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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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Framework of smart greenhouse service

Recommendation ITU-T Y.4466

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Recommendation ITU-T Y.4466

Framework of smart greenhouse service

Summary

A smart greenhouse service enables precision farming with the help of Internet of things (IoT) devices (such as sensors and actuators) installed in a smart greenhouse. A smart greenhouse service collects information about both the environment and crop-growth status and then analyses the information to produce an optimal growth model for each crop. With the optimal growth model, a smart greenhouse service can maximize agricultural productivity and improve crop quality. In addition, it can enhance user convenience.

To describe a smart greenhouse service framework, Recommendation ITU-T Y.4466 specifies requirements, a reference model, a functional architecture and interfaces for a smart greenhouse service.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.4466	2020-01-13	20	11.1002/1000/14169

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IoT devices, smart greenhouse, smart greenhouse service.

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FOREWORD

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The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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1 Scope

This Recommendation describes a framework of a smart greenhouse service for precision farming.

The scope covered by this Recommendation includes:

– overview;

– requirements of each service entity;

– reference model and functional architecture;

– interfaces between service functions.

Use cases of a smart greenhouse service and examples of optimal growth models are also provided in Appendix I and Appendix II respectively.

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.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of things*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 device [ITU-T Y.4000]: With regard to the Internet of things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage and data processing.

3.1.2 Internet of things (IoT) [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.1.3 application [b-ITU-T Y.2091]: A structured set of capabilities, which provide value-added functionality supported by one or more services, which may be supported by an API interface.

3.1.4 sensor [b-ITU-T Y.4105]: An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic.

3.1.5 actuator [b-ITU-T Y.4109]: A device performing physical actions caused by an input signal

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 greenhouse: A facility that can control a crop-growth environment (i.e., light, temperature, humidity, etc.).

3.2.2 optimal growth model: A recipe to set an environment to maximise crop productivity as well as quality according to the life cycle.

3.2.3 smart farm: A group of smart greenhouses under management of an administrator.

3.2.4 smart greenhouse: A facility that can control the environment of a greenhouse with minimum human intervention using Internet of things (IoT) technologies.

3.2.5 smart greenhouse service: A service that enables precision farming based on a smart greenhouse.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

IoT Internet of Things

SF Smart Farm

SG Smart Greenhouse

SGA Smart Greenhouse Actuating

SGC Smart Greenhouse Control

SGI Smart Greenhouse Integration

SGM Smart Greenhouse Management

SGO Smart Greenhouse Operation

SGS Smart Greenhouse Sensing

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.

– The keywords "can optionally" indicate an optional requirement that is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

– The keyword "function" is defined as a collection of functionalities. It is represented by the following symbol in this Recommendation:

Function

– The keyword "functional entity" (FE) is defined as a group of functionalities that has not been further subdivided at the level of detail described in this Recommendation. It is represented by the following symbol in this Recommendation:

Functional Entity (FE)

NOTE – In the future, other groups or other Recommendations may possibly further subdivide these FEs.

Frame borders of "function" and "FE", and relational lines among "function" and "FE" are drawn with solid lines or dashed lines. The solid lines mean required functionalities or relations. On the other hand, the dashed lines mean optional functionalities or relations.

6 Overview

In order to improve crop production and quality and to control the production period, it is necessary to have an isolated space which can control environment conditions (i.e., humidity, temperature, and light intensity). To provide this isolated space, the greenhouse came into existence; a greenhouse is a structure with walls and roof made chiefly of transparent materials in which a crop cultivation environment can be controlled.

NOTE – A greenhouse can be used to overcome the problems accompanied by the growing season and land space.

However, traditional greenhouses exhibit the following shortcomings:

– Users are necessary to control the crop-growth environment manually for better harvesting.

– Users have to monitor the crop-growth environment continuously and then adjust the environment to meet specific conditions.

– User's lack of experience may necessitate undergoing a lot of trial and error in cultivating crops.

To overcome these shortcomings, various Internet of things (IoT) technologies are applied. Based on a number of collected sensing data, the crop-growth environment can be intelligently adjusted to meet optimal conditions for cultivating crops. To differentiate a greenhouse with IoT technologies from a typical greenhouse, a new term, smart greenhouse, has been introduced. A smart greenhouse is a greenhouse using IoT technologies for stable and efficient crop production. A smart greenhouse monitors both the environment status and the crop-growth status and controls the crop-growth environment intelligently and automatically with the help of IoT technologies. A smart greenhouse enables users to cultivate crops anytime and anywhere, it minimizes user's interventions, labour costs, energy consumption and fertilizers consumed.

Figure 1 shows a conceptual diagram of a smart greenhouse. A smart greenhouse has the following features:

– A crop-growth condition is configured according to a specific optimal growth model.

– A controller monitors both environment and crop-growth status using various sensors.

– A controller controls the crop-growth environment using various actuators.

