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Technical Note

Development of Seeding Rate Monitoring System Applicable to a Mechanical Pot-Seeding Machine

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Abstract: In this study, we developed a monitoring system to accurately track the seeding rate and to identify the locations where the mechanical pot-seeding machine failed to sow seeds correctly. The monitoring system employs diverse image processing techniques, including the Hough transform, hue–saturation–value color space conversion, image morphology techniques, and Gaussian blur, to accurately pinpoint the seeding rate and the locations where seeds are missing. To determine the optimal operating conditions for the seeding rate monitoring system, a factorial experiment was conducted by varying the brightness and saturation values of the image data. When the derived optimal operating conditions were applied, the system consistently achieved a 100% seed recognition rate across various seeding conditions. The monitoring system developed in this study has the potential to significantly reduce the labor required for supplementary planting by enabling the real-time identification of locations where seeds were not sown during pot-seeding operations.

Keywords: coated seed; monitoring system; pot-seeding machine; seeding rate

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Citation: Kim, S.-J.; Lee, H.-S.; Hwang, S.-J.; Kim, J.-H.; Jang, M.-K.; Nam, J.-S. Development of Seeding Rate Monitoring System Applicable to a Mechanical Pot-Seeding Machine. *Agriculture* **2023**, *13*, 2000. https://doi.org/10.3390/agriculture13102000

Academic Editors: Myung Hwan Na, Wanhyun Cho and In Seop Na

Received: 12 September 2023
Revised: 10 October 2023
Accepted: 12 October 2023
Published: 15 October 2023

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1. Introduction

Numerous countries worldwide, including developing countries, are encountering aging farming populations and insufficient labor forces owing to industrialization and urbanization [1,2]. The development and utilization of various agricultural machines are required to address these issues [3,4]. In China, India, and Korea, the mechanization rates of seeding and transplanting are 12.6%, 33.8%, and 52.8%, respectively, i.e., relatively lower than the mechanization rates of overall dry-field farming of 63.3%, 40.0%, and 65.2%, respectively [5–7]. The demand for a mechanical pot-seeding machine with higher work efficiency to improve the mechanization rates in seeding and transplanting is consistently growing [8,9]. Mechanical pot-seeding machines can be categorized based on the seeding method into roller-type, vacuum nozzle-type, and flat-plate-type, and their average seeding rates are 77.3%, 94.3%, and 74.0%, respectively [10].

When seeds are not properly sown during mechanical seeding, it necessitates additional manpower to pinpoint the locations where the seeds are missing [11,12]. Therefore, several studies have been conducted on monitoring systems for automatically detecting these locations. Dong et al. [13] developed a monitoring system capable of detecting missing rice seeds using machine vision and reached a detection accuracy of 94.67%. Bai et al. [14] developed a monitoring system for corn seeds and improved the average detection accuracy to 97% by using RGB and hue saturation value (HSV) color space conversions. Gao et al. [15] developed a green onion seed monitoring system with 99% detection accuracy by

using a detection algorithm and applying RGB, HSV, and hue–saturation–lightness color space conversions. Gao et al. [16] developed a deep learning-based corn seed detection system with a residual attention network for minimizing the misrecognition of seeds; the average detection accuracy was 98%. Yan et al. [17] developed a deep-learning model applying "You Only Look Once" Version 5x to identify missing tomato seeds and demonstrated an average detection accuracy of 93%. Taheri-Garavand et al. [18] developed an algorithm based on convolutional neural networks (CNNs) for detecting chickpea seeds, obtaining an average detection accuracy of 94%. Xie et al. [19] developed an algorithm that utilizes Analog-to-Digital Converter signals to detect seeds, targeting maize and mung bean seeds, to solve the problem of recognizing double-overlapping seeds. The average detection accuracies of maize and mung beans were 91% and 83%, respectively. Accordingly, several studies have been conducted on identifying the locations where the seeds are missing, but most have focused on original seeds; in contrast, relatively few studies exist concerning coated seeds. Original seeds are difficult to apply to a mechanical pot-seeding machine owing to their small sizes and irregular shapes. Contrarily, coated seeds are covered with colors, organic substances, and adhesives, allowing them to be processed in a more uniform globular shape. Thus, they are more advantageous in terms of growth and development, as well as in their applicability to a mechanical pot-seeding machine [20,21]. Development efforts are taking place worldwide to improve the seeding accuracy of mechanical pot-seeding machines [22,23].

Given that coated seeds generally possess a spherical shape, a circle detection algorithm can effectively identify these seeds regardless of their varying diameters. This holds true even amidst size differences among the crops. Accordingly, this study developed a seeding rate monitoring system capable of identifying the locations where coated seeds are missing (as seeded by a mechanical pot-seeding machine) and tracking the seeding rate in real time.

2. Materials and Methods

2.1. Structure of a Mechanical Pot-Seeding Machine

Figure 1 depicts the structure of a mechanical pot-seeding machine commonly used in agriculture. A mechanical pot-seeding machine generally consists of a pot tray auto-feeding device, soil feeder, compressing device, seeding device, and covering soil feeder. Some machines are also equipped with a watering device.

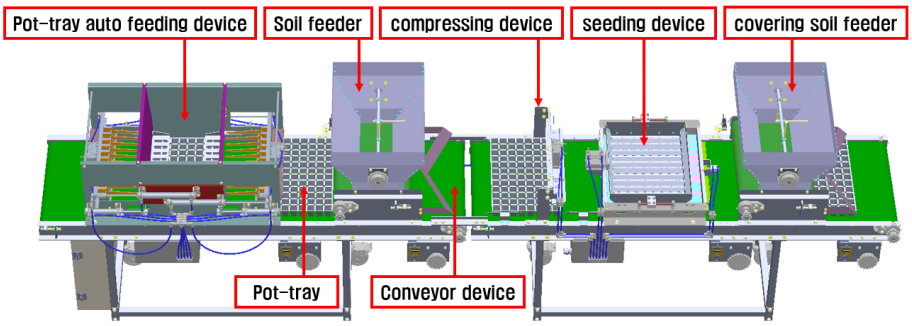


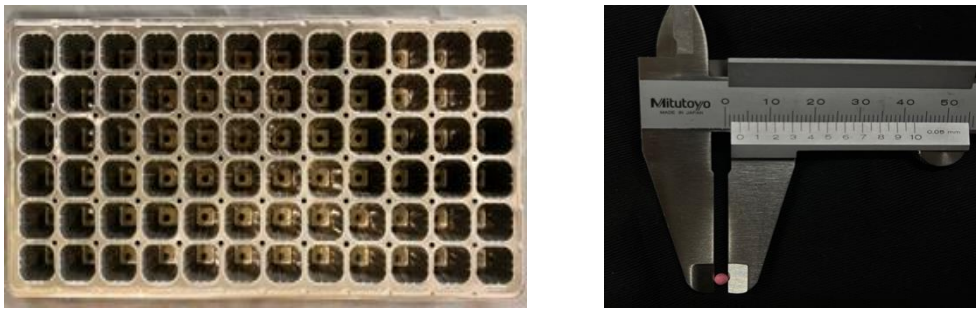
Figure 1. Structure of a mechanical pot-seeding machine.

