Remote control of greenhouse hybridized with AI technique and LoRa communication

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Abstract. To increase agriculture harvesting, an online monitoring system equipped with multiple environmental sensors which can be wirelessly transmitted to a remote port using LoRa technique is presented. In addition, to ensure food safety, a portfolio of plants using a cloud connected to the remote port is also built. Moreover, in order to explore best chlorophyll of the vegetable in greenhouse, a study in obtaining appropriate environmental parameters (i.e. air temperature, air humidity, sunshine intensity, soil humidity, soil ph, and carbon dioxide) via artificial intelligent (AI) technique is proposed. Considering the cost down of manpower fee, the automation techniques using sensors and actuators in conjunction with a micro-controller is adopted. Furthermore, in order to ease monitoring and controlling, area is divided into small zones.

1. Introduction

Both water and temperature are essential parameter in cueing seasonal crops [1]. Because of the greenhouse effect, global climate changes are obviously getting worse. In addition, the hydrology and water resources will be highly influenced [2, 3]. According to FAO report, greenhouse can increase the production of vegetable crops if a greenhouse is installed [4]. Researches [5, 6] indicated that a plastic greenhouse used to protect the crop is necessary. Buchholtz et al. [7] designed a greenhouse which can reserve the temperature and humidity for crop growth. Recently, researches indicated that agriculture can be modernized and manpower saving by using Internet of Things (IoT) in monitoring greenhouse environment [8]. Obviously, smart farming based on IoT technologies will assist growers and farmers to enrich productivity. Quin et al. [9] used PIC 16F877 and ZigBee module to wirelessly monitor and control greenhouse. In order to increase the production of plant, Chiu, in 2010, developed the automatic thermal control monitoring system of greenhouse [10]. According to Hemming et al. [11], both dynamic greenhouse climate models and dynamic crop models can determine the set points. Sensors will turn back the detected data for the control loop and actuators are operated based on the set points.

Artificial intelligence (AI) has been widely applied reached major breakthroughs in various fields [12, 13, 14]. Faouzi et al. [15] has applied Fuzzy logic in the greenhouse to a promising future for the climate control and management of the greenhouse. In order to explore best green house’s environmental parameters that can enrich crop productivity, five kinds of AI logics, including Ordinary Least Square (OLS), Support Vector Regressor (SVR), Decision Tree Regressor, Random Forest, eXtreme Gradient Boosting (XGboost), have been conducted in this paper. The system can also serve as an ornamental...
farm. Moreover, because there is no network in remote areas or farms, a wireless communication between the greenhouse and the control center is essential. For traditional communication technique using WiFi [16], the allowable transmission distance of 250 m around is too short. To increase the transmission distance between the greenhouse and the control center’s PC, LoRa module, a low electrical power with long distance (2km to 5 km) is adopted in the greenhouse system. Furthermore, all the traditional environmental sensing (a rain detector, a chlorophyll, a thermal sensor, a humidity sensor, a soil humidity sensor, a soil ph meter, a luxmeter, and a carbon dioxide sensor) and controlling devices (a heater, a lighting, a carbon bottle, a mist sprayer, a fan, a sound-proofing curtain, a chemical water supply and a water sprayer) for a greenhouse are included in the system. In addition, two kind of green energy devices, including solar board and wind generator, are also used.

2. Greenhouse system

2.1. Greenhouse structure
As indicated in Figure 1, the sensors installed inside the greenhouse include a sunshine intensity sensor, a chlorophyll, an air thermal sensor, an air humidity sensor, a soil humidity sensor, a soil ph meter, and a carbon dioxide sensor. In order to adjust the environmental condition within the greenhouse, lots of actuators, including mist spray, water spray, purple light, sunshine-proofing net, carbon dioxide bottle, water supply valve, heating bulb, and fan have been installed. In addition, to assure the greenhouse security, a body temperature sensor in conjunction with burglar, web cam, and security light have been adopted. Moreover, to save the electrical power, two electrical power generating units (one of Photovoltaic Solar Energy System and the other of wind generator) are applied and established onto the greenhouse.

