Mobile mecanvision: automatic plant monitoring system as a precision agriculture solution in plant factories

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Abstract. Precision agriculture (PA) is an approach in farming systems based on information and technology to enhance agricultural production. PA is applied in plant factories to produce high-quality vegetables in a controlled environment by implementing an automatic crop growth monitoring system. Optimization of the observation process carried out with computer system techniques used in the monitoring process and assessment of the plant condition. Individual observation of cultivated plants requires a monitoring system and numerous equipment. Therefore, a monitoring system equipped with a mobile mechanism is needed to support the monitoring process of crops individually by a single observer. The objective of this study was to design and implement an automatic plant monitoring system based on mobile mechanisms and computer vision using simple equipment in plant factories. The Mobile Mecavision, a monitoring system consists of a mobility system and an image acquisition system controlled by Raspberry Pi. The components are A4988, NEMA 17, and Logitech C270 HD Webcam. The evaluation for system performance carried out using the extreme point shift system and t-test. The aspect of image functionality evaluated using the Structural Similarity Measure test and the result was obtained an image similarity value of 89% to 92% with a 90% level of confidence. The result of the performance test on the mobility aspect obtained that the system shifted numerically but not statistically. The overall performance of the system indicated that the monitoring system could be applied to monitor the crop growth in plant factories.

1. Introduction
Uncontrollable climate change causes changes in the pattern of tropical agricultural production so that new adaptations are needed as the development of conventional agriculture [1]. Precision Agriculture (PA) is a method of increasing agricultural productivity by reducing costs and environmental impacts using resources with the help of technology [2-3]. One application of PA is, can obtain accurate information regarding specific environmental conditions and crop conditions. One example of technology in the future supporting PA is a plant factory application. The plant factory is a plant cultivation system, especially vegetables in a closed room and controlled environments. The advantages
of this system are given an opportunity to do farming in an unfavorable place for agricultural cultivation [4]. In addition, the plant factory can also produce vegetables in large quantities in a place that is not extensive. The crop quality is also good because of the controlled atmosphere in the room according to the conditions needed by crops [5].

One of the production quality parameters can be observed in the process of plant growth. monitoring system becomes an important aspect of plant factory application. This system has a function for observing precisely the growth during the process of agricultural cultivation in the growth chamber. However, observations of plant growth are still done directly by human labor using a ruler or scale with manual recording. This conventional method has an impact on damage and disrupts plant growth. From those conditions, there is a method of monitoring plant growth indirectly with a computer vision system.

The computer vision system is a science and technology which can see surrounding conditions in the form of images to be converted into information [6]. One of its parts is the camera. There are several pieces of research that apply cameras as a tool for observing plant growth such as An et al. observing plant growth by placing the camera on the plant with a certain distance [7]. There are also Yeh et al. who designing an automatic plant growth monitoring system using a stereo vision system [8]. Story and Kacira who designing an automatic plant growth monitoring system with computer vision in real-time [9]. Chen et al. developed a mobile machine vision system to measure plant mass in a plant factory [10]. Wijanarko et al. developed an observation system with a camera that is placed on a plant with a certain distance to record plant growth and motion [11].

The designed systems in these researches are using components with good quality so that the level of accuracy and system precision in monitoring plant growth is better. However, good quality components have high prices. From those conditions, the automatic plant growth monitoring system using a camera has the potential to be developed. In addition, a plant growth monitoring system which is developed based on low-cost microcontrollers also has the potential to increase the simplicity, flexibility, and affordability to be applied in plant factories [12].

The objective of this study was to design and implement an automatic plant monitoring system based on mobile mechanisms and computer vision using simple equipment in plant factories. The developed system combining mobile mechanism and computer vision features. With the combination of both systems, the plant monitoring process is maximized by moving the camera to take an image of each plant making the process well observed. This mobile mechanism process also allows the plant to have an optimal growth distance to avoid canopy of leaves from colliding or accumulating with each other. If using one static camera, the installation distance between the camera and plants must be made higher for it to be able to cover the whole area. In addition, the positioning of plants must be made tight so that they are covered by the camera. But this will make the leaf canopies to collide or accumulate, interfering the monitoring process. Meanwhile, installing cameras on top of each plant may complicate the installation process and spend more costs. Evaluation of the work is related to the level of system accuracy in plant growth monitoring, which is an evaluation of aspects of mobility and functionality of the image. The aspect of mobility is carried out to analyze the accuracy of the system move according to the specified position. The aspect of image functionality aims to find out the similarity of the system capture results.

