Original scientific paper
10.7251/AGRENG1803056P
UDC 628.8:631.544.4

SPATIOTEMPORAL ANALYSIS OF SMALL SCALE GREENHOUSE MICROCLIMATE BASED ON SMART AGRICULTURE SYSTEM

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ABSTRACT

There is a need for high cutting-edge technological ICT application in agriculture in order to embark on the current decline in agriculture labor force in Japan. However, few small-scale farmers are able or willing to risk significant capital on sensing technologies. There is a challenge in horticultural greenhouse farming to provide a well-controlled microclimate environment to meet well-developed crops with high yield and quality crop production while using fewer resources. In this study, a cost-effective simplified smart agriculture system was developed and deployed in small-scale tomato greenhouse farming in Nara, Japan. The system real-time information capability is used for monitoring crop environment for proper crop management. A spatiotemporal analysis was done to assess variations and understand the underlying microclimate conditions in the partitioned tomato greenhouse (blocks). Crop production is done all year around (An average of 2.5 times cropping cycle per one greenhouse block). Spatiotemporal analysis and statistical analysis results show well-defined micro-climate control strategies that could relatively be used in greenhouse facility management to enhance crop cultivation while using less energy resource that is relatively cost-effective. The reliability of the system data makes it efficient and consequently it could be used for accurate crop production planning, improvement in cultivation management and support in decision-making regarding cultivation activities.

Keywords: *Smart Agriculture, small scale farmer, greenhouse, spatiotemporal.*

INTRODUCTION

Shrinking agriculture workforce due to aging population and rural depopulation are alarming situations in Japanese agriculture (Nakamura, 2008). There is a concern of serious labor shortage in the near future. There is need to reinventing Japan's agriculture, this requires refined production technologies that produce high-yield, high-quality agricultural goods as well as groundbreaking, highly profitable high-function products. Current efforts are targeting promotion of smart agriculture aiming for labor-saving and efficiency improvement using state-of-the-art robot technology and ICT (Shinichi *et al* , 2017). Smart agriculture focuses on developing production systems leading to higher-quality agricultural products.

This paper focuses on spatiotemporal analysis of small scale tomato greenhouse microclimate based on smart agriculture system. The area of this study within the controlled microclimate environment is determination of spatiotemporal conditions using wireless sensor network (WSN) collected data. According to (Nicolosi *et at*, 2017), microclimate control of greenhouse is a critical issue in agricultural practices, due to often common sudden daily variation of climatic conditions, and its potentially detrimental effect on plant growth. They further state that a greenhouse is a complex thermodynamic system where indoor temperature and relative humidity have to be closely monitored to facilitate plant growth and production. However, the daily variation of microclimate parameters i.e. temperature, relative humidity, carbon dioxide concentration, irradiation and irrigation, is not always favorable to plant growth therefore, maintaining favorable climate conditions in the greenhouse across the crop growth stages becomes necessary.

A greenhouse technology ensures a flexible and reliable solution for sustainable year-round cultivation of tomato for a relatively more cost-effective and competitive production. The farmer's tomato greenhouse used in this research, cultivate year-round tomato in six parts (blocks) within one greenhouse house. However much a greenhouse technology can provide the tomato plants with optimally-controlled microclimate growth conditions, there is still a challenge for ensuring there is well-controlled microclimate growth conditions for all the respective tomato crop growth within the greenhouse per each crop cycle. Solar radiation, temperature distribution and relative humidity are the main microclimate parameters needed to evaluate climate suitability in a greenhouse. The need to properly manage a greenhouse microclimate condition could therefore lead to significant increase in fruit quality and yields (Shamshiri *et al*, 2018). Understanding the spatiotemporal microclimate conditions would therefore lead to efficient management of facilities and ensuring a well-controlled microclimate within the greenhouse and thus reducing the excessive energy required for greenhouse heating and cooling.

MATERIALS AND METHODS

Smart Agriculture System Architecture

The smart agriculture system was deployed on already existing horticultural facilities. The system component consisted of physical components for data collection, installed WSN, database server. The software component consisted of designed database for data mining, data visualization and data analysis) as represented by the system architecture figure 1. The tomato greenhouse uses soilless cultivation technique - Nutrient film technique (NFT).