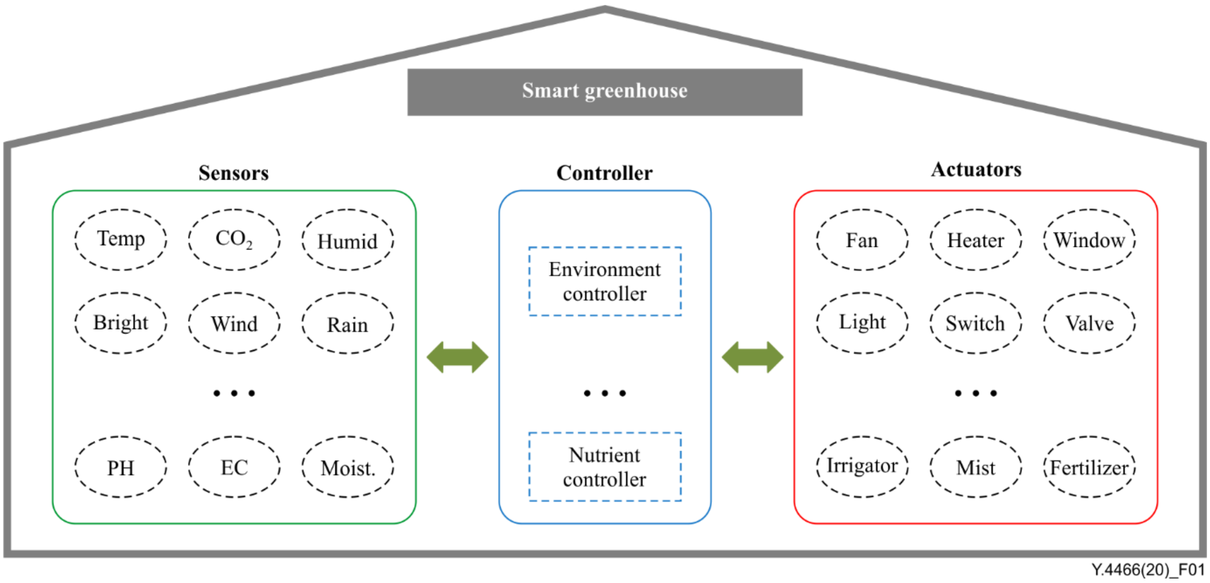

Figure 1 – Conceptual diagram of smart greenhouse

Figure 2 shows a conceptual diagram of a smart greenhouse service, in which three stakeholders are involved in the service; a smart greenhouse can perform precision farming, a smart greenhouse service user can be provided with a management strategy, and a service provider can create various services.

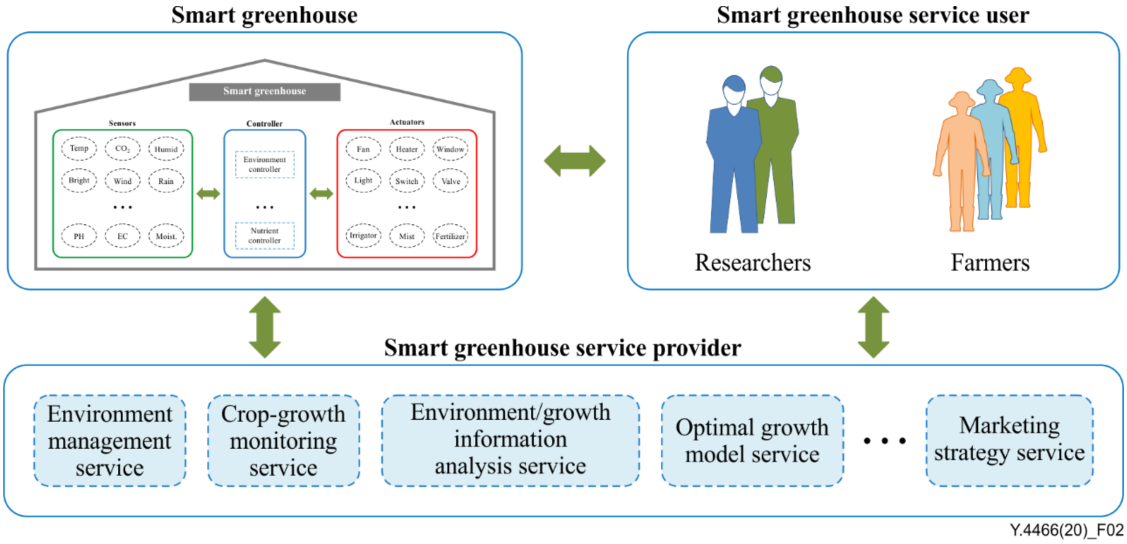

Figure 2 – Conceptual diagram of smart greenhouse service

A smart greenhouse service has the following features:

– analysis of the relationship between environment and crop-growth information measured by sensors;
– generation and provision of an optimal growth model for each crop;
– sharing of optimal growth models;
– improvement of productivity and quality through optimal growth models;
– reduction of trial and error by sharing users' experiences;
– generation of a management strategy to reduce resource consumption;
– generation of a marketing strategy based on the production information.

The ultimate goal of a smart greenhouse service is not only to maximize crop productivity and quality but also to enhance user convenience.

7 Requirements of smart greenhouse services

7.1 Requirements of smart greenhouse

A smart greenhouse (SG) includes one or more sensors and actuators to configure optimal growth conditions to maximize crop productivity and quality. The following are the requirements of SG:

– SG is required to be equipped with one or more sensors and actuators;

– SG is required to have a capability of monitoring environment conditions of both inside and outside of SG;

– SG is required to have a capability of monitoring crop-growth conditions;

– SG is required to notify information including both environment and crop-growth status to SG service users in a real-time or a non-real-time manner;

– SG is required to report information including both environment and crop-growth status to an SG service provider in a real-time or a non-real-time manner;

– SG is recommended to have a capability of specifying crop-growth and environment conditions to be monitored or controlled;

– SG is required to have a capability of adjusting a specific environment condition;

– SG is required to have a capability of handling multiple sensors and actuators simultaneously to adjust environment conditions;

– SG is required to operate a specific actuator according to SG service user's instructions;

– SG is recommended to operate a specific actuator according to SG service provider's instructions;

– SG is required to report the execution result of a control command to the SG service user or the SG service provider who issued the control command;

– SG is recommended to provide the information of crop cultivation to the SG service provider;

– SG is recommended to have a capability of providing information regarding crop cultivation activities to the SG service user, in case SG is operated automatically or by the SG service provider's instructions;

– SG is required to have a capability of logging crop cultivation activities;

– SG is required to have a capability of maintaining historical data on environment status;

– SG is recommended to have a capability of maintaining historical data on a specific crop-growth status;

– In order to ensure SG to be tolerant, SG is recommended to inform the SG service user and/or the SG service provider of the device status installed in the SG.

7.2 Requirements of SG service provider

A SG service provider is an entity providing a SG service to its service users. The following are the requirements of the SG service provider:

– SG service provider is required to collect the information of both environment and crop-growth status for a specific SG in a real-time or a non-real-time manner, in order to produce optimal growth models to maximize crop productivity and quality;

– SG service provider is recommended to collect the SG's crop cultivation information in a real-time or a non-real-time manner, in order to produce optimal growth models to maximize crop productivity and quality;

– SG service provider is recommended to collect the information of resources consumed by the SG service user, in order to produce a management strategy to maximize the SG service user's profitability;

NOTE 1 – Examples of information about resources consumed include electricity consumption, water consumption, and fertilizer usage.