The seeding process of a mechanical pot-seeding machine is as follows. The seeding process begins as a pot tray is supplied to a conveyor belt one at a time by the pot tray auto-feeding device. A pot tray is filled with soil by the soil feeder. Then, the compressing device compresses the soil to make space in each cell of the biodegradable pot tray for seeding the coated seed. A coated seed is seeded in each cell using the seeding device. Then, seeding is completed by covering the soil using the covering soil feeder [24].

2.2. Seeding Rate Monitoring System

The seeding rate and locations where seeds were not sown can be identified by inspecting whether one coated seed is seeded in each cell of the pot tray. In the seeding process of a mechanical pot-seeding machine, the seeding rate monitoring system must be positioned between the seeding device and covering soil feeder.

The shape and specifications of the coated seed and pot tray used in this study are shown in Figure 2 and Table 1. For the coated seed, a product in which organic substances and adhesives have covered a cabbage seed was used; for the pot tray, a pot tray designed for cabbage seedlings was used.



(**a**) (**b**)

Figure 2. Pot tray and coated seed used in this study: (**a**) pot tray; (**b**) coated seed.

Table 1. Specifications of pot tray and coated seed of this study.

Items		Specifications
Pot tray	Length/width/height (mm) Color	540 × 280 × 45 Glare black
Cell of pot tray	Length/width/height (mm) Number of cells (ea)	35 × 35 × 45 72
Coated seed	Average diameter (mm) Color	3.3 Pink

2.2.1. Overall System Configuration

A commercial mechanical pot-seeding machine uses a conveyor belt to transport pot trays in a continuous process. Therefore, the seeding rate monitoring system was also designed to capture images in real time to identify seeding rates and locations where seeds were not sown as the seeded pot trays continuously moved along the conveyor belt.

A schematic diagram of the seeding rate monitoring system is shown in Figure 3. A motor controller and conveyor are used for transporting the seeded pot trays. The size of the conveyor is 2000 mm × 630 mm × 750 mm (L × W × H). When the pot trays pass through the camera station, the seeding state is photographed. The camera station consists of a camera, LED, photosensor, and an Arduino photosensor attached inside the camera station. Accordingly, a photosensor capable of detecting objects at distances of 630 mm or more was selected.

The locations where seeds were not sown and the seeding rate are deduced from the images of the pot trays after applying image processing techniques (the on-board computer and monitor are used for these deductions). An alarm bell rings to easily notify workers when a seed is missing in one or more cells or when two or more seeds are seeded in one cell. The main components and specifications are presented in Figure 4 and Table 2, respectively.

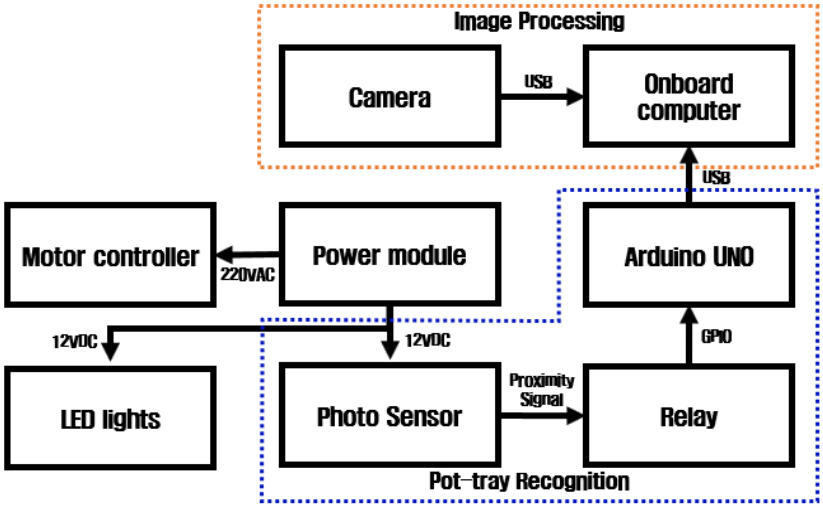


Figure 3. Schematic diagram of seeding rate monitoring system.

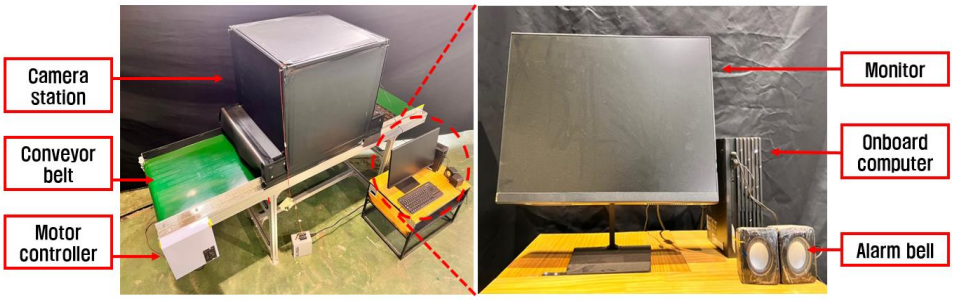


Figure 4. Structure of seeding rate monitoring system.

Table 2. Main components of camera station.

Components	Items	Specifications
Camera	Nation/Company/Model Resolution (pixel) Frames per second (FPS)	Lausanne, Swiss/Logitech/C170 1024 × 768 30
LED	Color temperature (K) Rated voltage (V)	3000–10,000 12
Photosensor	Nation/Company/Model Detection distance (m) Response time (s)	Busan, Korea/Autonics/BTS1M-TDTD-P 1.0 0.001
Arduino	Nation/Company/Model Operating voltage (V) Programming interface	Torino, Italy/Arduino.cc/UNO 5 USB
Motor controller	Nation/Company/Model Rated voltage (V) Range of speed (m/s)	Shanghai, China/Shanghai Qiyi/US-52 220 0.018–0.2

The structure of the camera station is shown in Figure 5. The size of the camera station is 620 mm × 600 mm × 640 mm (L × W × H). An aluminum profile was used for the external frame; the internal space was designed as a dark space blocked from natural and external light sources, which could potentially affect the image data. LED lighting was attached to the top four corners of the camera station to establish a uniform imaging environment. The camera used to capture images was positioned top–center.

The photosensor and Arduino enabled the images to be taken by the camera at the exact moment when the seeded pot tray passed through the center of the camera station.