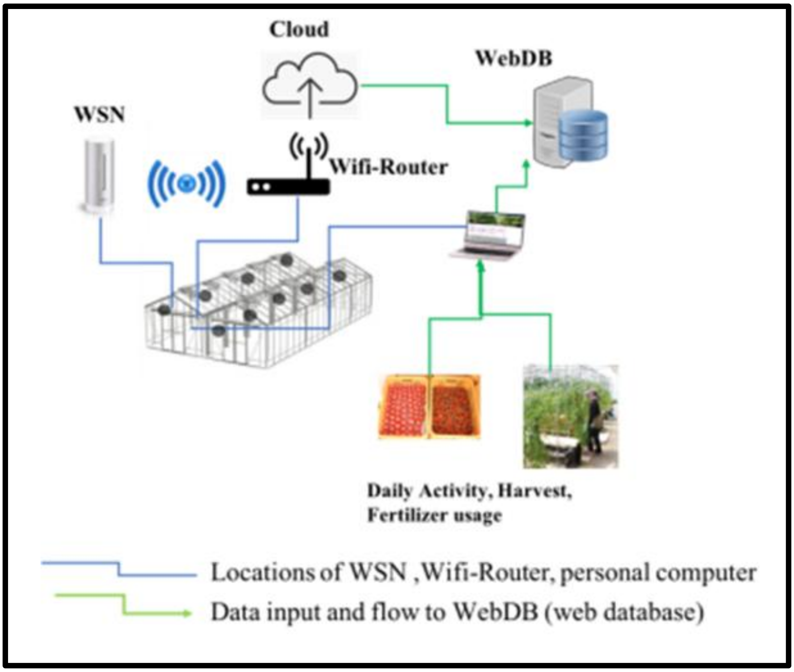

Figure 1: Smart agriculture System architecture composed of WSN for microclimate parameter data collection, Wi-Fi-Router for internet and personal computer for daily activity data entry such as harvests, fertilizer usage, crop cycles. All data is stored in the Web database (WebDB).

The smart agriculture system was installed in tomato greenhouse that is composed of six (6) blocks. WSN were distributed in the tomato greenhouse as shown in the layout figure 2. WSN measure microclimate variables air temperature, humidity, carbon dioxide concentration in the greenhouse in five minutes interval. Microclimate parameters (air temperature, carbon dioxide, humidity) between July 2017 and March 2018 were collected for analysis.

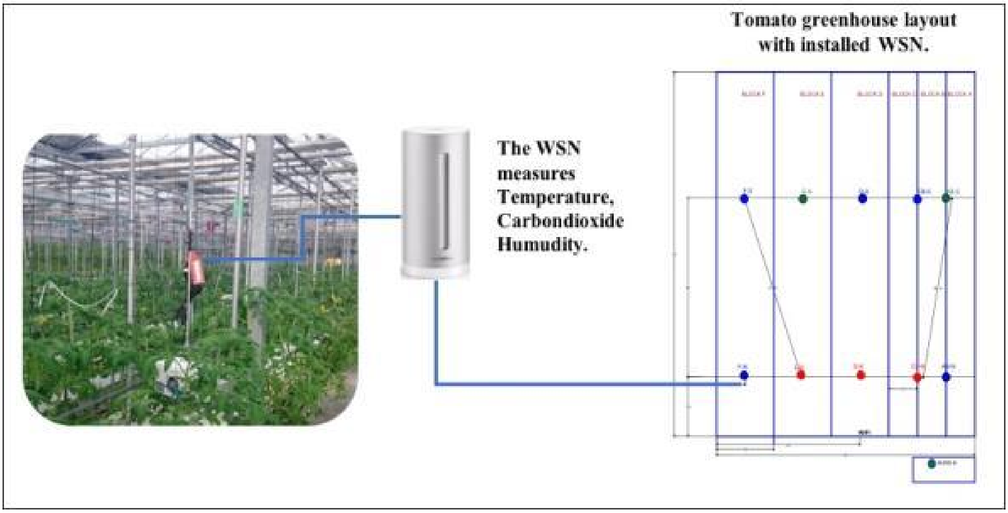

Figure 2: Tomato greenhouse layout showing the location of the installed WSN. The black, green, red points represent the location of the WSN (red points are the base module that receive data from the additional module (green points) and inside modules (blue points). The blue vertical line represent the block boundaries. y represent the length (meters) and x represent the width of the greenhouse. A total of eight (8) WSN sensors were installed in the greenhouse and one WSN in the nursery house located besides the greenhouse.

Spatiotemporal Method

The WSN measured microclimate parameters, air temperature variables used in this study, were transformed into agro-climatic index, Growing Degree Day (GDD) using degree-day method following the equation; $= ¢_i(T_{mean} - T_C)$. Where $¢_i = 1$ for $T_{mean} > T_C$, $\delta_i = 0$ for $T_{mean} \leq T_C$, T_{mean} is the mean daily air temperature, T_C is the threshold or base temperature (a base temperature of 10^0 was used).

