Plant Factory Solution with Instrumentation and Control Technology

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ABSTRACT

In recent years, plant factories have been attracting attention due to agricultural production instability resulting from the shrinkage in the farming population and abnormal weather. Against this backdrop, Fuji Electric has been offering plant factory solutions specializing in a complex environmental control system, which controls multiple environmental factors, such as temperature and humidity. We are currently advancing in the development of technologies for production process data forecasting systems that cooperate with the complex environmental control system. Among these technologies, we have developed a crop yield forecasting function for strawberry farmers, which is capable of forecasting crop yields up to one week in advance. This technology is expected to improve profitability by helping reduce sales loss and facilitating the effective use of human resources. In the future, we plan to pursue the development of technologies that can deal with differences in plant varieties and crops.

1. Introduction

In recent years, plant factories have been attracting attention due to agricultural production instability resulting from the shrinkage in the farming population and abnormal weather. Plant factories are facilities capable of year-round production by carrying out sophisticated control of temperature, humidity, CO_2 concentration, and other growing environmental conditions.

Fuji Electric has been offering plant factory solutions including equipment featuring a composite climate control system, which controls multiple environmental factors such as temperature and humidity. One major practical example is a type of plant factory that uses sunlight, and it is owned by Tomatoh Farm Co., Ltd. and was constructed in Tomakomai City, Hokkaido in 2014. We have delivered a composite climate control system, electric distribution facility, environmental measurement equipment, refrigeration equipment and the "D-BOX" cold storage container for logistics.

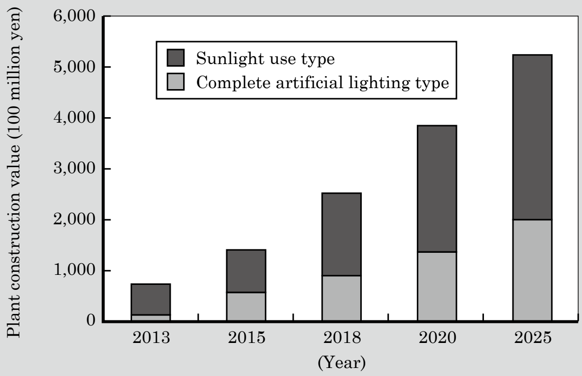
This paper describes trends in the plant factory market, outlines the Tomatoh Farm plant factory and presents plant factory solutions that make use of instrumentation and control technology.

2. Trends in Plant Factory Market

The amended "Agricultural Land Act," enforced in December 2009, has significantly relaxed the conditions for corporations' entry into agriculture. It has accelerated the entry of players from other categories of business and they are becoming increasingly diverse. In particular, new entries into the plant factory business, which allows year-round production, are increasing and the market is expected to grow significantly. Figure 1 shows an estimate of the plant construction value of plant factories in Japan. In 2025, the total value is estimated to reach 524.7 billion yen, about 3.5 times that in 2015.

Plant factories can be roughly classified into those that use sunlight and those that use complete artificial lighting. While sunlight use-type factories use sunlight in greenhouses to control the environment in the facilities, complete artificial lighting-type factories are facilities in a closed environment with artificial lighting such as fluorescent lamps and LEDs used as the light sources.

Operation of plant factories essentially requires controlling air conditioning and liquid feeding equip-



Source: Shusaku Hayakawa, Yuichi Owada, "Present Condition Surrounding Plant Factories in Japan and Future Prospects," Deloitte Tohmatsu Group, 2014

Fig.1 Estimate of plant construction value of plant factories in Japan

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ment to achieve appropriate environmental conditions, as well as measuring the environment in the facilities. To this end, the instrumentation and control technology of Fuji Electric can be effectively applied.

Fuji Electric's plant factory solutions are offered on an engineering, procurement and construction (EPC) basis, in which all of the design, procurement and construction processes of plant factories are undertaken, and the main component is a composite climate control system.

3. Outline of Tomatoh Farm

Tomatoh Farm is a plant factory located in the Tomakomai East Area in Tomakomai City, Hokkaido. It is operated by Tomatoh Farm Co., Ltd., a company co-funded by Fuji Electric, Shimizu Corporation, Ushio Inc., financial institutions, and other companies. It has been selected as a "Supportive Project for Accelerating the Introduction of Next-generation Greenhouse Horticulture" of the Ministry of Agriculture, Forestry and Fisheries and started strawberry cultivation in 2014. Figure 2 shows the appearance of Tomatoh Farm and rendering of the entire factory.

