Rule Based Artificial Intelligent System of Cucumber Greenhouse Environment Control with IoT Technology

Kohei Arai
Graduate School of Science and Engineering
Saga University
Saga City, Japan

Yoshikazu Saitoh
Takeo Training Farm
Saga Prefectural Training Farm
Takeo City, Japan

***Abstract*—The method proposed here allows control cucumber greenhouse environment based on IoT technology. IoT sensors are to measure the room and air temperature, relative humidity, CO_2 content, water supply, liquid fertilizer, water content. The basic system is rule based system. All the required rules to control the cucumber greenhouse environment are proposed here. Through regressive analysis between IoT sensor data and the harvest cucumber quality, it is found that the proposed rule based system is appropriate to control the cucumber greenhouse environment.**

Keywords*—Temperature; relative humidity; CO_2 content; water supply; liquid fertilizer; rule-based system; IoT; artificial intelligence; expert system

I. Introduction

Vitality monitoring of vegetation is attempted with photographic cameras [1]. Grow rate monitoring is also attempted with spectral reflectance measurements [2]. Bi-Directional Reflectance Distribution Function: BRDF is related to the grow rate for tealeaves [3]. Using such relation, sensor network system with visible and near infrared cameras is proposed [4]. It is applicable to estimate nitrogen content and fiber content in the tealeaves in concern [5]. Therefore, damage grade can be estimated with the proposed system for rice paddy fields [6]. This method is validated with Monte Carlo simulation [7]. Also Fractal model is applied to representation of shapes of tealeaves [8]. Thus the tealeaves can be asse3ssed with parameters of the fractal model. Vitality of tea trees are assessed with visible and near infrared camera data [9].

Rice paddy field monitoring with radio-control drone mounting visible and NIR camera is proposed [10] while the method for rice quality evaluation through nitrogen content in rice leaves is also proposed [11]. The method proposed here is to evaluate rice quality through protein content in rice crop with observation of NDVI which is acquired with visible and NIR camera mounted on radio-control drone. Rice crop quality evaluation method through regressive analysis between nitrogen content and near infrared reflectance of rice leaves measured from near field radio controlled drone is proposed and validated successfully [12].

Meanwhile, estimation of protein content in rice crop and nitrogen content in rice leaves through regressive analysis with NDVI derived from camera mounted radio-control drone is conducted successfully [13]. On the other hand, relation between rice crop quality (protein content) and fertilizer amount as well as rice stump density derived from drone data is well investigated [14]. Then, estimation of rice crop quality and harvest amount from drone mounted NIR camera data and remote sensing satellite data is carried out [15]. Furthermore, effect of stump density, fertilizer on rice crop quality and harvest amount in 2015 investigated with drone mounted NIR camera data is well reported [16]. Moreover, method for NIR reflectance estimation with visible camera data based on regression for NDVI estimation and its application for insect damage detection of rice paddy fields is proposed and validated [16].

There is a strong demand for automatic environmental condition control system of green-house in order to improve farmers' labor cost reduction as well as resource reduction. Also, in order to decrease the barriers to entry into agriculture, easy system for automatic environmental condition control system of green-house is highly required. The method proposed here allows cucumber greenhouse environment control based on IoT technology. In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert [17]. Expert systems are designed to solve complex problems by reasoning through bodies of knowledge, represented mainly as if–then rules rather than through conventional procedural code [18]. The first expert systems were created in the 1970s and then proliferated in the 1980s [19]. Expert systems were among the first truly successful forms of artificial intelligence (AI) software [20]-[24].

An expert system is divided into two subsystems: the inference engine and the knowledge base. The knowledge base represents facts and rules. The inference engine applies the rules to the known facts to deduce new facts. Inference engines can also include explanation and debugging abilities [25]. The most important things are environment control rules which are derived from the acquired environmental data through IoT sensors.

A study on greenhouse automatic control system based on wireless sensor network is recently well reported [26]-[34]. This is the typical system for greenhouse automatic control. Not only wireless sensor network but also knowledge base system and IoT related technologies are required for more efficient feedback control system which refers the product quality for control the environments of the greenhouse in concern.

The proposed method is described in the next section followed by experiments. The experimental results are validated in the following section followed by conclusion with some discussions.

II. PROPOSED METHOD

A. *IoT Sensor System*

The method proposed here allows control cucumber greenhouse environment based on IoT technology. IoT sensors are to measure the room and air temperature, relative humidity, CO_2 content, water supply, liquid fertilizer, water content. The basic system is rule based system. All the required rules for control the cucumber greenhouse environment are proposed here.

