Chapter 4
Design and Control of Smart Plant Factory

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Abstract Control system theory is applied to the design and modeling of smart plant factories. From control theory, the advantage of a closed plant factory is explained by the less disturbance in estimating the internal state of the controlled target. Several control models are explained from various viewpoints such as plant environment model, model-based control, hierarchical control, etc. Finally, three fundamental elements for designing a smart plant factory are shown.

Keywords Control system theory control model · Disturbance · Model-based control · Hierarchical control · Design elements

4.1 Introduction

4.1.1 General Control System Model

In this chapter, control system theory is applied to the design of the smart plant factory. In control system theory, controlled objects are generally represented as models with their own internal states and functions that convert their inputs to their outputs. Our aim is to obtain the desired outputs from controlled objects (the target plants) by controlling their inputs in accordance with their own specific algorithms (cultivation process of plant factories) which is called a controller. However, to do that, we must know internal states of the controlled objects, and they are not usually known directly. So, the output values are used to estimate the internal states. Controller is usually modeled by including this estimation.

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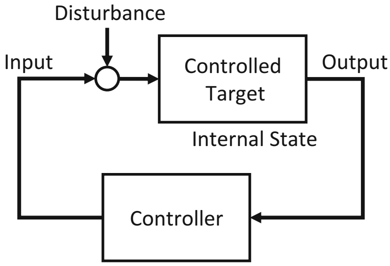

Fig. 4.1 Control system model with disturbance

4.1.2 Disturbance

If the state variables and the outputs of the controlled object vary regardless of their input, which is often seen in the reality, estimation of internal values becomes difficult, and we must consider the influence of disturbance (Fig. 4.1).

A lot of researches has been done to design a controller which encounter unexpected influences of disturbance. Here, in usual plant cultivation in open environment, the result of cultivation of plants as an output of controlled target does not necessarily become an expected value with respect to the input given by human and hence control theory. There are a lot of factors to be treated as disturbance in such case. In other words, it becomes extremely difficult to design a controller for plant cultivation in open environment by the framework of control theory.

On the other hand, in closed plant factories, the input and output of plants are strictly controlled, so there are few factors which need to be considered as disturbances. Therefore, there become possibilities of designing control systems by the control theory. To eliminate influence of disturbances, we should grasp all input variables accurately and measure the plant as output values to estimate its state variables as much as possible and also refine the target model to get a better estimation.

4.2 Control Models

4.2.1 Controlled Target of Smart Plant Factory

Now, when designing a control system, it is necessary to define what is the controlled target. In the design of a plant factory, we should notice that the controlled target must be the cultivation environment of plants rather than the plant to be cultivated as shown in Fig. 4.2.

The reason is that even if estimating internal state variables of the plants as much as possible, it is difficult to control them directly. In actual, the plant factory directly controls the cultivation environment such as temperature, humidity, light power,

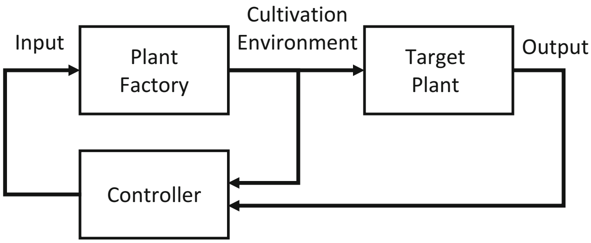

Fig. 4.2 Smart plant factory control model

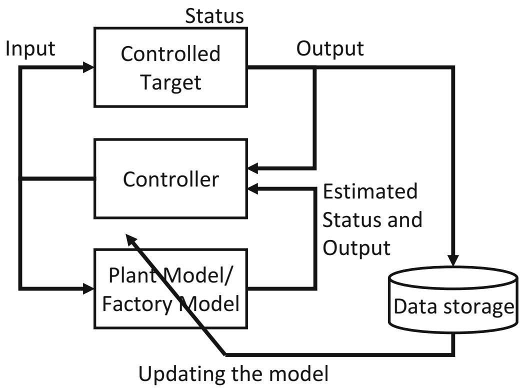

Fig. 4.3 Model-based control

cultivation solution concentration, and carbon dioxide concentration. What kind of cultivation environment gives plants how they grow is a plant growth model. The daily control of a plant factory is, for example, control of the LED, the air conditioner, the solution control device, etc. to maintain the target plant cultivation environment.

4.2.2 Model-Based Control

As mentioned above, it is not possible to directly know the state variables of the target plants. However, if we can obtain a virtual system that shows the same reaction as the target plant, i.e., if we can obtain a mathematical or computer model that can obtain the same output for a given input, we can know the internal state of the target equivalently and predict future outputs for scheduled inputs. As a result, we can use such mathematical model to adjust the input to obtain the desired output. This is the idea of model-based control which is shown in Fig. 4.3.

Obviously, an important point of model-based control is whether we can obtain a right model which shows the same behavior as the target plant. For that purpose, it is important to improve the model by feedbacking the difference between the assumed output and the actual output or by using more detailed knowledge about the target plants which is shown in Fig. 4.3 by the data storage and model update.