A greenhouse in Tomatoh Farm has an area of approximately 2 ha (width 8 m × depth 93 m × eaves height 4 m × 28 structures in a row), which is divided into 7 areas for production and environmental management for the individual areas. The cultivation method is elevated bed water culture (free flowing with granulated rock wool medium). A cropping type combining non-remontant strawberries that can be produced from winter to early summer (variety: Tochiotome and Benihoppe) and remontant strawberries (variety: Suzuakane) has been employed to build a system for year-round production of strawberries.

The seedling raising facilities have one complete artificial lighting-type seedling raising facility for raising cultured seedlings, pipe houses for raising parent vines by elevated bed water culture (250 m^2 × 2) and pipe houses for bench seedling raising (166 m^2 × 4). In the pipe houses for raising bench seedlings, small plants of non-remontant strawberries are cultivated in pots by inserting seedlings to use for production in cultivation greenhouses.

The energy supply facilities are comprised of a wood chip boiler and heat pump chiller. Cold water is supplied in summer and hot water in winter to be used for air conditioning and heating in the cultivation greenhouses.

We plan to add a cultivation greenhouse and energy supply facilities by the end of FY2016 to increase the greenhouse area to a total of 4 ha.

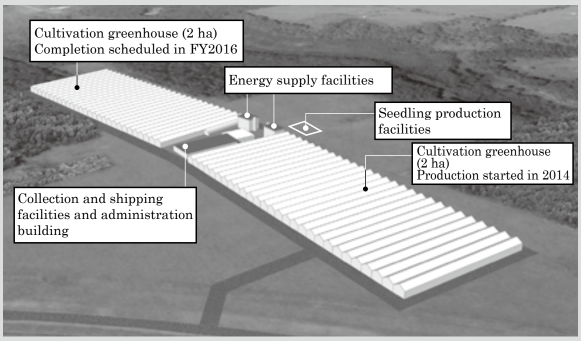
4. Environment Control at Tomatoh Farm

4.1 System overview and features

The environment in the cultivation greenhouses of Tomatoh Farm is controlled by using a composite climate control system. Figure 3 shows the configuration of the system.

The system is configured with a selection of Fuji Electric's products: various types of measuring instruments including the "FTNE" dual element temperature sensors and the "ZFP" CO_2 concentration analyzers, control equipment such as air-conditioning systems and liquid feeding equipment and "MICREX-SX" programmable controllers. The measurement items include the temperature and humidity, CO_2 concen-

(a) External appearance



(b) Rendering of entire factory

Fig.2 Appearance of Tomatoh Farm and rendering of entire factory

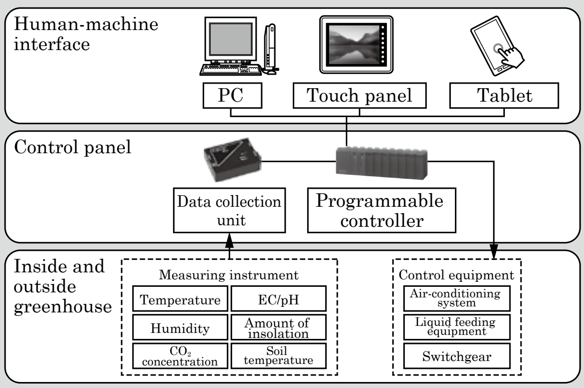


Fig.3 Configuration of composite climate control system at Tomatoh Farm

tration, amount of insolation, electrical conductivity (EC) and pH of the liquid supply and culture medium temperature in the greenhouse. The temperature and humidity, amount of insolation, wind velocity and wind direction outside the greenhouse and rainfall and snowfall are also detected. Based on the environmental data measured, the environment in the greenhouse is controlled to realize year-round production. The settings of the environmental control are configured by using a PC in the administration building. The control equipment can be operated from the "MONITOUCH" touch panel and tablet devices.

The cultivation greenhouse is divided into 7 areas and independent control can be provided for each area. Control functions include heating (snow melting), humidification, ventilation, thermal insulation, light supplementation, light shielding, CO_2 supply, air circulation and liquid feeding functions, and the functions can be activated individually or in a combined manner.

The functions meet the operating conditions for the peculiar weather conditions in Hokkaido, such as ventilation in an environment with a low external temperature and switching between air cooling and heating while the temperature greatly varies between night and day.