Fig. 1 shows IoT sensor system of the proposed rule based artificial intelligent system of cucumber greenhouse environment control system. In the ambient, There are solar illumination sensor, air temperature sensors at the east end and the west end, relative humidity sensors at the both ends, as well as CO_2 sensor in the west end, while room temperature sensors at the both ends as well as room humidity sensors at the both ends, and also CO_2 sensor at the east end. Furthermore, water supply and liquid fertilizer sensor are also equipped. Moreover, water content in the soil, leaf color and size can be monitored with camera images.

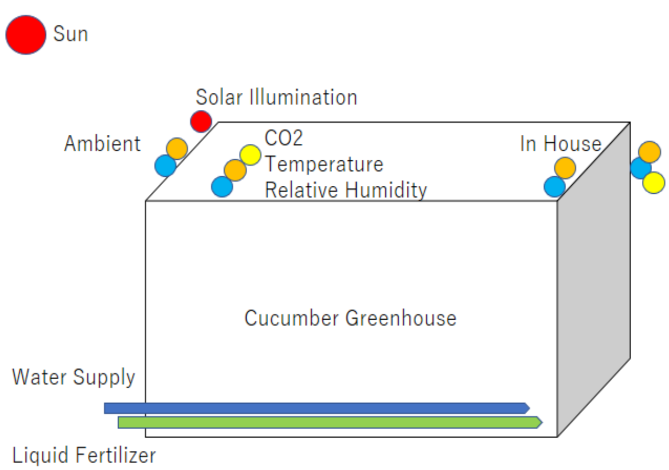


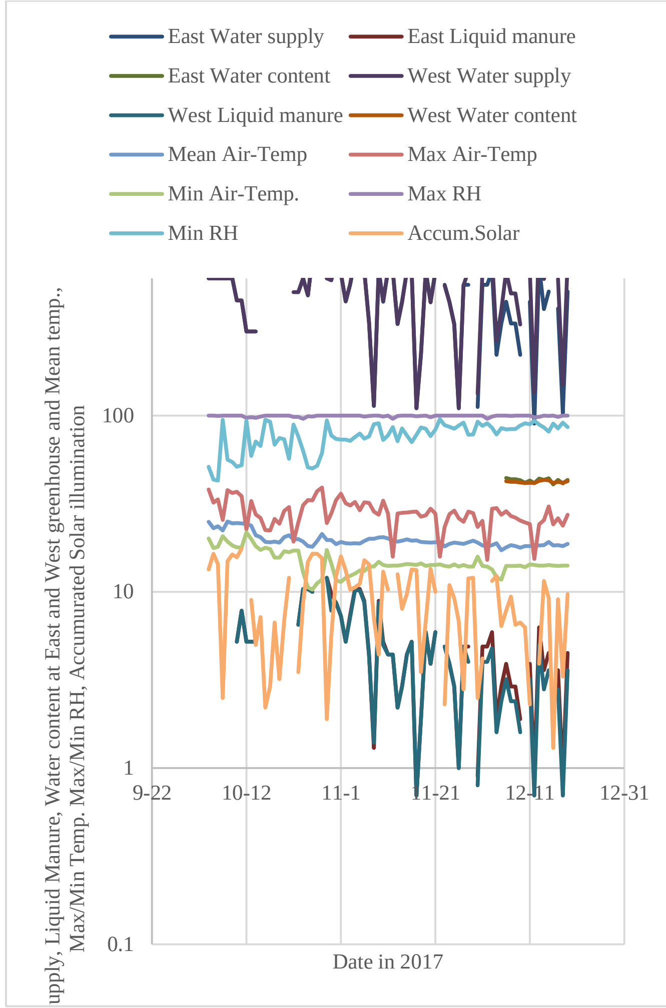
Fig. 1. IoT sensor system of the proposed rule based artificial intelligent system of cucumber greenhouse environment control system.

With the acquired environmental data and cucumber products data of quality and harvest amount, the all the required rules for maximizing cucumber product quality and harvest amount can be derived.