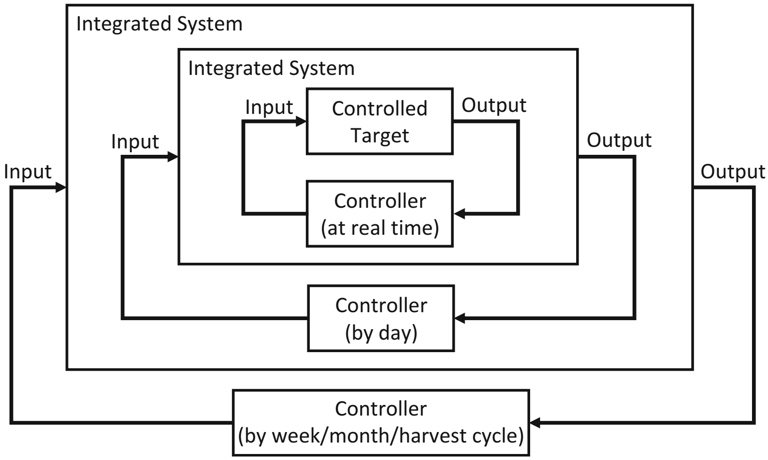

Fig. 4.4 Hierarchical control model

4.2.3 Hierarchical Control Model

If we consider the control method for the model of plants more practically, we must consider the control cycle of the controller. For example, daily temperature and humidity control by air conditioning system, adjustment of LED light, etc. need to be controlled in real time based on sensor data feedback and/or the given growth model. On the other hand, it is also important to change the habitat environment daily or weekly according to the growing condition of the plant. In addition, control models may be switched for each cultivation cycle, and different cultivation tasks and target values may be given to control.

Differences in these control cycles can be modeled with hierarchical control models which are shown in Fig. 4.4. In other words, it is a model in which systems controlled in a short cycle are handled as one integrated system, and the integrated system is newly controlled by a superordinate control system.

4.2.4 Updating Control Models as PDCA Cycle

Regarding the updating of the model described in Sect. 4.2.2, it can be considered as a PDCA (plan, do, check, act) cycle that is even higher than the hierarchical control model shown in Sect. 4.2.3. In other words, it is important to improve the entire design of the smart plant factory by repeating the execution of the four processes of PDCA.

Therefore, we design the control system as “plan” and “do” the actual cultivation, and evaluate the cultivation result by the “check” process. In other words, it is important to define the results expected to be obtained in the previous design stage. It is important to analyze the results of this evaluation and/or stored data with knowledge-based considerations or AI and to review the models, the controllers, and the control structure including the hierarchical structure and/or design of the whole plant factory as an “act” process. As a result, the PDCA cycle is executed.

4.3 Three Fundamental Design Elements of Smart Plant Factory

Next, I will change the topic from control model to design elements of a plant factory. As a control system, what are the fundamental elements for designing a plant factory is discussed.

A control system consists of models of target objects and actual control systems. Therefore, there are both models and actual equipment regarding the control as design targets of plant factories, which represents two aspects of that an abstract information model and concrete physical substances. In other words, it is necessary to design both in the real world and the virtual information world in general.

Furthermore, the space design of plant factory is another important factor. The space designs, such as cultivation racks, various piping placements, air and heat flow, space for light rays, space for human worker, and/or sizing and scaling to reach, are all important for examples. Therefore, it can be summarized as three design elements of a smart plant factory as shown in Fig. 4.5.

As shown in Fig. 4.5, the three elements mutually influence each other. Some examples of the content of each element and mutual influence are described in the figure.

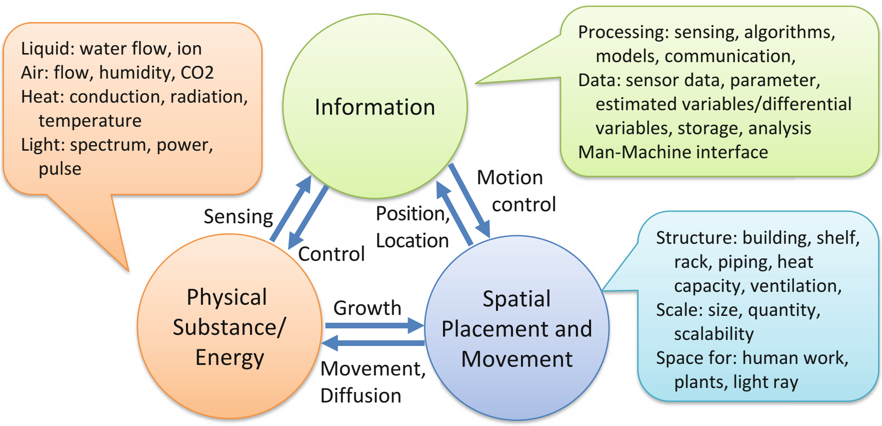

Fig. 4.5 Three design elements of smart plant factory