To determine the spatiotemporal distribution of the microclimate environmental variables in the greenhouse, collected data of the distributed WSN data in the greenhouse were interpolated based on two-dimensional Cartesian coordinate system with the length and width of the greenhouse layout considered as x-y plane. The assumption that microclimate variables are irregularly distributed in the greenhouse, a linear method was selected, a bivariate interpolation method and smooth surface fitting for values that are given at irregularly distributed points was used (Akima, H. 1978). In this method, the x-y plane is divided into a number of triangular cells, each having projections of three data points in the plane as its vertexes. The z values are given as $z_i = z(x_i,y_i)$, where $i = 1,2, \ldots,n$. The z value in a triangle is interpolated with a bivariate fifth-degree polynomial function in x and y is applied to each triangular cell as shown by;

$$z(x,y)=\sum_{j=0}^{5}\sum_{k=0}^{5-j} q_{jk}\, x^j y^k,$$

where z is the x, y interpolated value of the fifth-degree polynomial at each point in the x-y, q is the vertex of triangular cell with other vertices x, y at triangular points $_j$ and $_k$ of plane of the distributed WSN collected data within the greenhouse.

RESULTS AND DISCUSSION

The spatiotemporal distribution of GDD in the green house for the period between July 2017 and March 2018 showed that there were temporal variations for the monthly temperature averages. Further, spatiotemporal distribution of monthly averages of GDD and humidity microclimate variations within the greenhouse (using separate scale for each month) showed distinct variations and clearly showed how microclimate conditions within the greenhouse varied as shown in figure 3 and figure 4. The monthly averages we based on daily microclimate conditions between 6 A.M and 12 P.M. The results showed that microclimate conditions are unequally distributed.

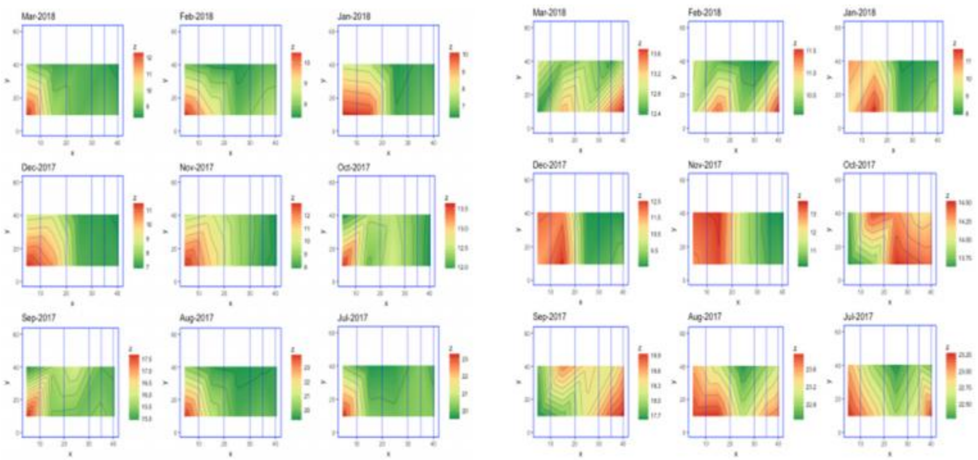

Figure 3. Spatiotemporal monthly GDD variations in tomato greenhouse. Left figure represent GDD variations between 06:00 to 12:00 in the morning and figure on right represent GDD variations between 12:00 and 18:00 in the afternoon for the period from July 2017 to March 2018.

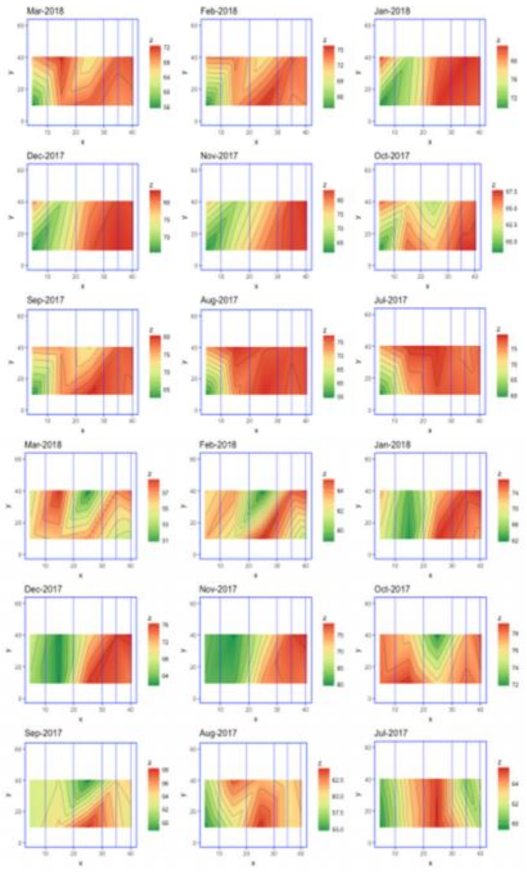

Figure 4. Spatiotemporal monthly humidity variations in tomato greenhouse. Left figure represent humidity variations between 06:00 to 12:00 in the morning and figure on right represent humidity variations between 12:00 and 18:00 in the afternoon for the period from July 2017 to March 2018.