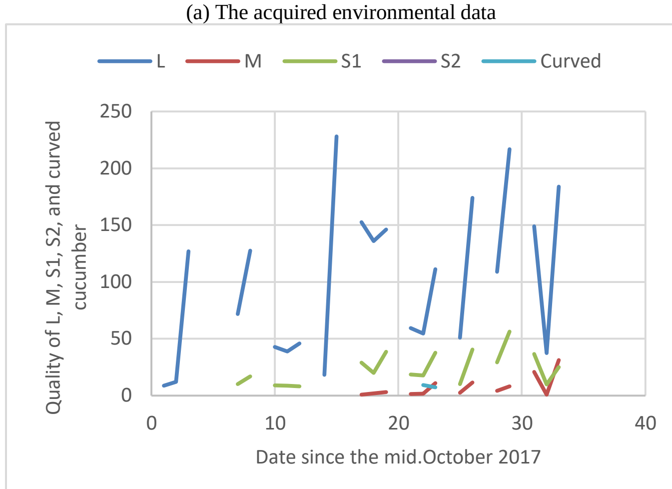
III. EXPERIMENT

A. *Preliminary Acquired Data*

Fig. 2(a) and (b) shows the example of the acquired environmental data and the cucumber products data of quality and harvest amount. By using the environmental and product data which are acquired from October 2017 to February 2018, all the required rules for control room temperature, room relative humidity, water supply, liquid fertilizer, room CO_2, can be derived.



(a) The acquired environmental data



(b) The cucumber products data of quality and harvest amount

Fig. 2. Example of the acquired environmental data and the cucumber products data of quality and harvest amount.

B. Derived Rules

The derived rules of room temperature is as follows:

1) Temperature Control:

It becomes management by principle "saturation difference value". It controls in correlation with humidity.

Means and means for raising the temperature inside the house:

○ October - March

① Heating machine (degree of influence 90%)

② Solar illumination (influence degree 10%)

Because the solar radiation is weak and the cloudy weather days are quite large compared to the Pacific side production area, we mainly keep the temperature by the heating machine.

○ April - September

① Solar illumination (degree of influence 85%)

② Heating machine (influence degree 15%)

From April the solar radiation gradually becomes stronger and the outside air temperature also rises.

However, since it may cool down in the evening too early in the morning around April, heater is often used.

Means and means for raising the temperature inside the house:

○ October - March

① Outside temperature (degree of influence 50%)

② Skylight ventilation (influence degree 50%)

Since the outside air temperature is low, basically the inside temperature of the house drops at the outside air temperature.

In the autumn of October to November, the daytime temperature may rise, so you may open the skylight to lower the temperature inside the house.

○ April - September

① Ventilation with skylight (degree of influence 85%)

② Side ventilation (influence degree 15%)

Because it will be a period of high trend both during the day and at night, it is a point when the temperature inside the house is lowered.

Actually both of ① and ② influence degree is 50% 50%, there are cases where side ventilation is not used due to the invasion of pests in the house.

On the other hand, room humidity control rules are as follows,

2) Relative Humidity Control:

It becomes management by principle "saturation difference value". It controls in correlation with temperature. As shown in the Table I on the right, the value of "saturation value 3 to 6". Control the temperature and humidity to make it. Where the color is attached corresponds to the proper value

In the case of cucumber it is a feeling of 2 ~ 6.

Means and degree of influence for raising humidity in house:

○ Same throughout the year (not related to winter or summer)

① transpiration of cucumber (degree of influence 70%)

② Watershed watering (influence degree 20%)

③ Skylight ventilation "close" (influence degree 10%)

Humidity inside the house basically keeps 80 ~ 90%, depending on the temperature. (This is sudden deviation management). Recently, a small fog cooling facility called "mist" has come out, but farmers who are introducing are rare at the moment. (It is likely to increase in the future.) If we put mist above, the influence will be around 90%.

