Once the growth model has been developed, it is distributed to the SG operation function with the help of a model deployment service.

By following this data flow, the smart greenhouse service can efficiently provide optimal growth environment conditions for each crop, resulting in higher yields and better overall outcomes.

However, manufacturers use their own data format and process data in different ways, limiting data sharing and interoperability in the integrated data analysis. This also hinders the smooth circulation of the associated data. For interoperability including integrated data analysis, the data model can be used to convert non-conformed data to conformed data. Figure I.2 shows an example of utilizing the data model for data conversion based on [b-ITU-T Y.4466].

NOTE – This Recommendation provides a conceptual data model and a logical data model since the physical data model is implementation-dependent.

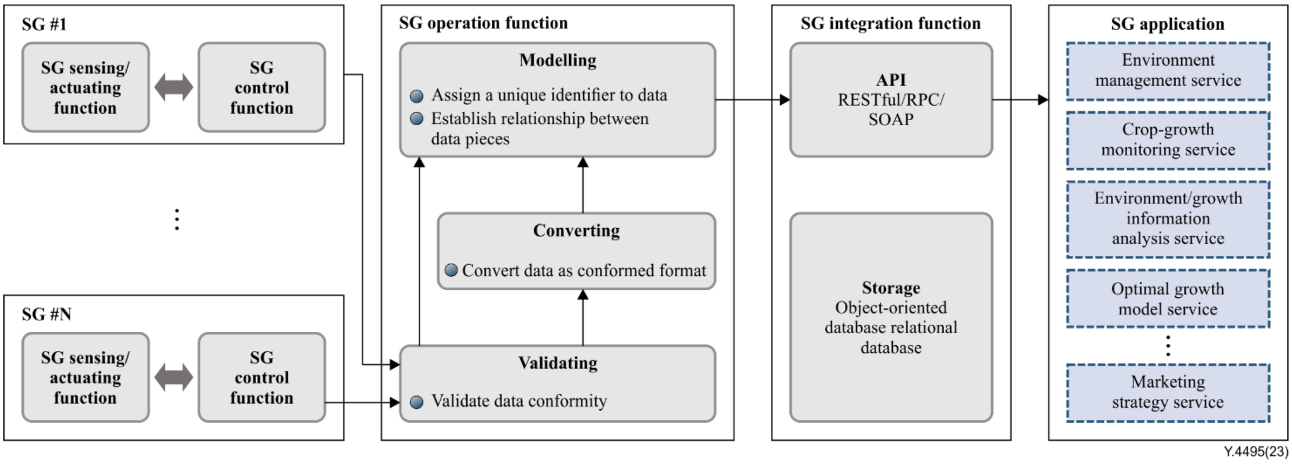

Figure I.2 – Example of data conversion using a data model

Multiple smart greenhouses denoted as SG #number in Figure I.2, collect and transmit data on various aspects of the greenhouse environment to the SG operation function in the central smart greenhouse management system. The SG operation function serves as an integrated management for the collected data, and it is responsible for validating its conformity. If the received data are in conformance with the expected format and structure, the system will assign a unique identifier to the data and establish the relationships between different pieces of data for integration and analysis purposes. However, if the received data are not conformant with the expected format, the SG operation function performs a data conversion process to transform non-conforming data into conformed data for integration with the other data. This data conversion process involves several procedures: 1) data cleaning for extracting the required data and identifying and correcting errors, inconsistencies, and inaccuracies in the data; 2) data normalization for organizing and standardizing the data to ensure consistency and comparability across different sources; and 3) data transformation for converting the data into a format that meets the requirements of the target application.

Bibliography

[b-ITU-T J.380.8] Recommendation ITU-T J.380.8 (2011), *Digital program insertion – Advertising systems interfaces – General information service*.

[b-ITU-T X.667] Recommendation ITU-T X.667 (2012), *Information technology – Procedures for the operation of object identifier registration authorities: Generation of universally unique identifiers and their use in object identifiers*.

[b-ITU-T Y.4466] Recommendation ITU-T Y.4466 (2020), *Framework of smart greenhouse service*.

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