The hourly spatiotemporal distribution was also determined. Results showed significant differences and unequal distribution during the day in the greenhouse.
For microclimate conditions between 6 A.M and 12 A.M figure 5, the average GDD was between 16.2 and 24. The lowest GDD difference between the lowest and highest was 0.8 at 6 A.M. From 12 A.M to 08:00 A.M, the GDD range was between 21.5 and 24.5 with the lowest GDD difference between the lowest and highest was 0.5 at 13:00 P.M. From the spatiotemporal variation graphs, it showed distinct microclimate condition distribution and variations within the house during the day. The hotter area at specific corner in the greenhouse depicted the location of the heating facility.

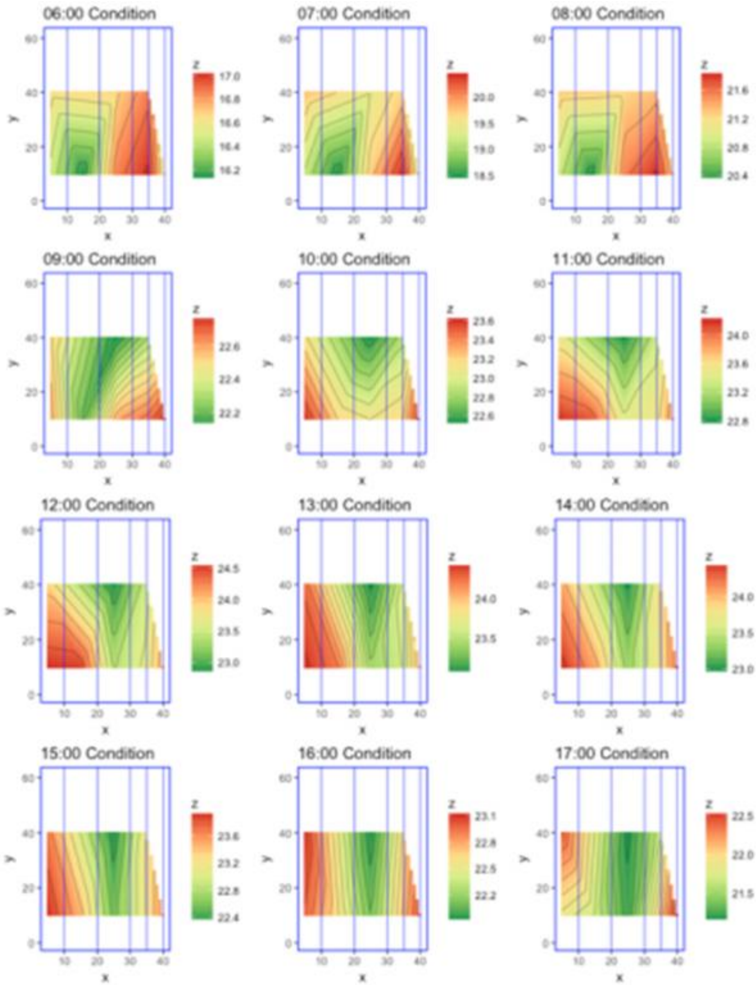

Figure 5: Daily Hourly average spatiotemporal variations between 0600 to 1800 hours for July, 2017.

CONCLUSIONS

In this study, spatiotemporal distribution of small scale greenhouse microclimate based on smart agriculture system, the spatiotemporal showed how microclimate distribution within the greenhouse varied. Further analysis of microclimate variations on an hourly basis helped understand the microclimate parameter distribution during the day within the tomato greenhouse this would be used for determining ways of ensuring recommended well-controlled and evenly distributed microclimate environment in the greenhouse by regulating heating and cooling facilities for optimum growing environment during the plant growth stage. This could also be used for improvement in cultivation management and support in decision-making regarding activities such as efficient management of facilities.

Ensuring a well-controlled microclimate within the greenhouse would thus reduce the excessive energy required for greenhouse heating and cooling.

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