TABLE I. ROOM TEMPERATURE AND RELATIVE HUMIDITY CONTROL

Room Temp。 (deg.C)	Relative Humidity(%) 95	90	85	80	75	70	65	60	55	50
16	0.7	1.4	2	2.7	3.4	4.1	4.8	5.5	6.2	6.7
17	0.7	1.5	2.2	2.9	3.6	4.3	5	5.8	6.5	7.2
18	0.8	1.5	2.4	3.1	3.8	4.6	5.4	6.2	7	7.7
19	0.8	1.6	2.5	3.3	4.1	4.9	5.7	6.5	7.4	8.2
20	0.9	1.7	2.6	3.5	4.4	5.2	6	6.9	7.8	8.7
21	0.9	1.8	2.7	3.7	4.6	5.5	6.4	7.4	8.3	9.3
22	1	2	2.9	3.9	4.9	5.7	6.8	7.7	8.8	9.7
23	1	2.1	3.1	4.2	5.2	6.3	7.3	8.3	9.3	10.3
24	1.1	2.2	3.3	4.4	5.5	6.5	7.7	8.7	9.8	10.9
25	1.2	2.3	3.5	4.7	5.8	6.9	8.1	9.3	10.4	11.5
26	1.3	2.5	3.7	4.9	6.1	7.4	8.5	9.8	10.9	12.2
27	1.3	2.7	3.9	5.2	6.4	7.7	9	10.3	11.6	12.9
28	1.4	2.8	4.2	5.5	6.7	8.2	9.5	10.9	12.3	13.6
29	1.4	2.9	4.4	5.8	7.3	8.6	10.1	11.5	13	14.4
30	1.5	3	4.7	6.2	7.6	9.1	10.6	12.1	13.6	15.2

Means and degree of influence to lower house humidity:

○ Same throughout the year (not related to winter or summer)

① Heating machine (degree of influence 50%)

② Skylight ventilation "opening" (degree of influence 50%)

The above is the way humans intentionally lower. The solar radiation is strong from April to June, and it is very difficult to maintain 70 to 90% if humidity is intentionally raised. Also, if the cucumber leaves get wilted, transpiration will also decrease, so it will become more dry. The humidity is lowered by the above means mainly because the inside of the house at night is high humidity (humidity becomes 100% depending on the day). We will intentionally use skylight ventilation and heating when the humidity becomes 100%.

In addition, there are the following points to note about the saturation value. “harvest start time ~ harvest end time” is used as a guideline to manage while checking the value of the difference. In addition, in the period of “settling ~ harvest start”, the number of leaves is small and transpiration from the leaves is small, so the saturation value cannot be reached. Therefore, temperature and humidity management will be carried out while confirming the withering condition etc. of the cucumber.

When the set concentration value is cut off while always measuring with the CO_2 sensor, the control device issues an

ON command to the carbon dioxide gas generator. After that, it is controlled so that it turns OFF when it exceeds the set upper limit concentration.

Meanwhile, CO_2 control rules as are follows:

3) CO_2 Control:
We change the CO_2 concentration in the house according to the time.

- Winter season

Basically, the skylight does not open (because it warms the inside of the house with heating), so it is set to 550 ~ 600ppm.

We are trying to increase photosynthesis efficiency by making it darker than the concentration of outside air (approximately 400 ppm).

- Spring - summer season

Since the temperature inside the house will rise due to solar radiation, open and close the skylight to control the temperature inside the house.

Due to the nature of CO_2, it cannot be made as high as in winter because it has the property to move from high concentration to low concentration. Therefore, control is made so that 400 to 440 ppm can be maintained so that the state can be maintained almost same as the outside air concentration.

Water supply and liquid fertilizer control rules are as follows:

4) Water supply and liquid manure control:
It is difficult for water, liquid fertilizer. The basic judgment criterion is "looking at the state of cucumber" and "moisture content".

Point to judge

"State of cucumber"
① Leaf color

→ Leaf color is thin · Water is high or there is not enough fertilizer → Action is "Reduce water" or "To increase liquid fertilizer"

→ Leaf color is dense · Water is little or fertilizer is too effective → Action is "increase water" or "thin or cut liquid fertilizer"

② Leaf size
→ Leaves are developing widely · · · Water works well. The action in this case is "as is".

→ Leaves are small · Water is not working → Action increases water.

Leaf color and size can be estimated with the camera images. Example of the acquired camera image is shown in Fig. 3.

Fig. 3. Example of the acquired camera image of cucumber leaf.

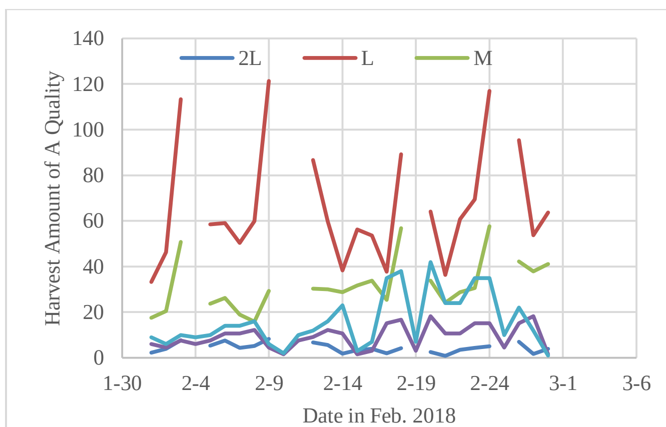
"Moisture percentage"

This is my own way. Confirm the moisture content at the end of the day (around 17 o'clock).