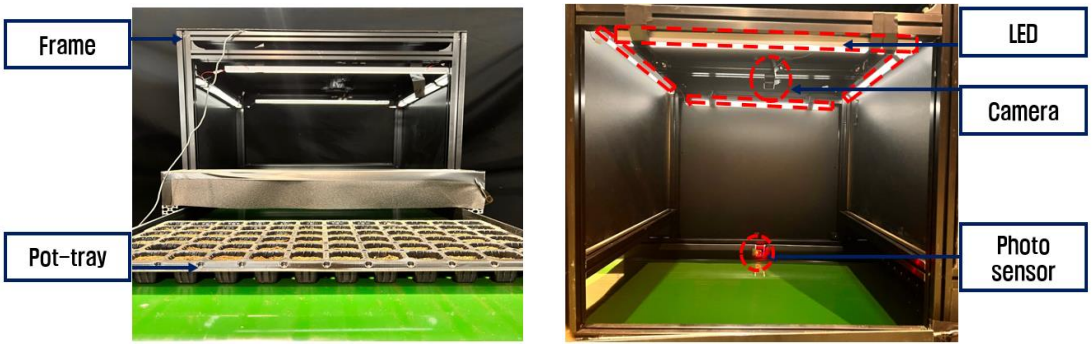


Figure 5. Structure of camera station: (**a**) outside view; (**b**) inside view.

In general, the moving speed of the conveyor belt in a roller-type commercial mechanical pot-seeding machine is 0.02 m/s for the vacuum nozzle type and 0.07 m/s [24,25].

In this study, the range of conveyor belt speeds of the motor controller included the speeds specified above.

2.2.2. Coated Seed Detection Algorithm

Figure 6 depicts a flowchart of the coated seed detection algorithm. In this study, the Hough transform circle detection algorithm is employed to identify coated seeds. Coated seeds exhibit a spherical shape, which appears as a circular shape in the captured images. Therefore, coated seeds can be effectively detected through circle detection of the Hough transform based on OpenCV. In addition, other image processing techniques were applied to the image data, such as brightness and saturation adjustments, a color space conversion, image morphology adjustments for noise removal, and a Gaussian blur. After detecting coated seeds from the processed image data, the locations and numbers of coated seeds were marked in the initially extracted image data. Signals were sent to set off the alarm when abnormal seeding situations occurred.

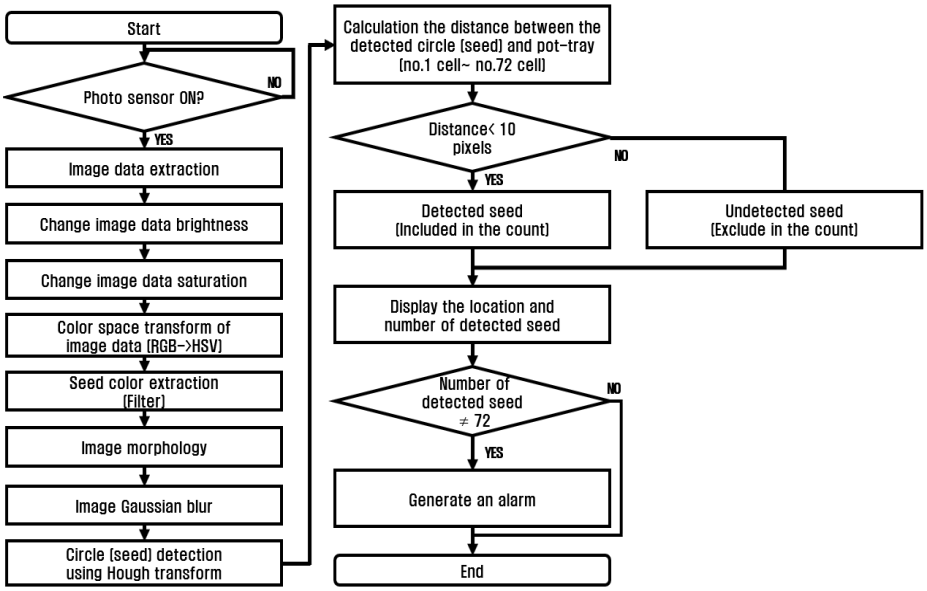


Figure 6. Flowchart of image processing algorithm.

Image Data Extraction

Once the seeded pot tray reached the location of the photosensor inside the camera station, the photosensor generated a trigger. Then, the camera captured the image of the pot tray and the original image data were extracted, as shown in Figure 7.

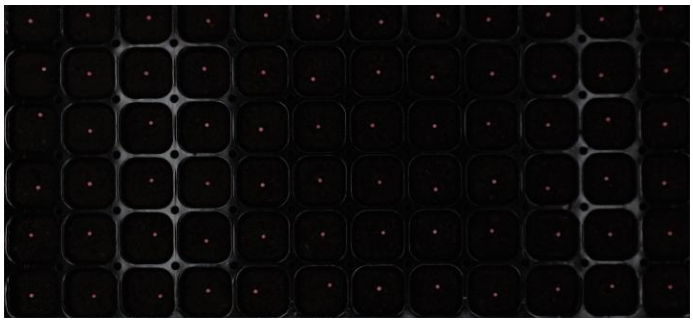


Figure 7. Original image data captured with the camera.

Brightness and Saturation Adjustment

The brightness and saturation values were adjusted to apply image processing to the extracted image data. In general, the brightness and saturation have values between 0 and 255, representing RGB units; any value between −255 and 255 was arbitrarily input within the algorithm to adjust the image data. When the brightness and saturation values are altered, the HSV values of each pixel in the image change accordingly. This subsequently affects the process of extracting the seed's HSV values. Therefore, it is necessary to adjust the brightness and saturation values to match the desired HSV range for seed extraction. Figure 8 depicts the image data as adjusted according to various brightness and saturation values.