4.2 Issues

To improve profitability, the key issues are labor saving and improvement of the yield per unit area, in addition to energy saving by improving the current control system. Tomatoh Farm accumulates environmental data, growth survey data, yield data. We aim to build a comprehensive production system by conducting analysis for improving the yields for the individual varieties while linking between the respective types of data.

5. Production Process Data Prediction System

Table 1 shows products demanded by the market and technologies required for resolving the issues in plant factories. Fuji Electric is systematically working on the development of products and technologies to resolve the issues for the purpose of improving the profitability of plant factories. Of those, this paper presents the system to predict production process data and the yield prediction function, which is one of its applications.

5.1 Configuration

As a product for addressing the issues with plant factories, we are developing a system to predict production process data. It is intended to improve the profitability of plant factories by predicting the content, scale and timing of the farm work that will need to be done in the future.

Decisions on whether or not to carry out work or the amount of work traditionally depended on the results of daily checks and intuition of skilled farmers. At plant factories, however, skilled farmers themselves cannot check all of the areas. In addition, variation due to environmental fluctuations and other reasons makes it difficult to use intuition to make work decisions. For this reason, a pressing issue was to develop technology allowing work decisions to be made based on objective and quantitative data.

Table 1 Market demands for resolving issues with plant factories (products and technologies required)

Issue	Product	Technology required
Energy saving	Environmental control system	○ Technology for optimizing operation of equipment according to the environment and production ○ Technology for efficiently realizing an environment suited for cultivation
Labor saving	Production automation system	○ Technology for automating the state management, harvesting and conveyance of crops
Yield improvement	Environmental control system	○ Technology for equalizing temperature, humidity, CO_2 and wind velocity distribution in facilities ○ Cultivation fundamental technology for grasping relationships between various parameters in environment and work and yields in environment and work
	Indoor air quality improvement system	○ Technology for improving cleanliness of air in facilities
	Production process data prediction system	○ Technology for predicting outbreak of diseases and insect pests, occurrence of cultivation failures and cultivation yields

Figure 4 shows the configuration of the production process data prediction system. The following describes the flow of processing in this system.

(1) Input function

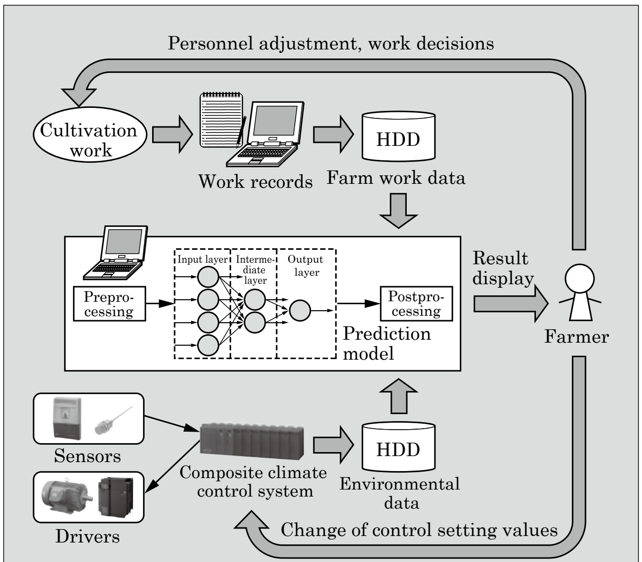


Fig.4 Configuration of production process data prediction system

Data for inputting into the prediction model are prepared. Data include environmental data and farm work data.

(a) Environmental data

Environmental data include time-series data such as temperature, humidity, amount of insolation and CO_2 concentration and are acquired from the environmental control system.

(b) Farm work data

Farm work data are inputted daily data including the yield and whether or not tending work was carried out.

(2) Preprocessing function

Various data are processed and converted into usable data type to create a prediction model using such conversion methods as standardization of data formats and sampling periods, completion of missing values and merging of data.

(3) Prediction function

The prediction function consists of the process of generating prediction models and the process of utilizing the models.

(a) Generation of prediction models

Past data are used to generate prediction models. the prediction model is generated by learning the data to be predicted such as the yield as the objective variable and the data relevant to the prediction target such as the environmental data as the explanatory variable.

(b) Utilization of prediction models

By inputting the explanatory variable data into the prediction model generated, the system can output the result of the prediction target in real time.