– SG service provider is recommended to collect the information of the SG service user's production, in order to produce a management strategy with which to maximize the SG service user's profitability;

– SG service provider is required to have a capability of producing a series of optimal growth models based on the information gathered from SGs as well as SG service users;

– SG service provider is required to provide optimal growth models to the SG service user in a push or an on-demand manner;

– SG service provider can optionally provide market information to the SG service user, in order to maximize the SG service user's profitability;

NOTE 2 – Market information is the information for forecasting crop prices that can be used by SG service users.

– SG service provider is recommended to have a capability of interoperating with an external data center, in order to store, analyse and utilize the data.

7.3 Requirements of SG service user

A SG service user is an entity consuming the SG service provided by a SG service provider. The followings are the requirements of the SG service user:

– SG service user is recommended to provide the information of resource consumption to the SG service provider, in order to maximize crop productivity and quality, and to minimize the resource consumption;

– SG service user is recommended to provide the production information to the SG service provider, in order to maximize the SG service user's profitability by controlling the amount of agricultural goods and the harvest timing;

NOTE – An example of production information includes the sales amount of the agricultural goods.

– SG service user is required to approve and apply one of the optimal growth models provided by the SG service provider, in order to make automatic operation possible;

– SG service user is required to have a capability of operating the SG manually, in case the communication with the SG service provider is not possible.

8 SG service reference model

Figure 3 shows a SG service reference model in accordance with the IoT reference model [ITU-T Y.4000]. The IoT reference model consists of application layer, service support and application support layer, network layer and device layer, and capabilities of management and security. Among those layers and capabilities of the IoT reference model, the SG service reference model defines six more functions specific to a SG service. In this regard, the following functions are defined as components of the SG service reference model:

– SG sensing function;

– SG actuating function;

– SG control function;

– SG operation function;
– SG integration function;
– SG management function.

Each function of the SG service reference model shown in Figure 3 is defined to meet the concept and requirements of the SG service described in clauses 6 and 7 respectively.

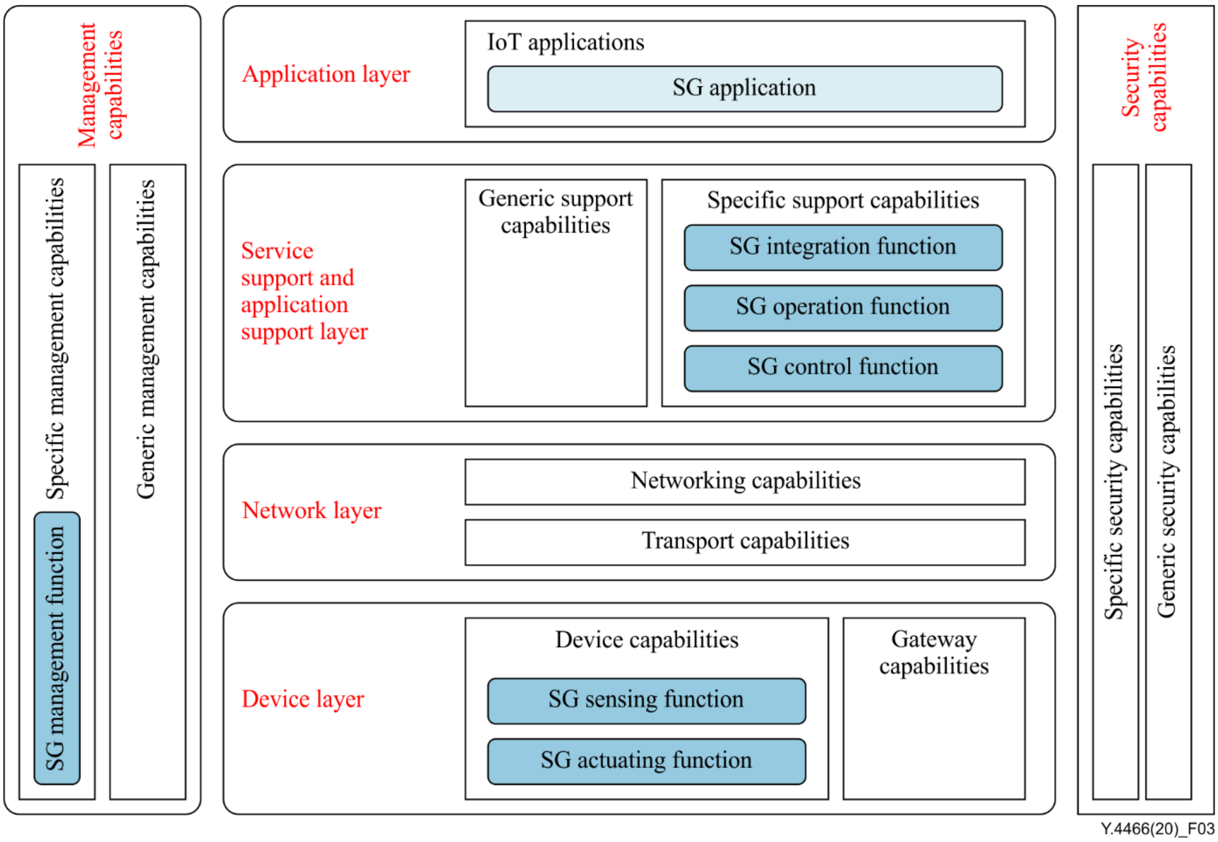

Figure 3 – SG service reference model in accordance with the IoT reference model [ITU-T Y.4000]

The following describes the role of each function:

– **The SG sensing function** collects information of environment and crop-growth status of a SG from sensors installed in a SG and delivers it to the SG control function. The SG sensing function also delivers information about each sensor (such as type, location, description and unit of sensing value, etc.) to the SG management function;

NOTE 1 – A SG can have multiple SG sensing functions for various sensors.