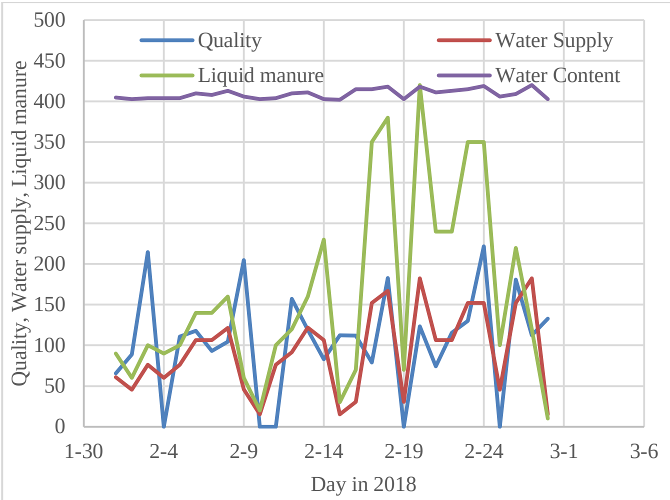
- Moisture content is clearly decreasing → We firmly absorb water but judge that it is not enough to increase irrigation volume
- Moisture content has not changed so much → It is judged that it is roughly irrigated.
- Moisture content is increasing → Multiple irrigation. Set to reduce irrigation setting.

C. Validation of the Proposed Role Base System

The proposed rule based artificial intelligent system of cucumber greenhouse environment control with IoT technology is validated with the daily averaged of the environmental data and the product data which are acquired in February 2018. Fig. 4(a) and (b) shows the product quality and the environmental data of water supply, liquid fertilizer and water content in the soil. In the Fig. 4(b), summarized product quality is shown as 2L+0.5L+0.3M (the number of highest quality of cucumber: 2L followed by L and M. therefore, Quality in Fig. 4(b) is calculated weighted sum of these numbers).



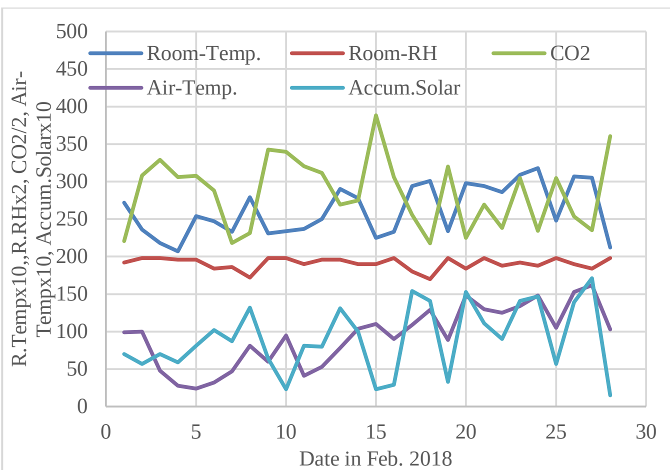
(a)Product quality data



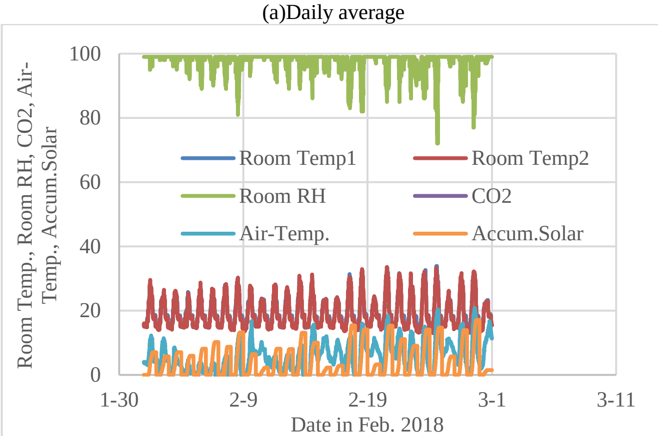
(b)Environmental data

Fig. 4. Product quality and the environmental data of water supply, liquid fertilizer and water content in the soil.