2.2. Data communication system
As indicated in Figure 2, a LoRa module with low electrical power and long distance is adopted. Using the wireless LoRa protocol, the data detected from the equipment (near) will be sent to the LoRa and wirelessly transmitted to the remote port.
Figure 2. Communication between the greenhouse and the control center’s PC.

For a remote and larger area or farm, the farm can be divided into several parts (shown in Figure 3). Each part of the farm can be equipped with individual LoRa module and wirelessly connected to the remote control center’s PC. As indicated in Figure 4, the greenhouse (equipment) will get the environmental information from the sensors. The detected environmental data will be received by the micro-controller (an arduino Uno micro-controller) and wirelessly forwarded to remote control center via the pair of LoRa module. For the Remote port, a HMI written by C# language will receive the environmental data and write down on the PC with excel format. Furthermore, the data set stored in the PC will be automatically forwarded to the internet cloud. The related flow diagram for the greenhouse under an automatic controlling mode is depicted in Figure 5. As illustrated in Fig. 5, the system will read environmental information from the sensors. The fan and heating bulb will be actuated if the greenhouse’s inside temperature is out of the specified temperature threshold. Similarly, the mist sprayer will be ON if the air humidity is less than the specific value; otherwise, the fan will be triggered if the air humidity is beyond the targeted value. In addition, the water spray will open if the soil humidity is less than the specific value. Also, the water sprayer will be triggered if the soil ph value is out of the soil ph threshold. Furthermore, the CO2 bottle will be ON if the concentration of the carbon dioxide is less than the specified threshold. On the contrary, the fan will be actuated if the concentration of the carbon dioxide is beyond the CO2 threshold. Consequently, the sunshine-proothing device will be forwarded or backward if the current sunshine intensity is out of the threshold of the sunshine intensity.

Figure 3. A large scale of farm.
3. Big data analysis
In order to seek the best growth conditions to increase the capacity of greenhouse plants, the correlation between the growth environment parameters of greenhouse plants and the corresponding target parameters will be explored. As mentioned in section 2, large and long-term information will be recorded and stored in remote port’s PC. Big data analytics are then applied in analyzing the correlation between the control parameters and the targeted parameter.

The purpose of the big data analysis is to evaluate the prediction of chlorophyll concentration in various regression models. Four experimental steps are described as below:

Step 1: Data regularization processing
Because the unit scale of the data which is different may affect the effectiveness of the training model, so converting the feature data to 0 to 1 is the first work. After that, the subsequent regression analysis can be performed.

Step 2: To build predictive model
Five kinds of big data methods, including Ordinary Least Square (OLS), Support Vector Regressor (SVR), Decision Tree Regressor, Random Forest, eXtreme Gradient Boosting (XGboost), are adopted in the study.

Step 3: Cross-validation
70% of the data are taken into training sets and the other (30%) are used as testing sets. The data are then randomly and averagely divided into 10 sets. For the cross-check purpose, the test set is finally put into the model of the optimal parameters to verify the performance.

Step 4: To estimate the model pointer
(1) Determination coefficient (R-Squared) is used to measure the proportion of the self-variant part of the dependent variable that can be interpreted as the model evaluation criterion.

(2) The mean square error (mean square error, MSE) represents the sum of the residual squares of the actual value and the predicted value, the purpose is to measure the degree of variation between the actual value and the predicted value, the smaller the MSE value, the better the effect, which means that the predictability is closer to the actual data.

4. Portfolio of plants

Because food safety problem is the most concern issue today, how to ensure that the food is organic and non-toxic crops is crucial. The food safety can be achieved by organic planting in conjunction with automated greenhouse planting technology mentioned above. It also can be reassured by using the platform of growth resume system shown in Figure 6. Since both the plant’s environmental parameters data and photo are automatically sent and stored on the cloud, people can link to the growth resume data in the cloud anytime, anywhere to learn about the information of the purchased agricultural products and fell confidence.