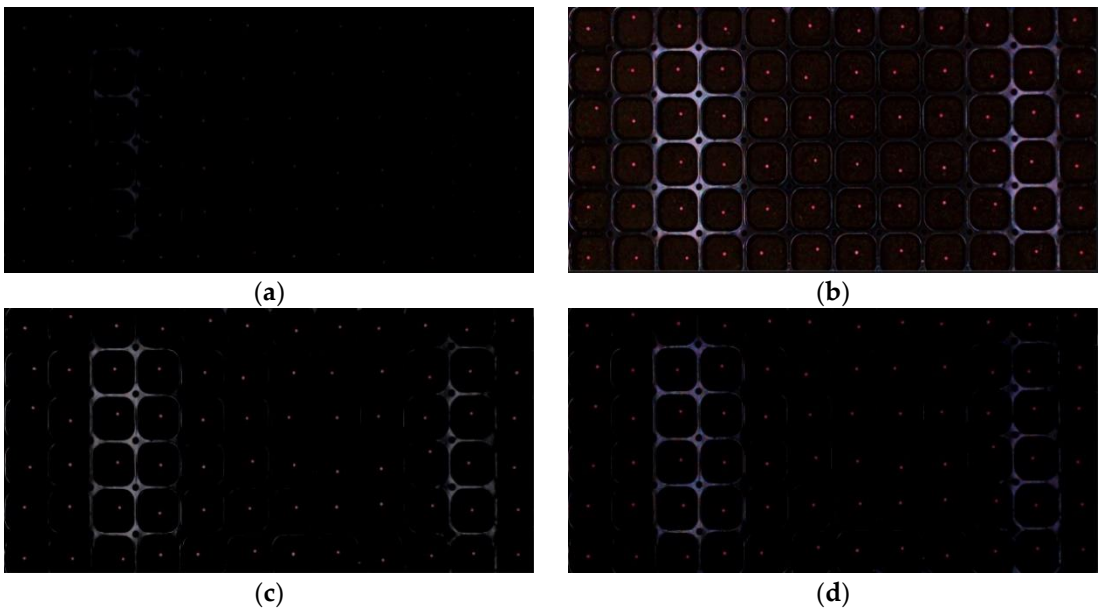
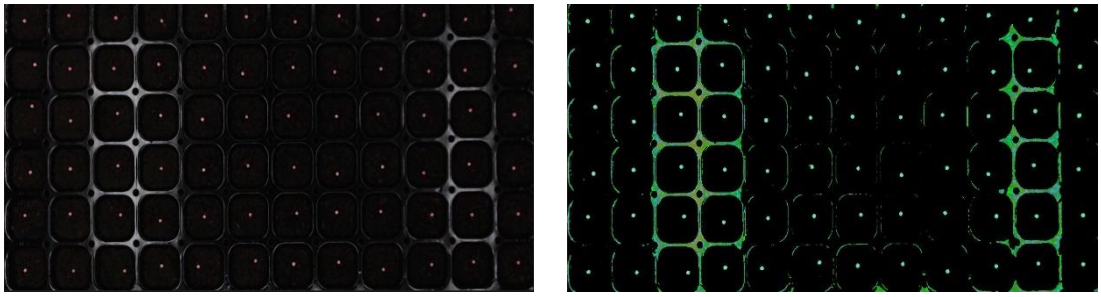


Figure 8. Image data according to brightness and saturation settings: (**a**) brightness −90 and saturation 90; (**b**) brightness 0 and saturation 90; (**c**) brightness −30 and saturation 30; (**d**) brightness −30 and saturation 120.

Color Space Conversion

The HSV color space resembles the color recognition space of humans and is considered to have more outstanding performance than the RGB color space when detecting specific colors [26,27]. In this study, the extracted image data were originally saved in

the RGB form and then were converted to the HSV color space, as shown in Figure 9, to enhance the seed recognition rate (SRR).



(**a**) (**b**)

Figure 9. Image data at the RGB and hue saturation value (HSV) color spaces: (**a**) RGB color space; (**b**) HSV color space.

Color Filtering

The color of the coated seed was extracted via color filtering using HSV thresholds. The ranges of H, S, and V were specified for each color being extracted to only extract the values within the specified range. The extracted colors were expressed as white if within the specified range or black otherwise (Figure 10). In this algorithm, the ranges of H, S, and V for extracting pink-coated seeds were set to 9–172, 160–236, and 38–190, respectively.

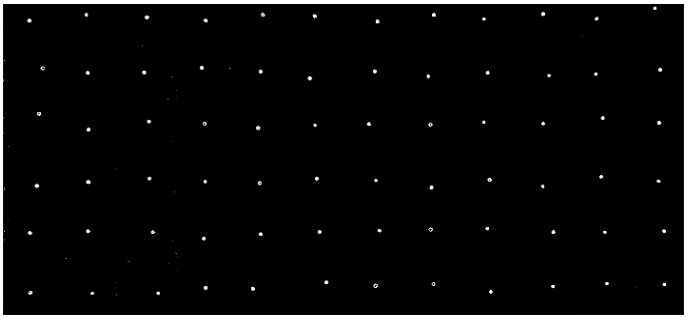


Figure 10. Color-filtered image data.

Noise Removal

Noise must be removed to improve the SRR because the color-filtered image data contained coated seeds as well as other types of noise. In general, the noises are largely classified into two types. The first type is when the light reflected off the soil and pot trays is recognized as pink, which is the color of the coated seed, when extracting colors through color filtering (noise 1 of Figure 11), and white noises are misrecognized as seeds. The second type is when a certain part of a coated seed is not recognized as pink (noise 2 of Figure 11), and black noises are generated in the extracted seed color, which causes a failure in recognizing the seed. Erosion and dilation operations of image morphology were applied to remove such noises. Erosion refers to eroding the parts surrounding the recognized seed color data; during this process, small-sized data are removed, which effectively removes the noise generated by the light reflection of the soil and pot trays. Dilation refers to dilating the size of the recognized seed color data, during which any noises generated in certain parts of the seed could be removed.

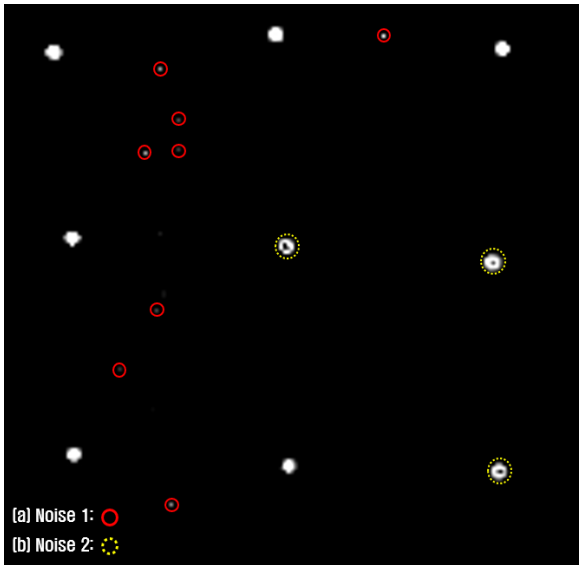


Figure 11. Image data with noise.

In addition, a Gaussian blur was applied for efficient seed detection. A Gaussian blur removes noise from image data by making the image data blurry; in this algorithm, it was applied to minimize the error where the parts that were not circles were recognized as circles.

The image data denoised using the above processes are shown in Figure 12.