Other daily averaged environmental data of room temperature, room relative humidity (RH). CO_2, Air temperature, accumulated solar illumination acquired in February 2018 are shown in Fig. 5(a) while hourly averaged environmental data is shown in Fig. 5(b), respectively.



(a)Daily average



(b)Hourly average

Fig. 5. Daily and hourly averaged environmental data.

All these product and environmental data acquired in February 2018 is shown in Fig. 6. The correlation coefficients between the products quality and the other environmental data of water supply (WS), liquid fertilizer (LF), water content in the soil (WC), room temperature (RT), room relative humidity (RH), room CO_2, (CO) air temperature (AT) and accumulated solar illumination (AS) are as follows:

WS	LF	WC	RT	RH	CO	AT	AS
0.400	0.339	0.415	0.324	-0.212	-0.160	0.216	0.370

These correlation coefficients are derived from the Fig. 4 of products quality data and the environmental data. Essentially, there is no relation among these parameters, WS LF WC RT RH CO AT AS because we can set these parameters intentionally.

Therefore, the product quality (Q) can be estimated with the following equation,

$$Q=0.237WS+0.2LF+0.245WC+0.192RT-0.125RH-0.094CO +0.127AT+0.219AS \quad (1)$$

The most influencing environmental factor to the product quality is water content in the soil followed by water supply, liquid fertilizer, room temperature, air temperature, room relative humidity, and CO_2 concentration.

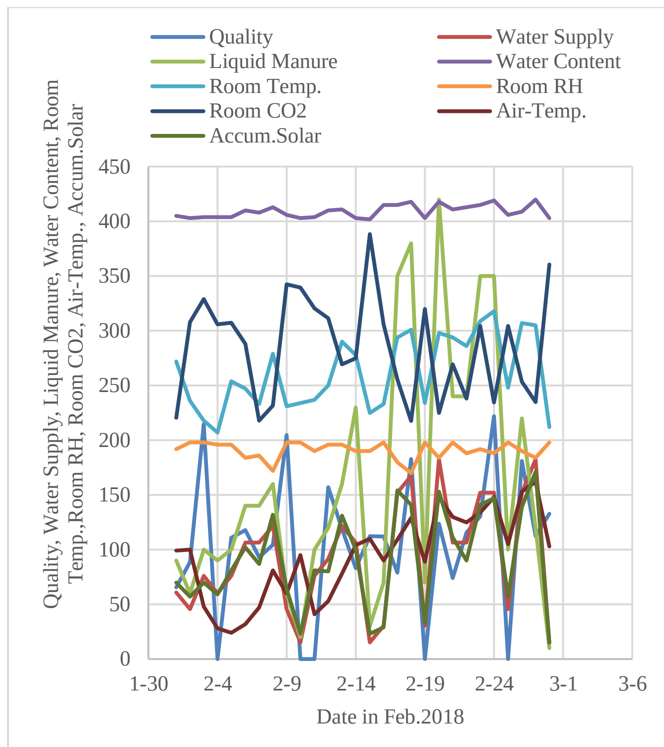


Fig. 6. Product and environmental data acquired in February 2018.

IV. Conclusion

The method which allows control cucumber greenhouse environment based on IoT technology is proposed. IoT sensors are to measure the room and air temperature, relative humidity, CO_2 concentration, water supply, liquid fertilizer, water content in the soil. The basic system is rule based system. All the required rules for control the cucumber greenhouse environment are also proposed. Through regressive analysis between IoT sensor data and the harvest cucumber quality, it is found that the proposed rule based system is appropriate for control the cucumber greenhouse environment. Also, it is found that the most influencing environmental factor to the product quality is water content in the soil followed by water supply, liquid fertilizer, room temperature, air temperature, room relative humidity, and CO_2 concentration.

Further research works are required for improvement of the prediction accuracy of cucumber quality and harvest amount. Also, cost performance evaluation is required for water and fertilizer managements.

Acknowledgment

The author would like to thank Mr. Kazuhiro Nagafuchi of Saga Prefectural Local Government for his effort to conduct the experiments.

References

[1] J.T.Compton, Red and photographic infrared linear combinations for monitoring vegetation, Journal of Remote Sensing of Environment, 8, 127-150, 1979.

[2] C.Wiegand, M.Shibayama, and Y.Yamagata, Spectral observation for estimating the growth and yield of rice, Journal of Crop Science, 58, 4, 673-683, 1989.