5. Results and discussions

In the green house, seven sensors (a chlorophyll sensor, an air thermal sensor, an air humidity sensor, a soil humidity sensor, a soil ph meter, a sunshine intensity sensor, and a carbon dioxide sensor) and seven actuators (a heater, a lighting, a carbon bottle, a mist sprayer, a fan, a sound-proofing curtain, and a water sprayer) have been adopted and established. The electrical panel for the greenhouse is depicted in Figure 7. And the monitoring of environmental parameters and plant’s chlorophyll is illustrated in Figure 8. As indicated in Figure 8, the related environmental parameters and plant’s chlorophyll value have been online detected and shown in the HMI of the remote port. In case of a greenhouse having 833 pieces of environmental control parameters (air thermal value, air humidity value, soil humidity value, soil ph value, sunshine intensity value, and carbon dioxide value) and respective objective parameter (chlorophyll value) which have been automatic detected and recorded by the above greenhouse system. The abstract of environmental parameters is listed in Table 1.
Five kinds of methods (Ordinary Least Square, Support Vector Regressor, Decision Tree Regressor, Random Forest, eXtreme Gradient Boosting) are adopted in finding the relevance of control parameters (air thermal, air humidity, soil humidity, soil ph, sunshine intensity, and carbon dioxide) with respect to the objective parameter (plant’s chlorophyll).

The multi-factor data (air temperature, air humidity, illuminance, carbon dioxide concentration, soil pH, soil moisture) has been standardized in advance before the Ordinary Least Square method used in regression process is performed. The result shown in Table 2 indicates that both illuminance and carbon dioxide concentration have stronger positive correlation to the plant’s chlorophyll.

| Factor                          | Coefficient |
|---------------------------------|-------------|
| Air Temperature(°C)             | -9.91       |
| Air Humidity(%)                 | -32.61      |
| Sunshine Intensity(lux)         | 259.37      |
| CO₂(ppm)                        | 220.21      |
| Soil pH                         | -16.14      |
| Soil Humidity (%)               | -52.12      |

Then, to see if the model has sufficient predictive ability, we bring the testing data into this model. The empirical results indicate that the mean square error between the predicted value of chlorophyll concentration and the true value of chlorophyll concentration is about 2047. The determination coefficient is around 0.795, as shown in Table 3. The results reveal that the OLS model may be too simplified which might result in limited forecasting.

| Evaluation Target | Value     |
|-------------------|-----------|
| MSE               | 2046.934  |
| R-Square          | 0.795     |

Regarding the Support Vector Regressor Method (SVR), because SVR follows the principle of structural risk minimization and is often used for nonlinear regression analysis, it has achieved good results in many fields. In the process of constructing SVR, in order to obtain the best prediction results under the premise of not being overfitting, a 10-fold cross-validation technique used in finding the best combination of parameters is adopted. We set the kernel is linear or rbf, and the range of γ value is between 0.1 and 10. The parameters within the fixed parameter set are ten times different from each other when the value of C is between 0.01 and 100. The prediction ability evaluation of the best

Table 1. The abstract of environmental parameters.

| Factor                      | Coefficient |
|-----------------------------|-------------|
| Air Temperature(°C)         | -9.91       |
| Air Humidity(%)             | -32.61      |
| Sunshine Intensity(lux)     | 259.37      |
| CO₂(ppm)                    | 220.21      |
| Soil pH                     | -16.14      |
| Soil Humidity (%)           | -52.12      |

Table 2. Result of ordinary least square method.

Table 3. Model’s performance evaluation for the ordinary least square method.
parameter combination model obtained after cross-validation is shown in Table 4. The observed results show that the prediction accuracy rate of SVR is higher than OLS in each prediction error. In terms of overall forecasts, SVR forecasts are better than OLS's.

| Evaluation Target | Value |
|-------------------|-------|
| MSE               | 782.677 |
| R-Square          | 0.922  |

Table 4. Model’s performance evaluation for the support vector regressor method.