– **The SG actuating function** operates actuators installed in a SG according to the control commands received from the SG control function. The SG actuating function delivers information about each actuator (such as type, location description and operation status, etc.) to the SG management function;

NOTE 2 – A SG can have multiple SG actuating functions for various actuators.

– **The SG control function** generates actuation control commands to operate actuators according to the final growth model information received from the SG operation function, and/or according to the operation status information of an actuator. The control commands reflect the capability of each actuator installed in a SG and a user's request for each actuator. The SG control function delivers the control commands to the SG actuating function. The SG control function also delivers the information of environment and crop-growth status, which received from the SG sensing function and the SG actuating function, to the SG operation function;

NOTE 3 – A SG can have one control function. However, if SG sensing functions or SG actuating functions are grouped according to a specific purpose, one SG can have multiple SG control functions.

NOTE 4 – An example of the SG control function's user includes a farmer or a SG administrator.

– **The SG operation function** generates final environment control conditions for a specific crop in a SG, which reflects the user's farming experience. The SG operation function also delivers the information of both environment and crop-growth status, which is received from the SG control function, to the SG integration function;

NOTE 5 – A smart farm (SF) has the SG operation function, and the SG operation function can manage multiple SGs. A farmer generally cultivates more than one type of crop in a SF, and crops may require various growth environment conditions. The crops in need of a similar environment conditions can be cultivated in a single SG, but the crops in need of different environment conditions cannot be cultivated in a single SG. Therefore, the environment condition of a SG determines a specific kind of crop that can be cultivated. Therefore, it is necessary to store the information about environment and crop-growth conditions of various crops cultivated. In addition, it is important for the SG operation function to modify the final optimal growth model to meet user's requests.

– **The SG integration function** accumulates the information of both environment and crop-growth status from the SG operation function; the scope of the information to be accumulated is not per SG but per SF. After accumulating the information of a SF, it produces an optimal growth model with the help of an experts group or an expert system, and then stores it. The produced optimal growth model is also delivered back to the SG operation function to reflect any user's additional requests;

NOTE 6 – This Recommendation uses the term 'experts group' to represent a group of experts who have extensive skill or knowledge in an agricultural field. This Recommendation also uses the term ‘expert system' to represent a computer program that can offer intelligent advice or make intelligent decisions in an agricultural field.

NOTE 7 – The SG integration function can generate an optimal growth model for each SF. Usually crops are being cultivated in many SFs in various environments, it is necessary to know the environment effects on crop-growth. This could be done by analysing the information of both environment and crop-growth status for a specific crop cultivated in various SFs. Therefore, it is necessary to collect information of both environment and crop-growth status for various crops cultivated in many SFs.

– **The SG management function** manages the information of both environment and crop-growth status in SGs of a SF; a SF consists of one or more SGs. A SG collects the information of sensors and actuators installed in SGs from the SG sensing function and the SG actuating function, respectively. The SG management function also interacts with the SG control function, the SG operation function, and the SG integration function to deliver the information respectively.

NOTE 8 – The SG management function maintains the information of multiple SGs.

In the SG service, there are two types of flows. One is the flow of transferring information of both environment and crop-growth status of each SG. The other is the flow of transferring control commands to each SG. Figure 4 shows a high-level flow of information and control commands between functions in terms of the SG service reference model.

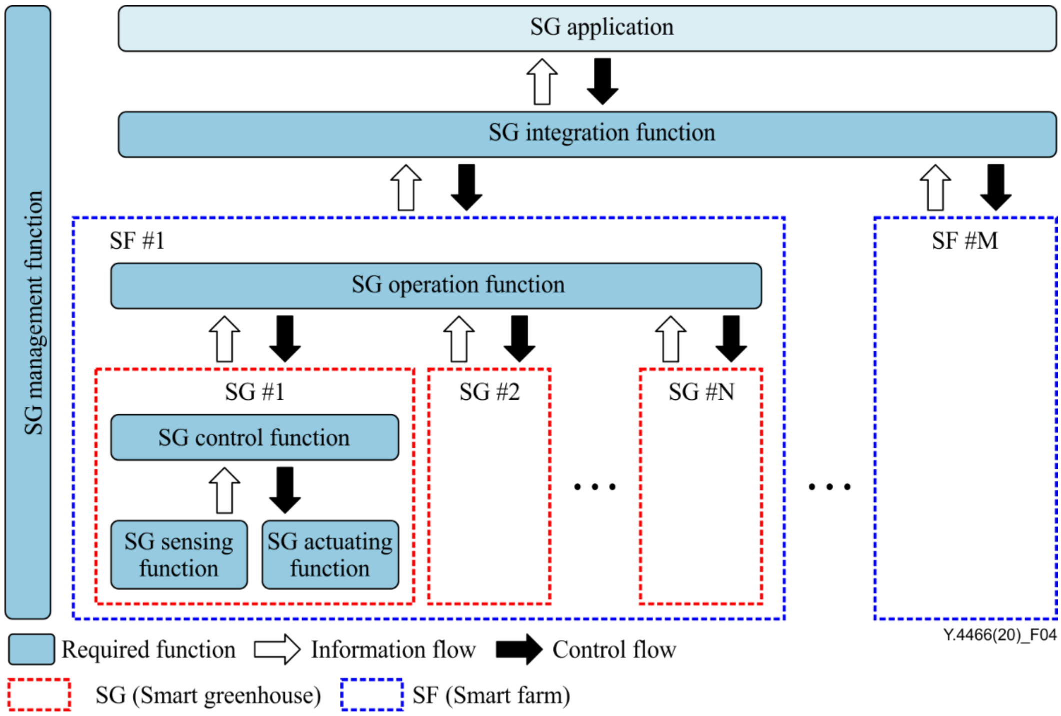

Figure 4 – A high-level information and control flow of SG service

The following are examples of SG services:

– **Production and consumption of SG environment and crop-growth information**: The information of both environment and crop-growth status of a SG, which is generated by the SG sensing function, is collected by the SG control function. This collected SG information is delivered to the SG operation function. The information is then transferred to the SG integration function. Finally, the SG integration function provides the information to the users such as an experts group or an expert system;

– **Creation of crop-growth conditions and execution of control commands**: The information, which is provided by the previous information flow, can be used by an experts group and an expert system to derive optimal growth conditions for each crop. The SG integration function retrieves optimal crop-growth conditions from an experts group and/or an expert system, and maintains them; and then it provides the optimal crop-growth conditions to the SG operation function. The SG operation function enables user's additional modification on the optimal growth conditions which are provided by the SG integration function; and then it delivers the modified optimal growth conditions to the SG control function. Finally, the SG control function issues a series of control commands to the appropriate SG actuating function to make the actuator execute proper operations.

