Early Warning System Using Change Point Analysis to Detect Microclimate Anomalies

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ABSTRACT
The agricultural sector is required to provide food products for human needs. To increase agricultural yields, precision agriculture approaches are required by the utilization of information and technology to maximize agricultural productivity. Precision agriculture systems cannot be separated from monitoring and controlling the environment. This system is necessary to keep the surrounding environment or microclimate by plants requirements. However, during the monitoring and control process, some failures may occur due to technical and non-technical problems, and they will cause damage if not treated immediately. Therefore, to keep the microclimate under control according to plant growing requirements, an early warning system is necessary. The objective of this study was to develops an early warning system for microclimate anomalies using Change Point Analysis based on evapotranspiration calculations. This system works to detect changes in microclimate anomalies caused by malfunctions in the monitoring or control system. Microclimate time-series data obtained from monitoring in the growth chamber are used to calculate evapotranspiration. To represent the environmental condition inside the systems, reference evapotranspiration time-series data estimated from climate data using Penmann-Monteith 56 model, were analyzed using Singular Spectrum Transformation (SST) to obtain the change point score. As the result of the performance test and observation, microclimate anomalies inside the growth chamber could be detected by the change point detection representing by the change point score.

Keywords: *early warning system, change point analysis, evapotranspiration, change point score, microclimate anomaly*

1. INTRODUCTION

Increased production in the agricultural sector is carried out to meet human food needs. To increase agricultural yields, precision agriculture is necessary. Precision agriculture (PA) comprises a set of technologies that combines sensors, information systems, enhanced machinery, and informed management to optimize production by accounting for variability and uncertainties within agricultural systems [3]. Precision agriculture cannot be separated from monitoring and controlling the environment. Monitoring and controlling are carried out to maintain the environment or microclimate that is needed according to the plant requirements. Various kind of field environmental monitoring and control devices and systems has been developed up to present [2], [7], [8], [9], [10], [13]. Another application is monitoring and controlling the microclimate in the growth chamber. The microclimate in the growth chamber is monitored using environmental sensors. If one of the microclimates in the growth chamber does not match with plant requirements, it will be actuated using an actuator. To maintain the microclimate in the growth chamber remains in2accordance with the plant requirements.

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In the microclimate monitoring and control system, anomalies may occur, which can be caused by an uncontrollable microclimate and technical disturbances. To prevent this, an early warning system is needed to find out if an anomaly occurs in the monitoring and control of the microclimate. One method that can be used as an early warning system is Change Point Analysis developed by Idé & Inoue [4] using Singular Spectrum Transform. Okayasu [12] applied Change Point Analysis in agriculture to extract differences in environmental conditions for tomato cultivation in greenhouses. Nugroho [6] developed Real-time Change Point Analysis for Field Environmental Information in Agriculture.

However, previous research on change point analysis still uses only one environmental parameter Okayasu [12] using this method to detect changes in CO2 concentration and Nugroho [6] to detect change points in air temperature. And research is still carried out in uncontrolled environmental situations such as greenhouses [12] and outdoor [6]. So that research is needed in developing change point analysis in controlled microclimate conditions and using parameters that can represent all microclimate measurements.

The purpose of this study is to develop an early warning system for microclimate anomalies based on the calculation of evapotranspiration in the growth chamber. This research was conducted at the Smart Agriculture Research, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Gadjah Mada University.

2. MATERIALS AND METHODS

2.1. Microclimate Data Collection

Microclimate data are automatically collected in the Agri-eye system, a cloud-based monitoring and control framework developed by Nugroho [8], [11]. Figure 1 shows a schematic of the microclimate actuation and monitoring framework. In part (a), the monitoring and actuation nodes function to record microclimate data and provide actuation to maintain the microclimate according to the setpoints. The collected microclimate data is then sent to the Agri-eye system (b) using an internet connection every 5 minutes. Besides being collected in the Agri-eye system, microclimate data will also be stored on the SD card and displayed on the LCD.