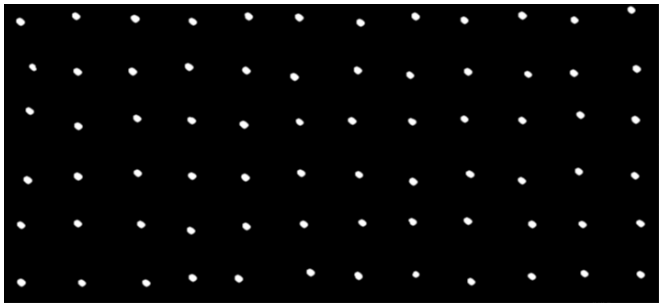


Figure 12. View of denoised image data.

Seed Detection

Seeds were detected by applying the Hough transform circle detection algorithm based on OpenCV to the image data that had undergone the image processing, including noise removal. In general, the center point and radius of a circle are needed for circle detection. As shown in Figure 13, the Hough transform circle detection algorithm involves detecting the shape edge in the image data, drawing a straight line in the direction of the gradient from all points of the edge, accumulating the values, and finding the center point of the circle by extracting the most accumulated point. Circles with different radii are drawn from the center point of the extracted circle; then, the most appropriate circle is detected by comparing them with the detected edge.

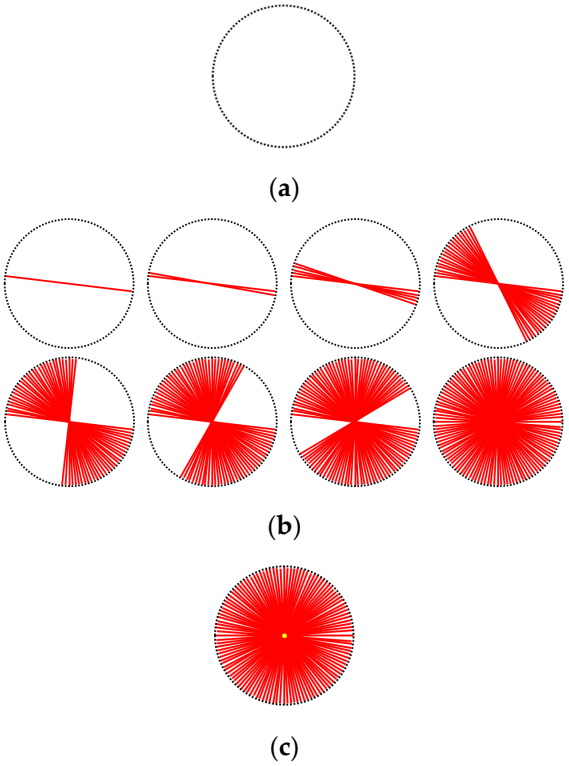


Figure 13. Detection process of center point of circle: (**a**) extracted image edge; (**b**) draw a straight line with the direction of gradient; (**c**) extracted circle center.

The center point of the detected circle and the center point of each cell in the pot tray were extracted, as shown in Figure 14. Then, the distance of a straight line between the center point of a seed and the cell was calculated, as shown in Equation (1).

$$D = \sqrt{x^2 + y^2} \quad (1)$$

where,

D = linear distance between the center of cell and seed (pixels);
x = horizontal distance between the center of cell and seed (pixels); and
y = vertical distance between the center of cell and seed (pixels).

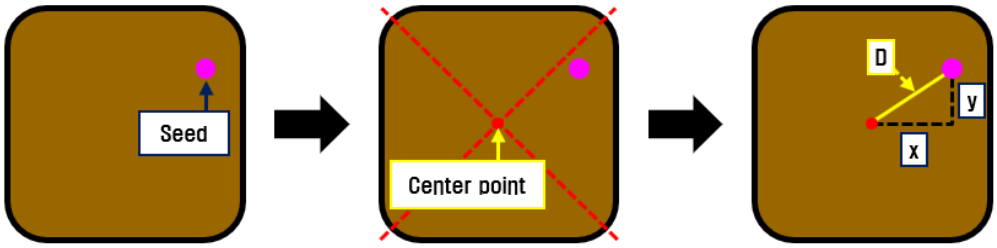


Figure 14. Extraction of linear distance between the center of cell and seed.

As coated seeds are seeded toward the center of a pot tray cell, the root growth becomes stronger during germination [9]. Therefore, if a coated seed is seeded too far from the center point of a cell, it will not be included in the number of detected seeds. When a pixel is converted to a length, one pixel is equal to 0.4 mm. As the size of a pot tray cell used in this experiment was 35 mm × 35 mm, it was determined that a coated seed was seeded excessively far from the center point of a cell if the distance from the cell's center

point to the seed exceeded 50 pixels (20 mm). Thus, a coated seed was included in the number of detected seeds, and it was determined that a coated seed was properly seeded only if the distance between the cell's center point and the coated seed was 50 pixels or less. In Figure 15, the numbers and locations of properly seeded seeds are marked in the initially extracted image data. The number of detected seeds is marked as a number at the top-left of the image data, and the locations of seeds are marked with squares. If the total number of detected seeds is less than the total number of cells in the pot tray (72) or if multiple seeds are seeded in one cell, the alarm goes off to notify about the locations where seeds were not sown. The original and image-processed data are saved in the internal storage space of the on-board computer in chronological order.

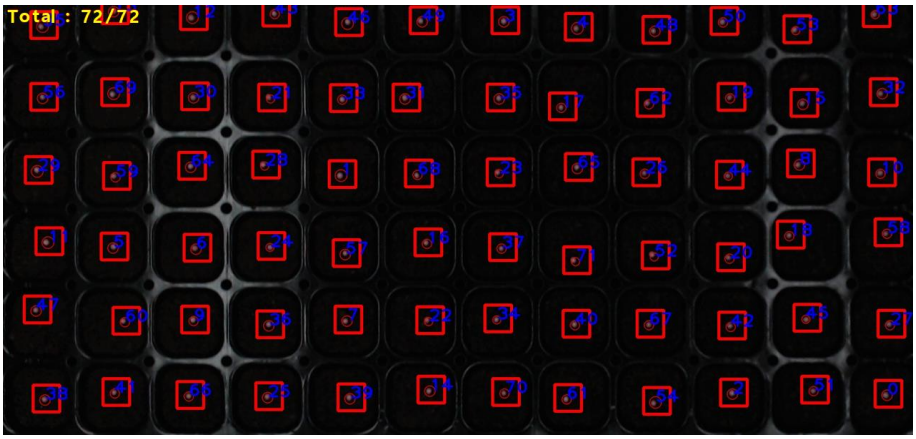


Figure 15. Display of the locations and number of detected seeds.