9 SG service functional architecture

Figure 6 shows the functional architecture of the SG service.

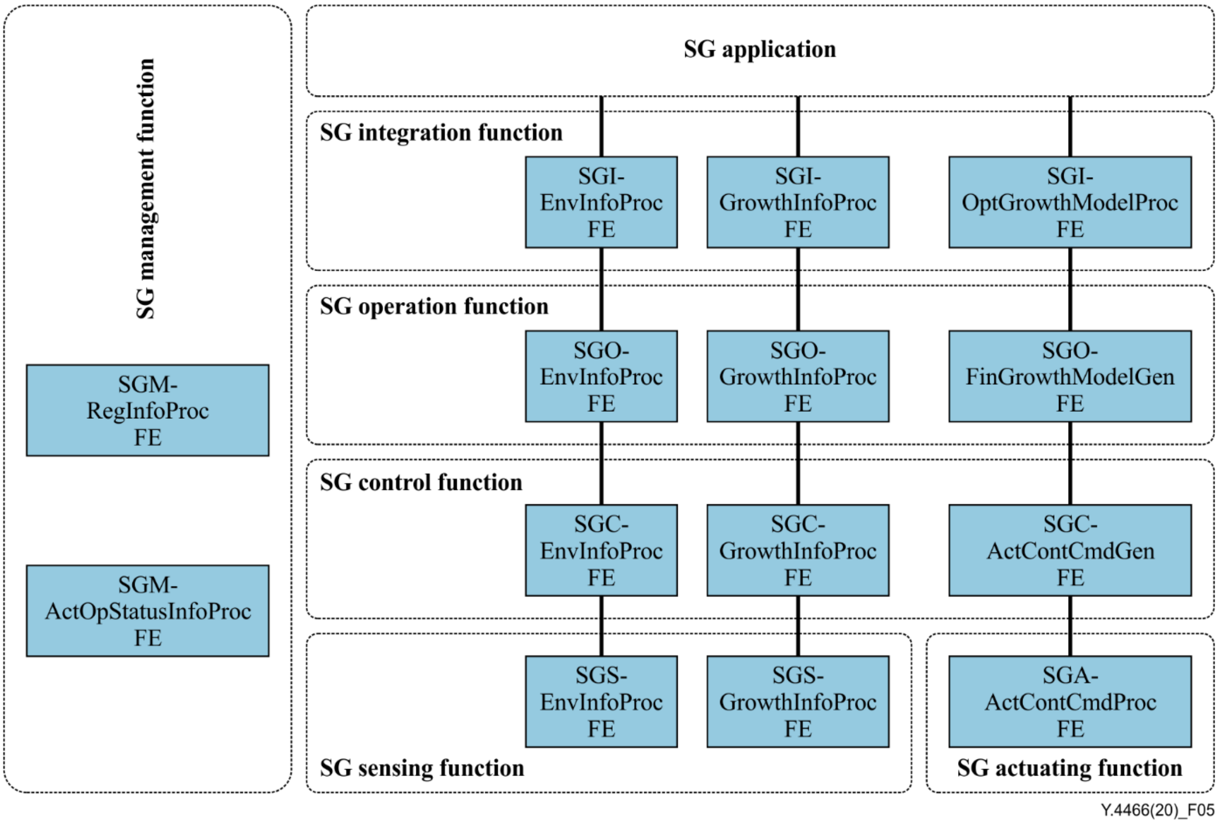

Figure 5 – Functional architecture of the SG service

9.1 SG sensing function

The SG sensing function, which consists of the SGS-EnvInfoProcFE and the SGS-GrowthInfoProcFE, collects environment information about SG and the crops growing information. And then this function provides the information to the SG control function. Details of each FE are:

– The SGS-EnvInfoProcFE (SG Sensing-Environment Information Processing FE) collects the environment information of a SG from various types of environment sensors (IoT devices), and then this FE provides the information to the SGC-EnvInfoProcFE;

NOTE 1 – The environment information has various forms of sensing values depending on the type of sensors, such as temperature, humidity or CO_2 concentration, etc.

– The SGS-GrowthInfoProcFE (SG Sensing-Growth Information Processing FE) collects the crop-growth information in a SG from various types of growth sensors (IoT devices) and then this FE provides the collected information to the SGC-GrowthInfoProcFE.

NOTE 2 – The crop-growth information has various forms of sensing values depending on the type of sensors, such as growth length, stem diameter, leaf length, etc.

9.2 SG actuating function

The SG actuating function, which consists of the SGA-ActContCmdProcFE, receives the control commands from the SG control function and then delivers them to the appropriate actuators. Details of the FE are:

– The SGA-ActContCmdProcFE (SG Actuating-Actuator Control Command Processing FE) receives a series of control commands as well as specific attributes of an actuator from the SGC-ActContCmdGenFE, and pass them to the corresponding actuator (the related IoT device).

NOTE 1 – The control commands of each actuator may differ by the type of actuators. Examples of control commands of an actuator include 'open/close', 'on/off' and 'operate/stop', etc.

NOTE 2 – Examples of actuator's attributes are 'operation time', 'operation duration', 'open position' and 'operation speed', etc.

9.3 SG control function

The SG control function collects the information of both environment and crop-growth status of a SG, and provides them to the SG operation function. In addition, the SG control function receives the environment conditions for the crops cultivated in the SG from the SG operation function, and issues a series of control commands to the actuator. Details of each FE in the SG control function are:

– The SGC-EnvInfoProcFE (SG Control-Environment Information Processing FE) collects the environment information of a SG through the SGS-EnvInforProcFE in the SG sensing function, and then this FE provides the information to the SGC-ActContCmdGenFE to adjust the actuator's operation;

NOTE 1 – The environment information can be provided in terms of 'at a specific time', 'periodically', 'on-demand' or 'when an event occurs' etc.