In this monitoring and actuation system using the Arduino Mega 2560 microcontroller board as the mainboard, several environmental sensors such as the DHT22 sensor to measure temperature and humidity and the MAX4409 to measure the light intensity of the growing light, ESP 8266 as a wifi module to connect to an internet connection, and several additional supporting components (RTC, LCD, Datalogger)

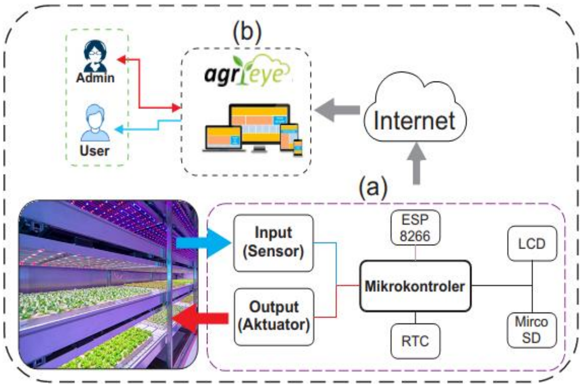


Figure 1. Micro-climate monitoring and actuation framework schema

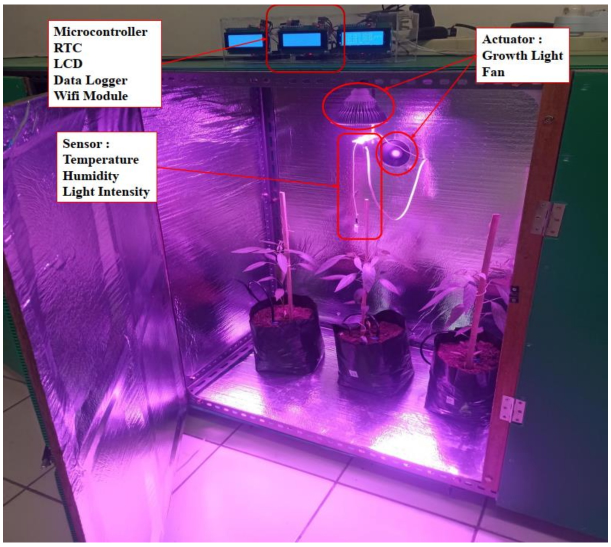


Figure 2. Actuator and Sensor Installed for micro-climate data collection

2.2. Reference Evapotranspiration Calculation

Reference evapotranspiration (ETo) was used as a microclimate assessment in the growth chamber. The ETo value can be estimated from the collected environmental data, measured with the built-in sensor, using the Penman-Monteith (PM) mathematical model [9]. The hourly step PM model is used to calculate the hourly ETo (mm h-1) as described in the Food and Agricultural Organization's Irrigation and Drainage No.56 [1] can be presented as follows:

$$ET_O = \frac{0.408(R_n - G) + \gamma \dfrac{900}{T_h - 273} u_2 VPD}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where T_h is hourly mean air temperature (°C), Δ is the slope of saturation vapor pressure curve at T_h (kPa °C-1), R_n is net radiation at the surface (MJ m-2 h-1), G is the soil heat flux density (MJ m-2 h-1), u_2 is the average hourly wind speed at 2 m height (m s-1), VPD is the vapor pressure deficit (kPa), γ is the psychrometric constant (kPa °C-1). For net radiation used 1 W/m-2 = 116 lux [5].

For the daytime period, ($R_n > 0$), $G = 0.1*R_n$, while for the night time period, ($R_n < 0$), $G = 0.5*R_n$

2.3. Calculate Change Point Score

To find out the Change Point Score using the equation developed by Nugroho [6] in a real-time application to detect change points from the environmental time-series data measured. The dynamics of the detected points before and after the current data segments are represented using the Hankel matrix, which is calculated as shown in Figure. 3.

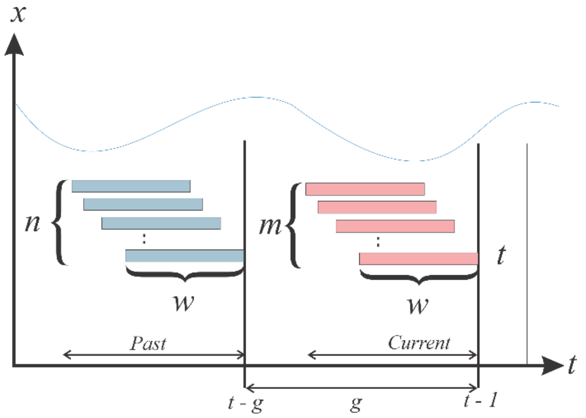


Figure 3. Changepoint analysis using SST [6]