(4) Post-processing and display function

By changing the unit or other data attributes and using integration or other calculation techniques, the prediction result data are processed and converted into a format that allows farmers to easily make work decisions, which are displayed on the screen. Farmers can use the displayed content as reference when deciding whether or not to carry out the work relevant to the prediction target.

5.2 Prediction targets and prediction models

The following are prediction targets desired in cultivation management.

(a) Emergence of diseases and insect pests

Powdery mildew, gray mold, anthracnose, red spiders, mites and plant lice

(b) Occurrence of cultivation failures

High temperature injuries, low temperature injuries, fruit deformation and tip burn

(c) Yield and cultivation work timing

Yield, timing of leaf pruning, flower picking, fruit thinning and mulching

The quantities of generation and implementation and timing of prediction targets are influenced by complex and natural factors such as the temperature, humidity, amount of insolation, amount of photosynthesis, growing period, growing condition of seedlings, amount of relevant work, soil components and activities of bees. In addition, influence quantities of the individual factors may greatly vary depending on the types of crops (strawberries), varieties (Tochiotome, Benihoppe), equipment conditions (soil or water culture, lighting condition, location). For that reason, mathematization by advance experiment using the individual factors as the conditions requires an enormous amount of man-hours.

The production process data prediction system uses a method based on machine learning. While prediction techniques using complicated formulae such as regression formulae requires complicated parameter setting, using this technique can significantly reduce the man-hours for changing the conditions because it does not require complicated formulae.

The following describes the data required for prediction. Acquisition of data that satisfy the following 2 requirements leads to smooth starting of prediction.

(a) Generation of prediction model: A few months' worth of data have been acquired in advance

(b) Utilization of prediction model: The data can be automatically acquired at constant intervals

Once a prediction model with similar conditions has been prepared, utilization of the prediction model can be started without the need for providing a data acquisition period in advance. For farm work data, inputting by means of a recording tool allows automatic acquisition of data.

5.3 Yield prediction function

As an application of the production process data prediction system, we are developing a function of predicting strawberry yields.

For improving profitability of a plant factory by reducing sales loss and improving work efficiency, the error between the predicted and actual yields should preferably be as small as possible. With strawberries, in particular, the shelf life after harvesting is very short, and yield prediction is required to be predicted in short-period of time, e.g. one day.

Yield prediction is processed according to the flow of the production process data prediction system described in Section 5.2. A prediction model is generated from the past data by using data such as the temperature and amount of insolation as the explanatory variables and the yield of one day as the objective variable. This allows prediction and display of the yield of one day.

In addition, the yield prediction model employs prediction data of the environment in the greenhouse based on the weekly weather forecast, which allows yield prediction for up to the following one week.

Farmers can use the predicted values as reference to provide the shipping volumes to customers, which raises expectations for profitability improvement by reducing the sales loss. Furthermore, estimating the amount of work such as harvesting can lead to profitability improvement by effective use of human resources.

Figure 5 shows the result of prediction of yield in a certain area at Tomatoh Farm. It has been confirmed that about 60% of all days have the error limited to within ±15%.

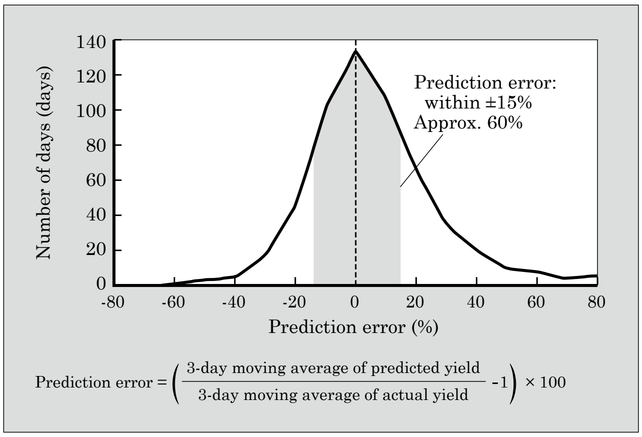


Fig. 5 Result of yield prediction

We aim at improvement of the prediction accuracy and application to other crops by constructing even more advanced prediction technology. We also intend to improve customer value at plant factories by combining mathematical application technologies at which Fuji Electric excels, such as anomaly diagnosis and optimization technologies, and linking with business management and control systems and other systems.

6. Postscript

This paper has described plant factory solutions that make use of instrumentation and control technology. Fuji Electric is committed to making continued efforts for comprehensive technology development by utilizing its core technologies including heating and cooling, control and mathematical application technologies for strengthening solutions.

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