2.3. Factorial Experiment for Deducing the Optimal Operation Conditions and Verification

In the coated seed detection algorithm, the brightness and saturation of the image data have a significant impact on the SRR. These values were arbitrarily adjusted, and a factorial experiment was conducted to find the optimal brightness and saturation values appropriate for coated seeds. Seeds may not be detected if the brightness and saturation values are excessively high or low. A preliminary experiment was used to deduce the ranges of brightness (−90–0) and saturation (30–120) values for detecting seeds. The factorial experiment was conducted by dividing the brightness and saturation values within the deduced ranges (brightness: −90, −60, −30, 0, saturation: 0, 60, 90, 120). The factorial experiment used a pot tray in which one coated seed was seeded in all cells. The speed of the conveyor belt was set to 0.02 m/s and 0.07 m/s, which are the typical speeds of a commercial mechanical seeding machine. Then, the brightness and saturation values demonstrating the best SRR were deduced for each speed. In addition, the ANOVA analysis was conducted to assess the impact of brightness and saturation on SRR and their reciprocal action.

Afterward, to verify the selected optimal operation conditions, the SRRs of the seeding rate monitoring system were evaluated for various seeding states. The following three states that may occur when seeding with a mechanical seeding machine were considered (Figure 16):

(a) State 1: every cell in the pot tray is seeded with a single coated seed (seeding rate = 100%);
(b) State 2: one or more cells are empty of coated seed without any overlap (seeding rate < 100%);
(c) State 3: one or more cells are filled with two coated seeds (overlap).

To create State 2, coated seeds were removed from cells arbitrarily selected from State 1. For State 3, two coated seeds were inserted after arbitrarily selecting cells of the pot tray. The SRR was deduced from the optimal operation conditions selected based on the three

different states applied for each conveyor belt speed (0.02 m/s and 0.07 m/s). Additionally, measurements were taken three times in each state.



(**a**)



(**b**)



(**c**)

Figure 16. Seeding states used in the verification test: (**a**) State 1 Every cell in the pot tray is seeded with a single coated seed (seeding rate = 100%); (**b**) State 2 One or more cells are empty of coated seed without any overlap (seeding rate < 100%); (**c**) State 3 One or more cells are filled with two coated seeds (overlap). The yellow circle indicates the location of coated seeds. In state (**c**), two coated seeds were filled, as shown by the red square.

3. Results and Discussion

3.1. Factorial Experiment Results of the Seeding Rate Monitoring System

The SRR is calculated as shown in Equation (2). The SRR is 100% when the monitoring system recognizes all the seeds seeded in the pot tray. As SRR approaches 100%, the performance of the seeding rate monitoring system becomes better.

$$\mathrm{SRR} = (DS/WS) \times 100\% \quad (2)$$

where

SRR = seed recognition rate (%);
DS = number of detected seeds (ea); and
WS = number of seeds sowed in the pot tray (ea).

Tables 3 and 4 present the results from deducing the SRR of the monitoring system by changing the brightness and saturation in four levels at the conveyor belt speeds of 0.02 m/s and 0.07 m/s for the pot tray with a single coated seed seeded in all cells. The measurements were taken three times under the same conditions.

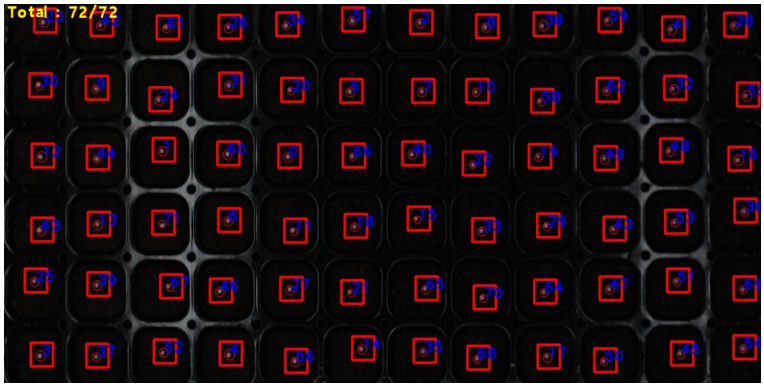
Table 3. Seed recognition rates at conveyor belt speed of 0.02 m/s.

Items		Seed Recognition Rate (%)		
Brightness	**Saturation**	**Test 1**	**Test 2**	**Test 3**
−90	30	0	0	0
	60	0	0	0
	90	15	21	15
	120	31	35	31
−60	30	0	0	0
	60	6	10	13
	90	96	89	93
	120	100	100	100
−30	30	0	0	0
	60	53	50	46
	90	100	100	100
	120	100	100	100
0	30	7	6	13
	60	76	78	81
	90	100	100	100
	120	0	0	0

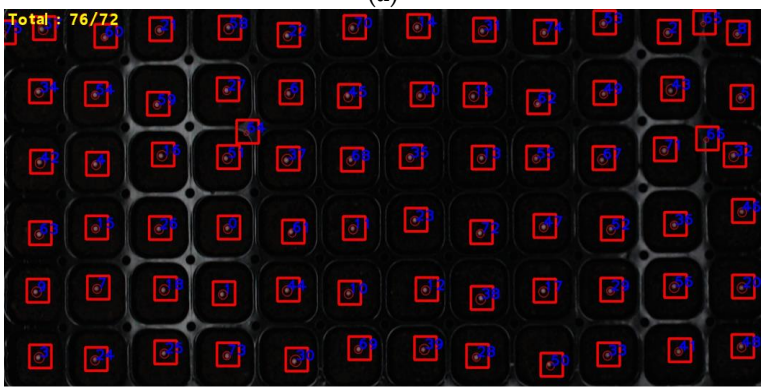
Table 4. Seed recognition rate at conveyor belt speed of 0.07 m/s.

Items		Seed Recognition Rate (%)		
Brightness	**Saturation**	**Test 1**	**Test 2**	**Test 3**
−90	30	0	0	0
	60	0	0	0
	90	0	0	0
	120	0	0	0
−60	30	0	0	0
	60	31	36	43
	90	42	54	58
	120	13	17	10
−30	30	56	50	65
	60	99	100	100
	90	100	100	100
	120	51	60	65
0	30	99	96	99
	60	100	100	100
	90	100	100	100
	120	0	0	0

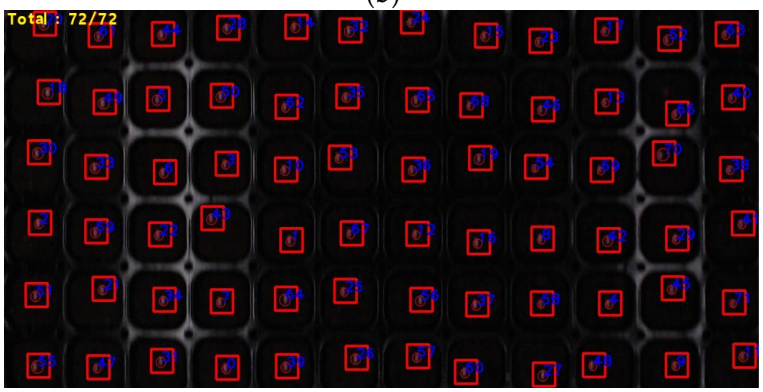
When the conveyor belt speed is 0.02 m/s, the SRR is 100% when the brightness and saturation are −60 and 120, −30 and 90, −30 and 120, and 0 and 90, respectively. In contrast, when the conveyor belt speed is 0.07 m/s, the SRR is 100% when brightness and saturation are −30 and 90, 0 and 60, and 0 and 90, respectively. At both conveyor belt speeds, the SRR is 100% when the brightness and saturation are −30 and 90 and 0 and 90, respectively (Figure 17).