For the set of time series data as (2):

$$\mathbf{T} = \{x(1), x(2), ..., x(t), ...\} \tag{2}$$

where t stands for time, a column vector **s** at time $t - g$ in the time series **T** in a reference window width w is selected as

$$\mathbf{s}(t-g) = \{x(t-g-w+1), ..., x(t-g-2), x(t-g-1)\}^T \tag{3}$$

where $(\bullet)^T$ is a transpose and g is a positive time difference. The Hankel matrix for a reference configuration at time $t - g$ is obtained by n pairs of s.

$$\mathbf{H}(t-g) = [\mathbf{s}(t-g-n), ..., \mathbf{r}(t-g-2), \mathbf{r}(t-g-1)] \tag{4}$$

which is called a trajectory matrix at the reference configuration. To extract a representative pattern of **H**, the following characteristic equation is considered as

$$\mathbf{H}(t-g) \cdot \mathbf{H}(t-g)^T \mathbf{u} = \lambda \mathbf{u} \tag{5}$$

where • is stands for an inner product. λ and **u** is an eigenvalue and eigenvectors for **H**, i.e. $||\mathbf{u}|| = 1$, respectively. The representative pattern of **H** is defined by selecting l pieces of λ in descending order as {(λ, $\mathbf{u}_1$), (λ, $\mathbf{u}_2$),…, (λ, $\mathbf{u}_l$)}. The pattern of matrix arranged by eigenvectors $\{\mathbf{u}_i \mid {}_{i=1,\dots,l}\}$ is given by

$$\mathbf{U} = [\mathbf{u}_1, \mathbf{u}_2, ..., \mathbf{u}_l] \tag{6}$$

Only the first l eigenvectors ($\mathbf{U}_l$) are kept representing the past change pattern. Other eigenvectors are neglected since these eigenvectors are regarded as noise, i.e. not primal data. Similarly, a column vector **r** for a current configuration at time t - 1 is selected in **T** with w.

$$\mathbf{r}(t-1) = \{x(t-w), ..., x(t-2), x(t-1)\}^T \tag{7}$$

Test matrix **G** is given by Henkel matrix for the current configuration is obtained by m pairs of **r** as

$$\mathbf{G}(t-m) = [\mathbf{r}(t-m), ..., \mathbf{r}(t-2), \mathbf{r}(t-1)] \tag{8}$$

As mentioned in Eq. (4), the characteristic equation of **G** is described as follows:

$$\mathbf{G}(t-m) \cdot \mathbf{G}(t-m)^T \bar{\mathbf{u}} = \bar{\lambda} \bar{\mathbf{u}} \tag{9}$$

where $\bar{\lambda}$ and $\bar{\mathbf{u}}$ ($||\bar{\mathbf{u}}|| = 1$) is the eigenvalue and the normalized eigenvector for **G**, respectively and the pattern matrix is given by

$$\bar{\mathbf{U}} = [\bar{\mathbf{u}}_1, \bar{\mathbf{u}}_2, ..., \bar{\mathbf{u}}_l] \tag{10}$$

The difference between the reference and the current pattern matrices U and $\bar{\mathbf{U}}$ called the change point score is defined as

$$z(t) \equiv 1 - \frac{\sum_{i=1}^{l} u_i \bar{u}_i^T}{l} \tag{11}$$

To realize the range of $z(t)$ fulfilling $0 \leqslant z(t) \leqslant 1$, $\mathbf{u}_i \bar{\mathbf{u}}_i^T = 0$ is adopted for $\mathbf{u}_i \bar{\mathbf{u}}_i^T \leqslant 0$ in Eq. (11). $z(t) = 0$ means for no difference between the reference and the current pattern and $z(t)=1$ for big differences each other. By using the value of z(t) we can detect anomalies from the time series data. Data processing using the R Studio program.

3. RESULT AND DISCUSSIONS

To verify the above method by simulating simple daily temperature data. The temperature data is simulated as shown in Figure 4. With the addition of anomaly phenomena at t=590 to t=595. The input parameters used for the analysis are w=35, n=m=5, g=144, and l=1. Changes in the change point values were detected at t=300 and t=444. At t=444 a change point was detected due to the previous anomaly as a reference pattern.