– The SGC-GrowthInfoProcFE (SG Control-Growth Information Processing FE) collects the crop-growth information in a SG through the SGS-GrowthInfoProcFE, and then it provides this information to the SGO-GrowthInfoProcFE and the SGC-ActContCmdGenFE.

NOTE 2 – The crop-growth information can be provided in terms of 'at a specific time', 'periodically', ' on-demand' or 'when an event occurs', etc.

– The SGC-ActContCmdGenFE (SG Control-Actuator Control Command Generation FE) collects the final growth model from the SGO-FinGrowthModelGenFE. This FE collects the information of both environment and crop-growth status from the SGC-EnvInforProcFE and the SGC-GrowthInfoProcFE respectively, and this FE collects the information regarding operation status of each actuator from the SGC-ActOpStatusInfoProcFE in the SG management function. According to the SG's environment conditions, the SGC-ActContCmdGenFE generates the appropriate control commands for the SGA-ActContCmdProcFE.

NOTE 3 – The control commands are generated according to the various items of information on profile, status, and capability of the actuator. All of these information items can be obtained from the SGM-ActOpStatusInfoProcFE in the SG management function.

NOTE 4 – The group of actuators are selected by the control commands in regard to the target period and target value to meet the optimal growth model.

NOTE 5 – If the current control command cannot create the environment conditions to meet the optimal growth model, the group of actuators must be reselected.

NOTE 6 – The control commands according to the final optimal growth model can be derived by the SG control function or the SG operation function.

9.4 SG operation function

The SG operation function, which consists of the SGO-EnvInfoProcFE, the SGO-GrowthInfoProcFE and the SGO-FinGrowthModelGenFE, collects the information of both environment and crop-growth status from the SG control function, and then provides the information to the SG integration function to produce the optimal growth models. Details of each FE in the SG operation function are:

– The SGO-EnvInfoProcFE (SG Operation-Environment Information Processing FE) collects the environment information of the SGs through the SGC-EnvInfoProcFE in the SG control function, and then provides the environment information to the SGI- EnvInfoProcFE in the SG integration function;

NOTE 1 – An example of the environment information collected by the SGO-EnvInfoProcFE includes the weather condition of each SG.

– The SGO-GrowthInfoProcFE (SG Operation-Growth Information Processing FE) collects the crop-growth information of each SG through the SGC-GrowthInfoProcFE, and then delivers the crop-growth information to the SGI-GrowthInfoProcFE in the SG integration function and the SGO-FinGrowthModelGenFE in the SG operation function;

NOTE 2 – An example of the information collected by the SGO-GrowthInfoProcFE includes crops-growth information in each SG.

NOTE 3 – The SGO-FinGrowthModelGenFE uses the crop-growth information to produce the final optimal crop-growth model for a specific crop.

– The SGO-FinGrowthModelGenFE (SG Operation-Final Growth Model Generation FE) collects the general optimal growth models from the SGI-OptGrowthModelProcFE in the SG integration function, and then produces the final optimal growth model for the SGS-ActContCmdGenFE in the SG control function. In addition, this FE allows SG service user's interventions while producing the final optimal growth model, in which SG service user's additional modifications on the produced final optimal growth model is allowed to produce the SG service user's customized final optimal growth model.

9.5 SG integration function

The SG integration function, which consists of the SGI-EnvInfoProcFE, the SGI-GrowthInfoProcFE and the SGI-OptGrowthModelProcFE, accumulates the information of both environment and crop-growth status, and then provides the information to an experts group and an expert system. Details of each FE are:

– The SGI-EnvInfoProcFE (SG Integration-Environment Information Processing FE) collects the environment information of the SGs in a SF from the SGO-EnvinfoProcFE, and provides the information to the SG application on demand;

NOTE 1 – Examples of the SG application include an experts group and an expert system.

– The SGI-GrowthInfoProcFE (SG Integration-Growth Information Processing FE) collects the crop-growth information for a SF from the SGO-GrowthInfoProcFE, and provides the information to the SG application on demand;

– The SGI-OptGrowthModelProcFE (SG Integration-Optimal Growth Model Processing FE) collects general optimal growth models for a SF from the SG application, and then provides the optimal growth models to the SGO-FinGrowthModelGenFE on demand.

NOTE 2 – The general optimal growth model describes well-known optimal crop-growth conditions in terms of crop life cycle.

9.6 SG management function

The SG management function, which consists of the SGM-RegInfoProcFE and the SGM-ActOpStatusInfoProcFE, manages and maintains the information of both environment and crop-growth status of SGs in a SF. Details of each FE are:

– The SGM-RegInfoProcFE (SG Management-Registration Information Processing FE) describes the information of IoT devices (e.g., sensors, actuators, etc.). This FE collects and manages the information from the SG sensing function and the SG actuating function;

NOTE 1 – The examples of information related to a sensor include type, description, location, sensing target and unit of sensing value.

NOTE 2 – The examples of information related to an actuator include type, description, location, actuating target, and operation speed.

– The SGM-ActOpStatusInfoProcFE (SG Management-Actuator Operation Status Information Processing FE) collects the information of actuators' operation status from the SGA-ActContCmdProcFE. This FE also provides the collected information to the SGO-FinGrowthModelGenFE to update the crop-growth conditions of the final growth model, and then it provides this collected information to the SGC-ActContCmdGenFE to generate a control command for a corresponding actuator.

10 Interfaces for smart greenhouse service

This clause describes the reference points between related functions, as illustrated in Figure 6. Arrows in Figure 6 indicate logical data flows between functions.