2. Materials and Methods
This research was conducted in January-April 2020 at the Smart Agriculture Plant Factory, Agro-Informatics Sub-Lab, Laboratory of Energy and Agricultural Machinery, Department of Agricultural and Biosystems Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada.

2.1. System development
Figure 1 shows the framework for the process of developing a monitoring system based on mobile mechanism and computer vision consist of main components and supporting components. The main components consist of a mobility system and an image acquisition system that is controlled by Raspberry Pi. The supporting components in the form of a buffer frame, box controller, and blackboard are used
to resemble the shape of a plant factory. This system consists of a Logitech C270 HD Webcam Camera to capture plant growth; Motor driver A4988 to control motor stepper; Motor stepper NEMA 17 for managing the movement of the camera according to the coordinates given; Raspberry Pi 3 Model B microcomputers for managing the shooting process; XY-plotter kit to adjust the position of the camera; and the network device to provide an internet connection to support the data transmission and synchronization from plant factory to the cloud system.

The experiment materials used are model plants, blackboard, and elbow iron. Model plants with the shape chosen resemble a hydroponic plant, which is lettuce. Blackboard was used as a base to put the model plant. The choice of black on the board is based on the need to take pictures that require a dark background to facilitate the process of identifying objects in the advanced data processing. Elbow iron used as a base for the construction of plant growth monitoring systems and its characteristic of elbow iron have holes to simplify the disassemble and reassemble activities.

![Figure 1. Design of a plant growth monitoring system.](image)

2.2. Verification and validation of the system

Evaluation of the mobility monitoring system work based on mobile mechanism and computer vision is done by comparing the extreme point coordinates on the four sides of the plant photo model of each replicate in one sample. The purpose of this comparison is to determine whether the system has shifted or not when acquiring images.

The step to get extreme point coordinates is done by converting photos to black and white mode. Photos of whites prefer to plant objects and black to the background. This is to make it easier to distinguish between plant objects with the background. Next, look for extreme points in the black and white image sample. This determination uses a reference about setting extreme points with OpenCV [13]. The results obtained are four points representing the outermost points on each side of the image and the X-axis and Y-axis on the side of the image. Extreme point coordinate values can be determined using Corel Draw software by adjusting the work screen according to the size of the image and positioning the cursor on the extreme point. The coordinate value will appear in the lower-left corner of the work page.

The Pythagorean formula can be applied for determining one of the extreme points from two paired images. The formula used to test the variable point ($\delta d_{ij}$) from session $i$ to session $j$ is as follows:
\[ \delta d_{ij} = \sqrt{dX_{ij}^2 + dY_{ij}^2} \quad (1) \]

This formula can be used when the point shift conditions are straight lines or slashes. After obtaining the value of the shift, the test results of each sample are averaged and made into a graphical form to determine the extreme point shift range of each sample. The calculated shift value needs to be tested statistically so that it qualitatively indicates whether the processing results are good or not. This statistical test is done by testing the point shift variable whose value can be calculated. Then the value is compared with the table value. This test can be called a t-test. The t-test carried out is as follows.

\[ T_{\text{calc}} = \frac{\delta d_{ij}}{\sigma(\delta d_{ij})} \quad (2) \]

A shift is declared significant or the null hypothesis is rejected if

\[ T_{\text{calc}} > t_{df,a/2} \quad (3) \]

Evaluation of the performance of image functionality on a monitoring system based on cellular mechanisms and computer vision is done by comparing the results of photographs of each repetition in one sample. In this study, the Structural Similarity Measure (SSIM) method is used. This method works by modelling changes through structural information in an image. The SSIM formula is

\[ \text{SSIM} (x, y) = \frac{(2\mu_x \mu_y + c_1)(2\sigma_{xy} + c_2)}{\mu_x^2 + \mu_y^2 + c_1(\sigma_x^2 + \sigma_y^2 + c_2)} \quad (4) \]

The SSIM method produces decimal values between -1 and 1. A value of 1 can be achieved if the two data sets of images are identical or show perfect structural similarity. The value of 0 indicates no structural similarity. In this study, the SSIM value can be obtained by inputting image data into the program code. This determination uses a reference about comparing two images with SSIM [14]. The SSIM results for each sample are then averaged and the percentage value is determined. In this study, a 90% confidence level was used.