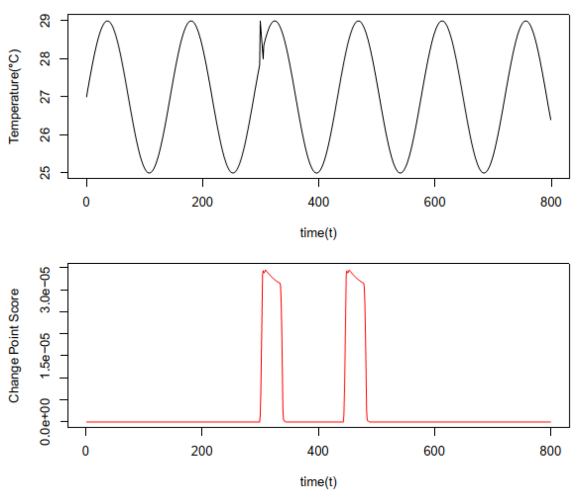


Figure 4. Changepoint analysis result for daily temperature

Then the application of change point analysis on the microclimate data in the growth chamber has been collected. Microclimate data was downloaded from the Agri-eye system. Figure 5 shows the microclimate data that has been obtained from June 5 to 11. From the data displayed, there was a technical problem in the form of a growth light turn-off on June 8 at 19.13.

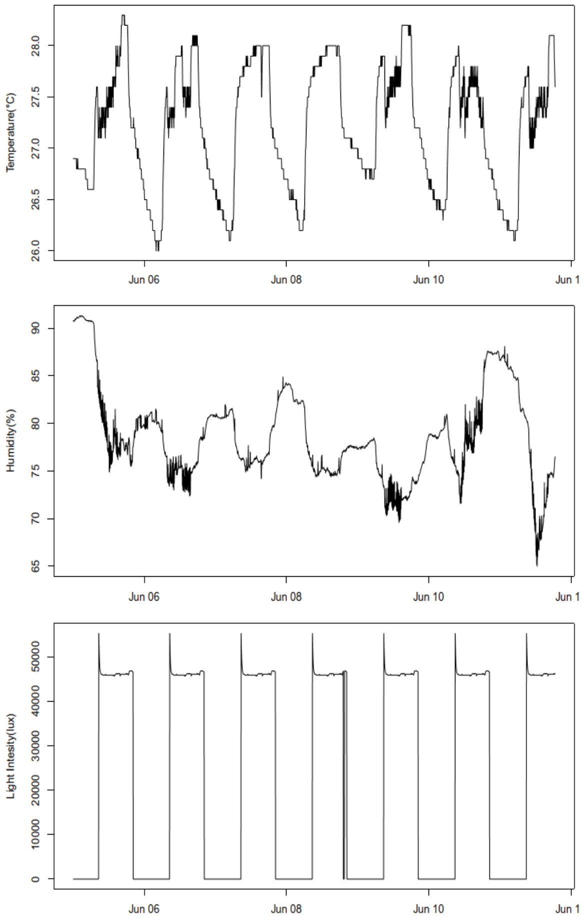
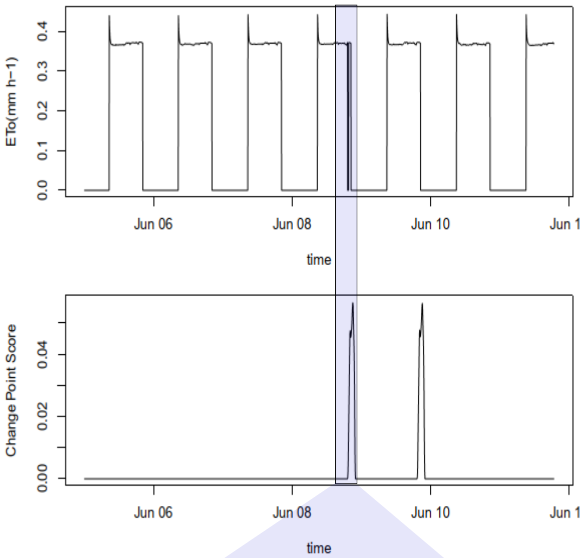