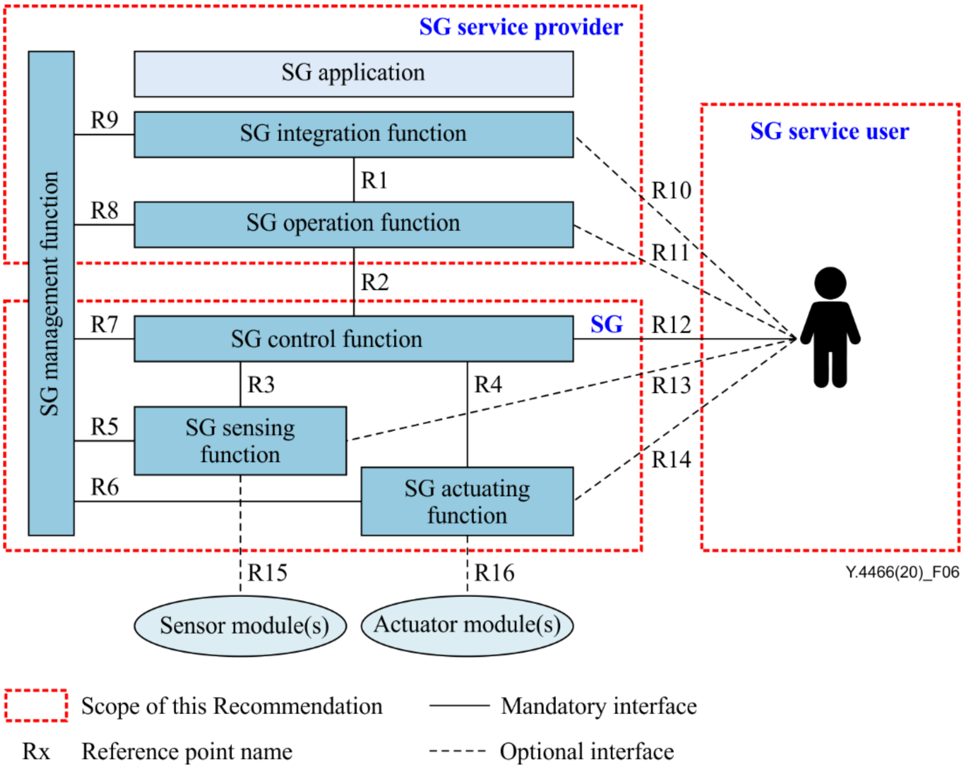

Figure 6 – Reference points among related functions

This Recommendation defines the following interfaces:

– The interface R1 is used between the SG integration function and the SG operation function to deliver the information of environment and crop-growth status as well as to deliver the general optimal growth model of SGs;

– The interface R2 is used between the SG operation function and the SG control function to deliver the information of environment and crop-growth status as well as to deliver the final optimal growth model of SGs;

– The interface R3 is used between the SG control function and the SG sensing function to deliver the information of environment and crop-growth status of SGs;

– The interface R4 is used between the SG control function and the SG actuating function to deliver the control commands to execute the actuator module and/or to deliver the actuator module's status information;

– The interface R5 is used between the SG management function and the SG sensing function to register IoT sensor modules with the information including type, manufacturer's description, location and characteristics;

– The interface R6 is used between the SG management function and the SG actuating function to register IoT actuator modules with the information including type, manufacturer's description, location, characteristics;

– The interface R7 is used between the SG management function and the SG control function to deliver the information regarding IoT sensor modules and IoT actuator modules installed in a SG;

– The interface R8 is used between the SG management function and the SG operation function to deliver the information regarding IoT sensor modules and IoT actuator modules installed in a SF;

– The interface R9 is used between the SG management function and the SG integration function to deliver the information regarding IoT sensor modules and IoT actuator modules installed in one or more SFs;

– The interface R10 is used between the SG service user and the SG integration function to deliver the information regarding the SGs' environment and crop-growth status;

– The interface R11 is used between the SG service user and the SG operation function to deliver the information regarding the SGs' environment and crop-growth status;

– The interface R12 is used between the SG service user and the SG control function to deliver the information regarding the SGs' environment and crop-growth status;

– The interface R13 is used between the SG service user and the SG sensing function to deliver the sensing data;

– Interface R14 is used between the SG service user and the SG actuating function to deliver the status information of actuator;

– The interface R15 is used between the SG sensing function and the sensor module(s) to read sensing values;

– The interface R16 is used between the SG actuating function and the actuator module(s) to execute the actuator modules.

NOTE – The interfaces R10, R11, R12, R13, R14, R15 and R16 are out of scope of this Recommendation.

11 Security considerations

This framework does not specify any specific requirements on security matters. Any well-defined existing security capabilities can be applied for this framework.

Appendix I

Use cases of smart greenhouse

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

The smart greenhouse use case shown in Figure I.1 gives an example of how a smart greenhouse can aggregate environment conditions and how to control a smart greenhouse.

The SG management function manages the information of both environment and crop-growth status in SGs of a SF; a SF consists of one or more SGs. SG collects the information about sensors and actuators installed in SGs from the SG sensing function and the SG actuating function respectively. This function also interacts with the SG control function, the SG operation function, and the SG integration function to deliver the information.

The SG integration function maintains a database which consists of optimal per-crop-growth conditions; the optimal growth conditions can be retrieved from the SG's cumulative environment information by an agricultural growth model, but the description on the agricultural growth model is out of the scope of this Recommendation. This function then provides the optimal growth conditions to the SG operation function.

The SG operation function can be handled by each user who has multiple separated smart SGs. Once this function receives optimal growth conditions, it generates an optimal growth model per SG, and then this function applies the model to the SG control function. During the crop cultivation, this function receives the environment information from the SG control function in real-time and passes the information to the SG integration function.

The SG control function selects an actuator to operate according to the optimal growth model and environment condition. Also, it passes the environment condition to the SG operation function.

The SG sensing function senses the environment condition of a greenhouse (inside as well as outside) and then it passes the sensed environment condition to the SG control function.

The SG actuating function executes actuators to adjust a greenhouse environment.