3. Results and Discussion

3.1. Monitoring system construction

![Figure 2. Design of a monitoring system based on mobile mechanism and computer vision.](image-url)
Monitoring systems construction can be grouped into two parts, that is the actuator system and the control system. The actuator system is a series of components that function in carrying out commands in the form of signals into a movement in a monitoring system based on mobile mechanism and computer vision. While the control system is a series of components to produce commands on the actuator system. The results of the design of a monitoring system based on mobile mechanism and computer vision can be seen in Figure 2.

![Figure 2: Monitoring system design.](image)

Figure 2. Monitoring system design.

According to Figure 2 there is one component that becomes the key to a mobile mechanism and computer vision, which is the box controller. This component contains a series of control systems on Mecavision. The systems controller box can be seen in Figure 3. Based on Figure 4. It can be seen that the control system circuit uses two sources of electricity, namely 12V AC power and electricity DC 5V. 12V AC power source serves to supply power to three motor drivers A4988. The DC 5V power source is functioning to supply power to the Raspberry Pi 3.

![Figure 3: Box controller design.](image)

Figure 3. Design of box controller on the system; dimension (A), front view (B), left side view (C), right side view (D).

![Figure 4: Control system design.](image)

Figure 4. Design of the control system in the box controller monitoring system based on mobile mechanism and computer vision.
3.2. Imagery and visualization

Testing a monitoring system based on mobile mechanism and computer vision has been completed by obtaining data from plant sample images. The data is obtained by taking an image from a vertical angle using a camera mounted on a moving platform. The camera will shift when it has finished taking a plant sample image underneath. The projection of image capture is shown in Figure 5.

![Figure 5. Projected plant images data from top view camera.](image1)

From Figure 5 it can be seen that the base part of the plant samples is black. This is considered as the most ideal color to be a background because it will not interfere with the process of taking and processing the data results of plant sample images. Also, these colors can help in distinguishing the objects that are observed and not observed. One example of the capture results on the monitoring system based on mobile mechanism and computer vision with a black background shown in Figure 6 and the sample image data results and file names in a one-time monitoring cycle in a mobile mechanism-based monitoring system and computer vision can be shown in Figure 6.

![Figure 6. Example results of monitoring systems based on mobile mechanism and computer vision and their information.](image2)

3.3. Verification and validation

3.3.1. Verification and validation of performance in the aspect of mobility

Analysis of monitoring systems based on mobile mechanism and computer vision in the aspect of mobility is demonstrated through the presence or absence of the shift in the image result of each plant sample. The shift can be known through a comparison of the image results of each repetition in one plant sample. The comparison is made by measuring the coordinate shift through the extreme point area of the plant sample. There are three stages to get extreme points, that is threshold image, making extreme points and axes in the image, and determination of extreme point coordinates.

After obtaining extreme point values in all four data points of the image, then determine the value of shifting each sample. The determination is done by comparing the two images each repetition on one sample. From the results of the comparison, 45 shift value data were obtained for one point on one sample. The total data in one of the samples is 180 data, or the overall total is 1620 data. That data then averaged and made into the graphs shown in Figure 7 as follows.

The four shift point values in each sample are in the range of 0.006 cm to 0.012 cm. The lowest shift value is in sample 5 for point 1, sample 8 for point 2 and 3, sample 6 for point 4 while the highest shift value is in sample 3 for point 1, sample 1 for point 2, sample 4 for point 3, and sample 2 for point 4. The lower the value of the shift, the results of each image repetition are in a position close to the same, and vice versa.
Figure 7. Graph of the relationship of the sample to the value of the shift.

Based on the results obtained, each sample experiences shifting. Therefore, it is necessary to check the significance statistics of the shift value obtained. T-tests were carried out for knowing whether or not the image has shifted. This experiment used a 95% confidence level ($\alpha = 5\%$) with degrees of freedom 44 so that the T table value of 2.0154 is obtained. If the value of T count is smaller than the T table value then the parameters tested do not have a significant difference, but if the T count value is greater than the T table means the parameter has a significant difference. As for the results from the t-test on the extreme point, shifts are shown in Table 1 as following.

Based on Table 1, it can be seen that all the T counts are less than the T table. This shows that the relationship between two extreme points is not experiencing a statistical shift, but the value is experiencing a shift numerically. Shifts in extreme points are not included in a significant shift so that the paint doesn't experience a shift.

3.3.2. Verification and validation of performance in the aspect of functionality

Image functionality is an effort to obtain image results image so that it can be used at an advanced stage. Data in the form of images must have a good quality to help analyze at an advanced stage. Therefore, image functionality testing is very important to know the quality of the image generated by a monitoring system based on mobile mechanism and computer vision.