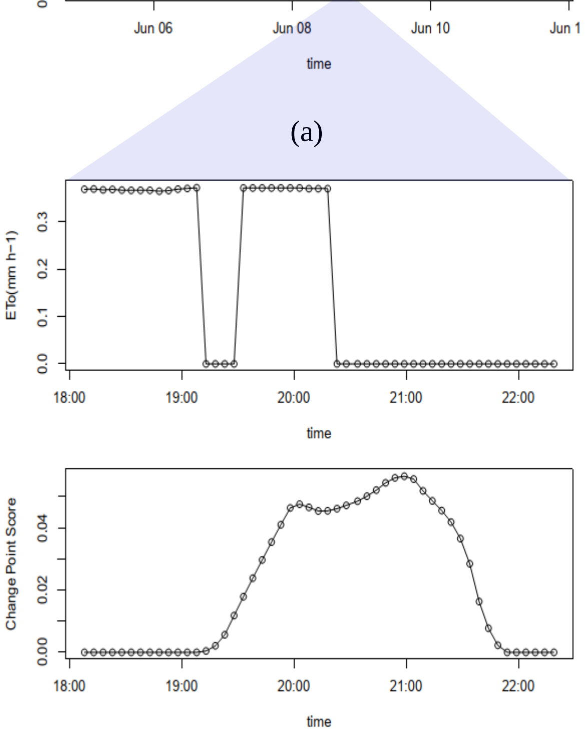
Figure 5. Microclimate data at growth chamber

From the microclimate data, evapotranspiration was calculated using the equation The hourly step PM model. Then calculate the change point score with the input parameters *w*=20, *n*=*m*=10, *g*=288, *l*=1. Selection of the input parameter is an important aspect in the Change Point Analysis, by choosing the high number of *w* and *n* can reduce the sensitivity and increase the calculation time. On the other hand, by selecting the lower value of *w* and *n*, the SST computation will become more sensitive and faster [6].

Figure 6 shows the results of the reference evapotranspiration calculation and the change point score. Change point score detected an increase on June 8 at 19.13. It shows the occurrence of microclimate anomalies. At the same hour, an increase in the change point value was also detected on the next day. This happens because the previous day's pattern is the reference.



(a)



(b)

Figure 6. Result of the change point analysis

Okayasu [12] applied this method to evaluate the environmental dynamics for CO2 concentration in a tomato greenhouse. The input parameters used are *w*=*g*=24, *n*=*m*=5, and *l*=1. The change point scores were detected from the change of CO2 concentration data clearly. The highest change point score when there is a change in CO2 concentration is 0.06. In another study Nugroho [6] applied this method to real-time change point detection from time-series data of outdoor air temperature. The input parameters used are *w*=12, *n*=*m*=6, *g*=24, and *l*=1. The highest change point score detected was 0.01. Meanwhile, this research was conducted in a growth chamber and the parameter used for testing the change point analysis is the reference evapotranspiration. The use of reference evapotranspiration values for change point analysis can represent all measured microclimate parameters. The highest change point value obtained when an anomaly occurs 0.05.

The results above show that Change Point Analysis can be used as an early warning system for microclimate anomalies. The use of the change point score as an early warning system is based on changes in the pattern of microclimate characteristics that occur in the growth chamber. So if there is a microclimate condition that is different from the previous pattern, it will be detected as an anomaly. This is compared to using the setpoint as an early warning system which will only detect dense microclimate anomalies when the microclimate is higher or lower than the setpoint only at the *t* time. The use of chance point analysis as an early warning system is faster to detect anomalies that occur in the growth chamber.

4. CONCLUSION AND FUTURE WORKS

The results of the verification test and testing using microclimate data show that the change point analysis method can detect anomalies. The use of reference evapotranspiration values for change point analysis can represent all measured microclimate parameters. Changepoint analysis can be used as an early warning system to detect microclimate anomalies. The use of the change point score as an early warning system is based on changes in the pattern of microclimate characteristics that occur in the growth chamber.

Farther, real-time calculation of change point analysis is needed to develop an early warning system. With it can provide information rapidly to users and can immediately take preventive action.

AUTHORS' CONTRIBUTIONS

Muhammad Salman Ibnu Chaer preparing the literature, modifying program code, preparing and editing the manuscript. Andri Prima Nugroho advises on program code and reviews the manuscript. Guyup Mahardhian Dwi Putra collects research data. Ngadisih Ngadisih designed the research environment settings. Lilik Sutiarso designed the research system. Takashi Okayasu recommends and advises on the development of change point analysis.

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