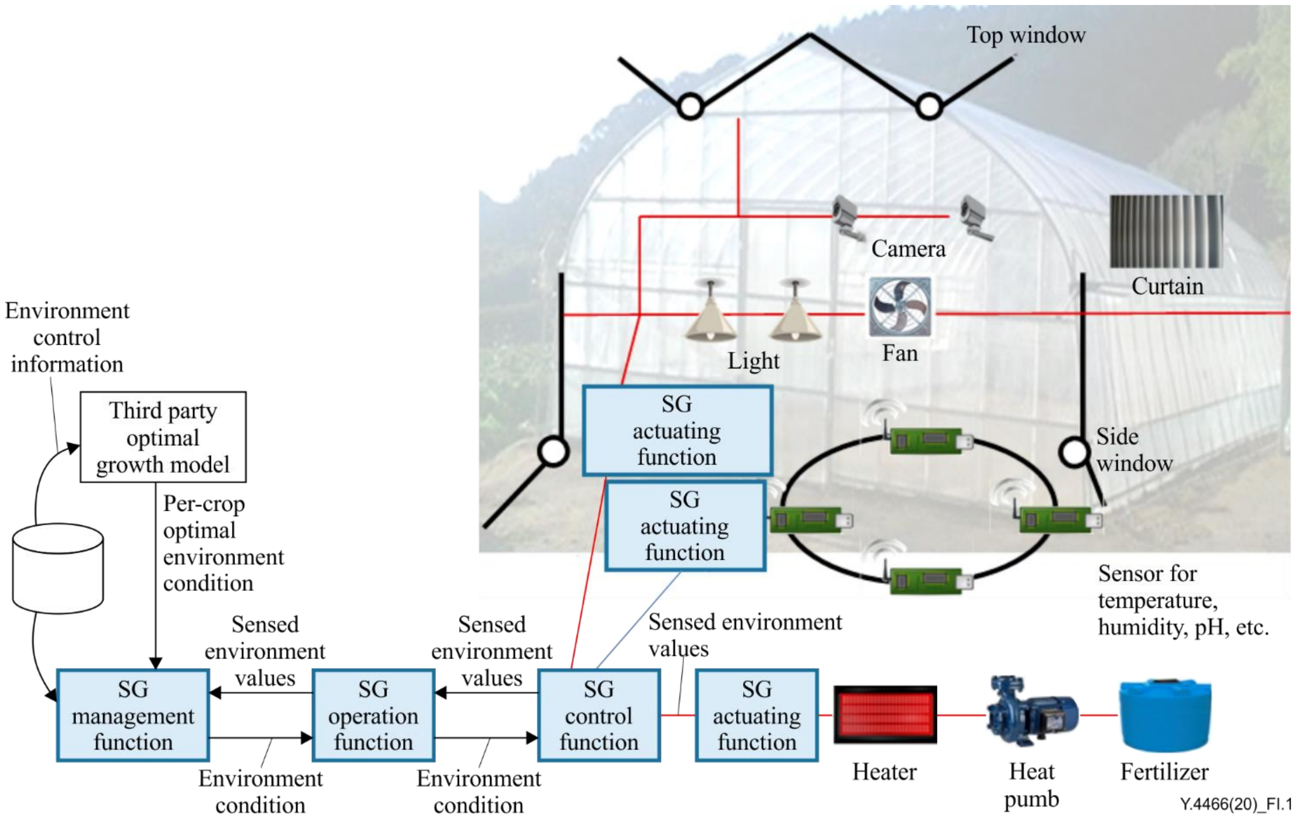

Figure I.1 – Smart greenhouse use case

Appendix II

Example of optimal growth models

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

The following are examples of optimal growth models for tomato, watermelon, paprika and strawberry.

NOTE – An optimal growth model can be derived from several environment conditions. Examples of environment conditions include temperature, CO_2 (carbon dioxide), nutrient solution (EC; Electrical conductivity), light intensity, potential of hydrogen (pH) and humidity.

II.1 Example 1: The optimal growth model for tomatoes

This is an example of the optimal growth model to describe how to adjust environment conditions during the life cycle of cultivating tomatoes.

Table II.1 – Optimal growth model for tomatoes

Growth stage	Temperature (day/night)	CO_2	Nutrient solution (EC)	Potential of hydrogen	Humidity (day/night)
Germination	25/25 °C	700 ppm	0.0-0.1 ds/m	pH 6.0-6.5	85/75%
Raising seeding	24/18 °C		2.0-3.01 ds/m		
Early growth	25/15 °C		2.5-4.01 ds/m		
Initial harvest	25/13 °C		2.0-3.51 ds/m		
Harvest	25/15 °C		1.8-2.5 ds/m		

II.2 Example 2: The optimal growth model for watermelon

This is an example of the optimal growth model to describe how to adjust environment conditions during the life cycle of cultivating watermelons.

Table II.2 – Optimal growth model for watermelon

Growth stage	Temperature (day/night)	Light intensity	Potential of hydrogen	Humidity (day/night)
Germination	25/30 °C	43,200~54,000 Lux	pH 5.0-6.8	90%
Raising seeding	25~28 °C /18~20 °C			
Grating	28/30 °C			
Planting	23~28 °C /13~18 °C			

II.3 Example 3: the optimal growth model for paprika

This is an example of the optimal growth model to describe how to adjust environment conditions during the life cycle of cultivating paprika.

Table II.3 – Optimal growth model for paprika

Growth stage	Temperature (day/night)	CO_2	Nutrient solution (EC)	Potential of hydrogen	Humidity (day/night)
Rooting	21 ℃	500~700 ppm		pH 5.5-5.7	70/80%
Vegetative growth	22/20 ℃	700 ppm	3.5 dS/m,		
Fruiting	16/18 ℃	700 ppm	3.0~2.5 dS/m		

II.4 Example 4: the optimal growth model for strawberry

This is an example of the optimal growth model to describe how to adjust environment conditions during the life cycle of cultivating strawberries.

Table II.4 – Optimal growth model for strawberry

Growth stage	Temperature (day/night)	CO_2	Light intensity	Potential of hydrogen	Humidity (day/night)
Vegetative growth	17/23 ℃	800~900 ppm	43,200~54,000 Lux	pH 6.0-6.5	70/80%
Floral differentiation	10/15 ℃				
Harvest	25/30 ℃				

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