In order to make the predicting model to be more reasonable, we used both the decision tree and random forest model to do the regression estimation. In order to avoid overfitting, the maximum depth is set to 4. In fact, the results shown in Table 5 reveal that the prediction ability of random forest is slightly better than the decision tree. However, the pointers of the two methods are not as good as that of the SVR regression model.

| Evaluation Target | Decision Tree | Random Forest |
|-------------------|---------------|---------------|
| MSE               | 1305.627      | 1130.033      |
| R-Square          | 0.869         | 0.887         |

Table 5. Model’s performance evaluation for decision tree method and random forest method.

It is worth mentioning that we can understand more intuitively the effects of factors on chlorophyll concentration from these two models through factor importance assessment and its decision-making process shown in Table 6.

| Factors               | Decision Tree Importance | Random Forest Importance |
|-----------------------|--------------------------|--------------------------|
| Sunshine Intensity(lux)| 0.651244                 | 0.715984                 |
| CO₂(ppm)              | 0.221357                 | 0.209041                 |
| Air Humidity(%)       | 0.069627                 | 0.0543                   |
| Soil Humidity(%)      | 0.033576                 | 0.020561                 |
| Soil pH               | 0.016526                 | 0.000088                 |
| Air Temp.(°C)         | 0.007669                 | 0.000025                 |

Table 6. Factor importance assessment for decision tree method and random forest method.

XGboost is the realization of determination tree algorithm via a gradient lift. It can be run using parallel calculation on a single machine, which is an efficient and high accuracy algorithm. In addition, it is highly interpretable and can effectively enhance our understanding of the problem. As shown in Table 7 and Table 8, after training the XGboost model, the prediction ability of the model has been significantly improved, and its determination coefficient and mean square error are optimal in all models. In addition, in the ranking of the explanatory ability sequester by the factors, it can also be seen that both illuminance and carbon dioxide concentration are still the key factors, which is no different from the other models mentioned above.

| Evaluation Target | Value |
|-------------------|-------|
| MSE               | 536.8824 |
| R-Square          | 0.946332 |

Table 7. Model’s performance evaluation for extreme gradient boosting method.
Table 8. Factor importance assessment for extreme gradient boosting method.

| Factors              | Importance  |
|----------------------|-------------|
| Sunshine Intensity(lux) | 0.651244   |
| CO₂(ppm)              | 0.221357    |
| Air Humidity(%)       | 0.069627    |
| Soil Humidity(%)      | 0.033576    |
| Soil pH               | 0.016526    |
| Air Temp.(°C)         | 0.007669    |

The chlorophyll concentration of plants was significantly influenced by photos and carbon dioxide concentrations, which were the most important factors, while the interpretation of other factors was weak. In assessing the influence and prediction of many environmental factors on plant chlorophyll concentration, OLS, SVR, Decision Tree Regressor, Random Forest and XGBoost are proposed. Consequently, it is found that the accuracy for the SVR and the XGBoost is better than other three methods. These two methods might be more suitable for its predictive model.

6. Conclusion

It has been shown that an online monitoring greenhouse system equipped with seven sensors and six actuators is established. In order to wirelessly transmit the environmental data from the agriculture farm to a remote control port, a LoRa module with low electrical power and long distance ability is adopted. A HMI interface written by C# language in the remote port’s PC can receive greenhouse’s data and write down on the PC with excel format via the LoRa module. The data and vegetable phone will be online sent to the cloud. And, the potential customer can login to the cloud. The plant safety can be reassured by using the platform of growth resume system mentioned above. Furthermore, to efficiently increase the plant’s productivity, five kinds of regression methods, including Ordinary Least Square, Support Vector Regressor, Decision Tree Regressor, Random Forest, and eXtreme Gradient Boosting, are adopted and assessed. Regression results reveal that both illuminance and carbon dioxide concentration have stronger positive correlation to the plant’s chlorophyll. Consequently, the accuracy for the SVR and the XGboost is better than other three methods.

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