[3] Kohei Arai, Method for estimation of grow index of tealeaves based on Bi-Directional reflectance function:BRDF measurements with ground based netwrok cameras, International Journal of Applied Science, 2, 2, 52-62, 2011.

[4] Kohei Arai, Wireless sensor network for tea estate monitoring in complementally usage with Earth observation satellite imagery data based on Geographic Information System(GIS), International Journal of Ubiquitous Computing, 1, 2, 12-21, 2011.

[5] Kohei Arai, Method for estimation of total nitrogen and fiber contents in tealeaves with grond based network cameras, International Journal of Applied Science, 2, 2, 21-30, 2011.

[6] Kohei Arai, Method for estimation of damage grade and damaged paddy field areas sue to salt containing sea breeze with typhoon using remote sensing imagery data, International Journal of Applied Science,2,3,84-92, 2011.

[7] Kohei Arai, Monte Carlo ray tracing simulation for bi-directional reflectance distribution function and grow index of tealeaves estimation, International Journal of Research and Reviews on Computer Science, 2, 6, 1313-1318, 2011.

[8] K.Arai, Fractal model based tea tree and tealeaves model for estimation of well opened tealeaf ratio which is useful to determine tealeaf harvesting timing, International Journal of Research and Review on Computer Science, 3, 3, 1628-1632, 2012.

[9] K.Arai, H.Miyazaki, M.Akaishi, Determination of harvesting timing of tealeaves with visible and near infrared cameradata and its application to tea tree vitality assessment, Journal of Japanese Society of Photogrammetry and Remote Sensing, 51, 1, 38-45, 2012

[10] Kohei Arai, Osamu Shigetomi, Yuko Miura, Hideaki Munemoto, Rice crop field monitoring system with radio controlled drone based near infrared cameras through nitrogen content estimation and its distribution monitoring, International Journal of Advanced Research in Artificial Intelligence, 2, 3, 26-37, 2013

[11] Kohei Arai, Rice crop quality evaluation method through regressive analysis between nitrogen content and near infrared reflectance of rice leaves measured from near field radio controlled drone, International Journal of Advanced Research in Artificial Intelligence, 2, 5, 1-6, 2013.

[12] Kohei Arai, Masanori Sakashita, Osamu Shigetomi, Yuko Miura, Estimation of protein content in rice crop and nitrogen content in rice leaves through regressive analysis with NDVI derived from camera mounted radio-control drone, International Journal of Advanced Research in Artificial Intelligence, 3, 3, 7-14, 2014.

[13] Kohei Arai, Masanori Sakashita, Osamu Shigetomi, Yuko Miura, Relation between rice crop quality (protein content) and fertilizer amount as well as rice stump density derived from drone data, International Journal of Advanced Research on Artificial Intelligence, 4, 7, 29-34, 2015.

[14] Kohei Arai, Masanori Sakashita, Osamu Shigetomi, Yuko Miura, Estimation of Rice Crop Quality and Harvest Amount from Drone Mounted NIR Camera Data and Remote Sensing Satellite Data, International Journal of Advanced Research on Artificial Intelligence, 4, 10, 16-22, 2015.

[15] Kohei Arai, Gondoh, Miura, Shigetomi, Effect of Stump density, Fertilizer on Rice Crop Quality and Harvest Amount in 2015 Investigated with Drone mounted NIR Camera Data, International journal of Engineering Science and research Technology, 2, 2, 1-7, 2016

[16] Kohei Arai, Kenji Gondoh, Osamu Shigetomi, Yuko Miura, Method for NIR Reflectance Estimation with Visible Camera Data Bsed on Regression for NDVI Estimation and Its Application for Insect Damage Detection of Rice Paddy Fields, International Journal of Advanced Research on Artificial Intelligence, 5, 11, 17-22, 2016.

[17] Jackson, Peter (1998), Introduction To Expert Systems (3 ed.), Addison Wesley, p. 2, ISBN 978-0-201-87686-4

[18] "Conventional programming". Pcmag.com. Retrieved 2013-09-15.

[19] Leondes, Cornelius T. (2002). Expert systems: the technology of knowledge management and decision making for the 21st century. pp. 1–22. ISBN 978-0-12-443880-4.

[20] Russell, Stuart; Norvig, Peter (1995). Artificial Intelligence: A Modern Approach (PDF). Simon & Schuster. pp. 22–23. ISBN 0-13-103805-2. Retrieved 14 June 2014.