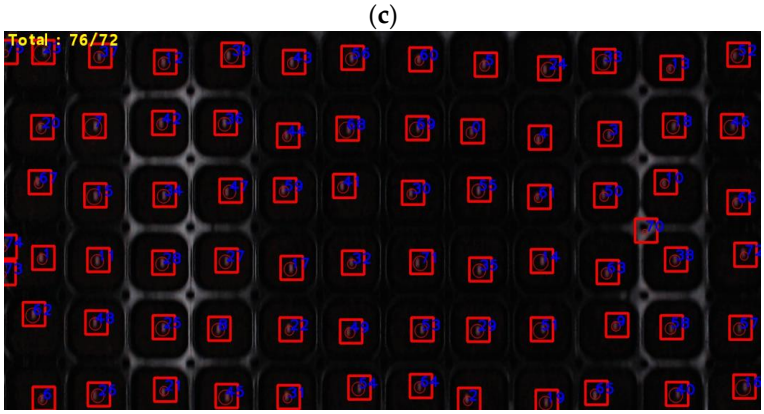
(**a**)



(**b**)



(**c**)



(**d**)

Figure 17. Conditions for 100% of seed recognition rate: (**a**) brightness –30 and saturation 90 (conveyor belt speed 0.02 m/s); (**b**) brightness 0 and saturation 90 (conveyor belt speed 0.02 m/s); (**c**) brightness –30 and saturation 90 (Conveyor belt speed 0.07 m/s); (**d**) brightness 0 and saturation 90 (conveyor belt speed 0.07 m/s).

When brightness and saturation are 0 and 90, respectively, the SRR is 100%, but certain parts that are not seeds are misrecognized as seeds (Figure 18). This is owing to insufficient filtering of noise because of the intense light reflection off of the soil and pot tray.

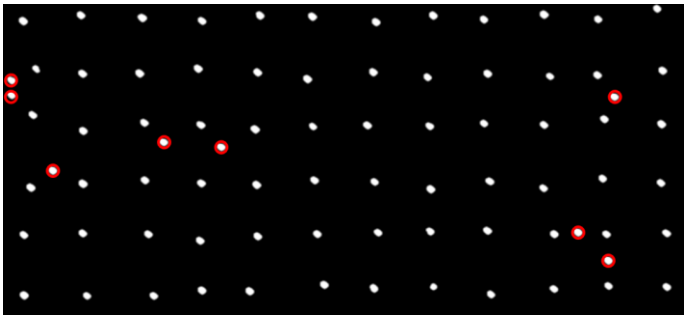


Figure 18. Misrecognition at brightness 0 and saturation 90. The red circle indicates the misrecognized seeds.

To analyze the SRR tendencies in the seeding rate monitoring system with respect to the brightness and saturation, the average of seed recognition (ASR) was deduced using Equation (3). The results are presented in Table 5.

$$\text{ASR} = S/N \tag{3}$$

where

ASR = average SR at a specific brightness or saturation condition (%);
S = sum of SRs at a specific brightness or saturation condition (%); and
N = number of experiments at a specific brightness or saturation condition.

Table 5. Average of seed recognition (ASR) according to operating conditions.

Items		ASR (%)	
		Conveyor Belt Speed	
		0.02 m/s	0.07 m/s
Brightness	−90	12	0
	−60	51	25
	−30	62	79
	0	47	75
Saturation	30	2	39
	60	34	59
	90	77	63
	120	58	18

The highest SRR appears when the brightness value is −30, regardless of the conveyor belt speed. The seed SRR increases as the brightness increases from −90 to −30 but decreases again from 0. The saturation value also exhibits a similar tendency. The highest SRR appears when the saturation value is 90, regardless of the conveyor belt speed. The SRR increases as the saturation increases from 30 to 90 but decreases again from 120. This is attributable to how brightness and saturation affect the hue (H), saturation (S), and value (V) of the image data. The SRR increases at specific brightness and saturation values because the H, S, and V values of the image data become closer to such values set during the color extraction, whereas the R decreases otherwise. In addition, the seeding rate

monitoring system cannot recognize any seeds if the H, S, and V values of the image data are outside the set range. Therefore, the H, S, and V values of the image data are closest to the set range when brightness is −30 and saturation is 90.

Therefore, the conditions under a brightness of −30 and saturation of 90, which demonstrated an SRR of 100% for both conveyor belt speeds and no misrecognitions, were deemed as the most optimal operation conditions for the seeding rate monitoring system.

3.2. Effect Analysis of Brightness and Saturation through Statistical Analysis

A two-way analysis of variance was performed to analyze the effects of the brightness and saturation on the SRR of the seeding rate monitoring system; the results are presented in Table 6. The SRR of the seeding rate monitoring system was set as a dependent variable, and the brightness and saturation values were set as the independent variables. The analysis results show that both brightness and saturation have statistically significant effects on the SRR of a seeding rate monitoring system at the significance level of 5%. In addition, the brightness and saturation are intercorrelated at the significance level of 5%. Therefore, it can be inferred that selecting optimal brightness and saturation values has a substantial impact on the performance of the seeding rate monitoring system.

Table 6. Result of two-way analysis of variance (ANOVA).

Values	SS	Degrees of Freedom (DF)	Mean Square	F-Value (*p*)	*p*-Value	Partial eta Square
Brightness	58,873.12	3	19,624.37	37.93	0.00	0.59
Saturation	30,712.62	3	10,237.54	19.79	0.00	0.43
Brightness × Saturation	42,326.09	9	4702.90	9.09	0.00	0.51

3.3. Verification of Optimal Operation Conditions of the Seeding Rate Monitoring System

The results from deducing the SRR for three seeding states at a brightness of −30 and saturation of 90 (the optimal operation conditions) are shown in Table 7 and Figure 19. As noted above, the measurements were taken three times under the same seeding states.

Table 7. Verification test results for each seeding state.

Items	Seeding State								
	State 1			State 2			State 3		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Detected seeds/Sowed seeds	72/72	72/72	72/72	56/56	59/59	64/64	72/72	72/72	72/72
Seed recognitionrate (%)	100	100	100	100	100	100	100	100	100

State 1: every cell in the pot tray is seeded with a single coated seed (seeding rate = 100%); **State 2**: one or more cells are empty of coated seed without any overlap (seeding rate < 100%); **State 3**: one or more cells are filled with two coated seeds (overlap).