Testing the performance of a monitoring system based on mobile mechanism and computer vision in the aspect of image functionality is done by the method Structural Similarity Measure (SSIM). The method works with model changes or differences through structural information of the image. Implementation of this method is done through the attached program code which is run through the Google Collaboratory application. SSIM method has been completed with the results in the form comparison between the results of the image of each repetition in one sample. The data of each sample is then averaged and converted into percent units (%).

The SSIM value for all samples in the range of 89% - 92%. The highest SSIM value found in sample 7 is 91.76% while the lowest value is in sample 5 which is 89.02%. Overall, the results obtained are not worth 100%, this shows that the results of the image are not the same for each repetition. Figure 18 also shows that there are two examples of results SSIM which value are 1 and 0.93. A value of 1 is indicated by two pictures identical or the same while the value of 0.93 does not. But despite the SSIM results, each sample is not identical; the value can still be tolerated because the confidence level used is 90% [15]. Therefore, it can be said that the image of a monitoring system based on mobile mechanism and computer vision-based on aspects of image functionality approaches the same.
4. Conclusions and Future Works
Based on the plant growth monitoring system design at Plant Factory using a camera stereo, two conclusions can be drawn. First, the RoboVision Mobile system can be designed at Plant Factory installations. Based on performance tests on the aspect of mobility, the Mecavision system experiencing a shift numerically but not statistically. As for the performance test on the aspect of image functionality, the Mecavision system produces an image similarity value of 89% to 92% with a confidence level of 90%. The overall performance of the system can be used to monitor plant growth automatically at the plant factory. Broadly speaking, in the future this research will produce a Mobile Mecavision system that can work in following with the position designed and acquires images appropriately to be applied at the Plant Factories

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References
[1] Nugroho A P, Sutiarso L, Okayasu T 2019 Appropriate adaptation of precision agriculture technology in open field cultivation in tropics. IOP Conf. Ser. Earth Environ. Sci. 2019 355 12028
[2] Shibusawa S 2003 Precision Farming Japan Model J. Agric. Inf. Res. 12 125–33
[3] Okayasu T, Nugroho A P, Arita D, Yoshinaga T, Hashimoto Y, Tachiguchi R 2017 Sensing and visualization in agriculture with affordable smart devices Smart Sensors at the IoT Frontier ed Yasuura H, Kyung C M, Liu Y, Lin Y L (Cham: Springer) pp 299-325
[4] Yamori W, Zhang G, Takagaki M, Maruo T 2014 Feasibility Study of Rice Growth in Plant Factories J. Rice Res. 2 119
[5] Nagase K, Shiraki T, Iwasaki H 2016 Plant Factory Solution with Instrumentation and Control Technology Instrum. Control Solut. New Age IoT 62 160
[6] Huang T 1996 Computer vision: Evolution and promise (Geneva: CERN; 19th CERN School of Computing.)
[7] An N, Welch S M, Markelz R J C, Baker R L, Palmer C M, Ta J, Maloof J N, Weinig C 2017 Quantifying time-series of leaf morphology using 2D and 3D photogrammetry methods for high-throughput plant phenotyping Comput. Electron. Agric. 135 222-232
[8] Yeh Y H F, Lai T C, Liu T Y, Liu C C, Chung W C, Lin T Te 2014 An automated growth measurement system for leafy vegetables Biosyst. Eng. 117 43-50
[9] Story D, Kacira M 2015 Design and implementation of a computer vision-guided greenhouse crop diagnostics system Mach. Vis. Appl. 26 495-506
[10] Chen W T, Yeh Y H F, Liu T Y, Lin T Te 2016 An automated and continuous plant weight measurement system for plant factory Front. Plant Sci. 7 392
[11] Wijanarko A, Nugroho A P, Sutiarso L, Okayasu T 2019 Development of mobile RoboVision with stereo camera for automatic crop growth monitoring in plant factory. AIP Conference Proceedings 2019
[12] Nugroho A P, Okayasu T, Horimoto M, Arita D, Hoshi T, Kurosaki H, Yasuba K, Inoue E, Hirai Y, Mitsuoka M, Sutiarso L 2016 Development of a Field Environmental Monitoring Node with Over the Air Update Function Agric. Inf. Res. 25 3 86-95
[13] Rosebrock A 2016 Finding extreme points in contours with OpenCV
[14] Rosebrock A 2014 How-To: Python Compare Two Images
[15] Wang Z, Bovik A C, Sheikh H R, Simoncelli E P 2004 Image quality assessment: From error visibility to structural similarity IEEE Trans. Image Process 13 4 600-612