[21] Luger, George; Stubblefield, William (2004), Artificial Intelligence: Structures and Strategies for Complex Problem Solving (5th ed.), The Benjamin/Cummings Publishing Company, Inc., p. 720, ISBN 0-8053-4780-1, 2004.

[22] Nilsson, Nils. Artificial Intelligence: A New Synthesis. Morgan Kaufmann Publishers. 1998. ISBN 978-1-55860-467-4. 1998.

[23] McCorduck (2004, p. 190-25) discusses Frankenstein and identifies the key ethical issues as scientific hubris and the suffering of the monster, i.e. robot rights, pp. 327–335, 434–435. 2004.

[24] Crevier, Daniel (1993), AI: The Tumultuous Search for Artificial Intelligence, New York, NY: BasicBooks, ISBN 0-465-02997-3, pp. 145–62, 197−203, 1993.

[25] Nwigbo Stella and Agbo Okechuku Chuks, School of Science Education, Expert system: a catalyst in educational development in Nigeria: "Knowledge-based systems collect the small fragments of human know-how into a knowledge-base which is used to reason through a problem, using the knowledge that is appropriated" Proceedings of the 1st International Technology, Education and Environment Conference (c) African Society for Scientific Research (ASS), 566-571, 2010.

[26] Dae-Heon ParkBeom-Jin KangKyung-Ryong ChoChang-Sun ShinSung-Eon ChoJang-Woo ParkEmail authorWon-Mo Yang, A Study on Greenhouse Automatic Control System Based on Wireless Sensor Network, Wireless Personal Communications, January 2011, Volume 56, Issue 1, pp 117–130, 2011.

[27] Alves-Serodio, C. M. J., Monteiro, J. L., & Couto, C. A. C. (1998). An integrated network for agricultural management applications. IEEE International Symposium on Electromagnetic Compatibility. America: Denver, pp. 679–683., 1998

[28] Serôdio C., Cunha J. B., Morais R., Couto C., Monteiro J. (2001) A networked platform for agricultural management systems. Computers and Electronics in Agriculture 31(1): 75–90, 2001..

[29] Sensors Magazine. (2004). Editorial: This changes everything—market observers quantify the rapid escalation of wireless sensing and explain its effects. Wireless for Industry, Supplement to Sensors Magazine, Summer, pp. S6–S8., 2004.

[30] Wang N., Zhang N., Wang M. (2006) Wireless sensors in agriculture and food industry—recent development and future perspective. Computer and Electronics in Agriculture 50: 1–14, 2006.

[31] Kim Y.-S. (2004) Expert development for automatic control of greenhouse environment. Journal of Korean Flower Research Society 12(4): 341–345, 2004..

[32] Huang, Y.-J., Evans, N., Li, Z.-Q., Eckert, M., Chevre, A.-M., Renard, M., & Fitt, B. D. L. (2006). Temperature and leaf wetness duration affect phenotypic expression of Rlm6-mediated resistance to Leptosphaeria maculans in Brassica napus. New Phytologist 129–141, 2006..

[33] Hartman J. R. (1999) Effect of leaf wetness duration, temprature, and conidial inoculum dose on apple scab infections. The American Phytopathological Society 83(6): 531–534, 1999.

[34] Wilks, D. S., & Shen, K. W. (1991). Threshold relative humidity duration forecasts for plant disease prediction. American Meteorological Society, pp. 463–465., 1991.

AUTHOR'S PROFILE

Kohei Aarai He received BS, MS and PhD degrees in 1972, 1974 and 1982, respectively. He was with The Institute for Industrial Science and Technology of the University of Tokyo from April 1974 to December 1978 and also was with National Space Development Agency of Japan from January, 1979 to March, 1990. During from 1985 to 1987, he was with Canada Centre for Remote Sensing as a Post Doctoral Fellow of National Science and Engineering Research Council of Canada. He moved to Saga University as a Professor in Department of Information Science on April 1990. He was a councilor for the Aeronautics and Space related to the Technology Committee of the Ministry of Science and Technology during from 1998 to 2000. He was a councilor of Saga University for 2002 and 2003. He also was an executive councilor for the Remote Sensing Society of Japan for 2003 to 2005. He is an Adjunct Professor of University of Arizona, USA since 1998. He also is Vice Chairman of the Commission-A of ICSU/COSPAR since 2008. He wrote 30 books and published 500 journal papers.