In State 2, 16, 13, and 8, seeds were arbitrarily set to be missing in the cells of the pot tray for the three trials, respectively; in State 3, two seeds were seeded in each cell of the sixth row to seed a total of 72 seeds. According to the results, the SRR is 100% in all seeding states regardless of the conveyor belt speed, and the alarm bell works properly when seeds are missing or overlap seeding.

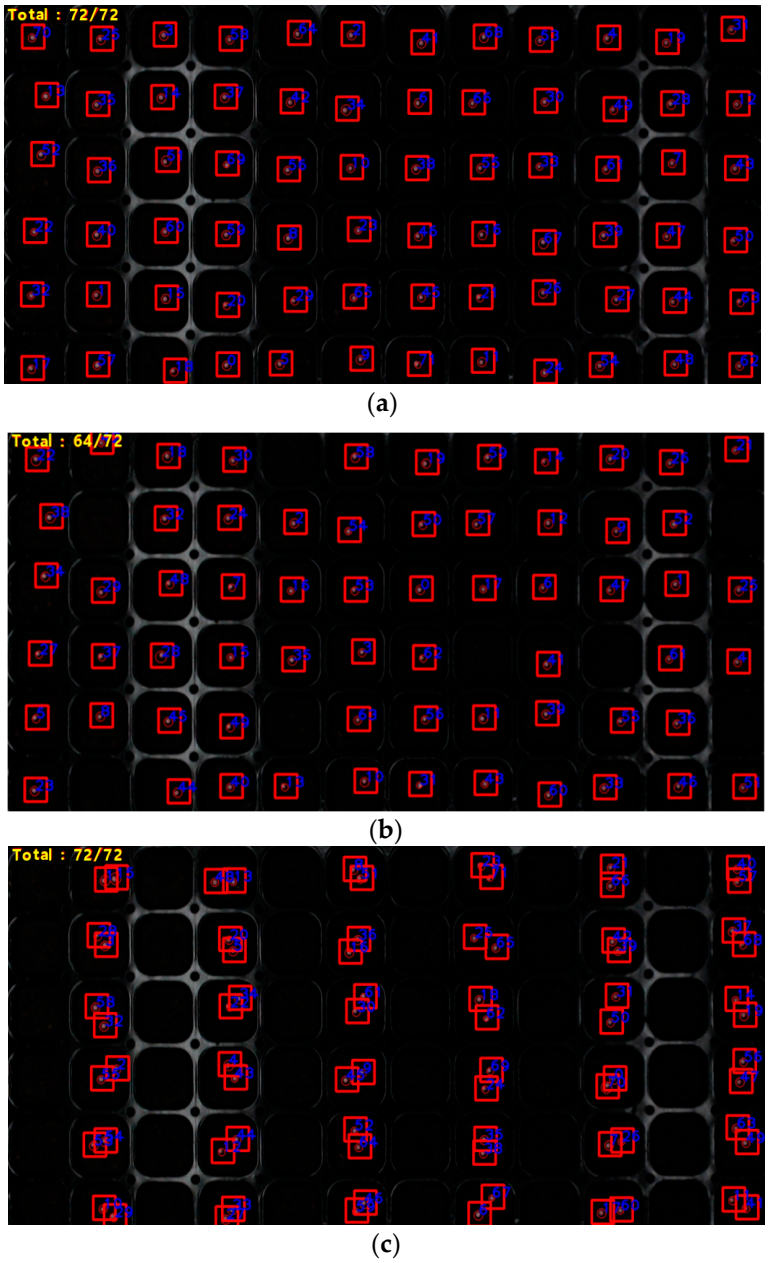


Figure 19. Verification test result according to seeding states: (**a**) State 1; (**b**) State 2; (**c**) State 3.

In previous related studies, the SRRs of monitoring systems developed for rice, corn, green onion, tomato and chickpea were 94.67%, 97.50%, 99%, 93%, and 94%, respectively [13–18]. Furthermore, in related studies [19], when detecting overlapping corn and mung bean seeds, accuracies of 91% and 83% were shown. These values indicate that the proposed seeding rate monitoring system has a relatively high SRR and is applicable to various seeding conditions. Furthermore, in related studies, an additional algorithm is required to identify whether the detected seeds are genuine or not due to the irregular shape of the seeds. However, the monitoring system developed in this study, which targets coated seeds, does not require such an algorithm, enabling faster and simpler seed detection. Therefore, the seeding rate monitoring system developed in this study is capable of deducing the seeding rate and identifying locations where seeds were not sown in a commercial mechanical seeding machine.

4. Conclusions

This study developed a seeding rate monitoring system capable of detecting coated seeds seeded in a pot tray and locations where seeds were not sown. The seeding rate monitoring system consisted of a camera station, on-board computer, monitor, alarm bell, conveyor, and motor controller and is based on the structure of a commercial mechanical pot-seeding machine. Diverse image processing techniques such as changing brightness and saturation of the image data, HSV color space conversion, image morphology adjustments, a Gaussian blur, and Hough transform were applied to detect coated seeds from the image data of the seeded pot tray. To identify the optimal operation conditions for the seeding rate monitoring system, the SRR was measured according to the brightness and saturation values of the image data. The experimental results showed that brightness of −30 and saturation of 90 achieved an SRR of 100% at both 0.02 m/s and 0.07 m/s conveyor belt speeds in the commercial mechanical pot-seeding machine; thus, they were the optimal operation conditions. Additionally, the optimal operation conditions were further verified by conducting an experiment on various seeding states potentially occurring in an actual mechanical pot-seeding machine. The seeding rate monitoring system applying the optimal operation conditions demonstrated a 100% SRR in all seeding states. Thus, it is applicable to commercial mechanical pot-seeding machines.

The seeding rate monitoring system developed in this study can be universally applied regardless of the characteristics of the pot tray and coated seeds. If the pot tray and coated seed type are changed, only the variables in the coated seed detection algorithm need to be changed. This study was conducted using pink-coated seeds with an average diameter of 3.3 mm and a 72-cell pot tray. Therefore, in order to universally use the monitoring system developed in this study, additional experiments will be conducted to set the different types of pot trays and coated seeds with various colors and diameters in future research.

Author Contributions: Conceptualization, S.-J.K.; methodology, H.-S.L.; software, S.-J.K., H.-S.L. and S.-J.H.; validation, S.-J.K., J.-H.K. and M.-K.J.; formal analysis, H.-S.L. and J.-S.N.; investigation, S.-J.K. and S.-J.H.; resources, H.-S.L.; data curation, S.-J.K. and H.-S.L.; writing, original draft preparation, S.-J.K. and H.-S.L.; writing, review and editing, S.-J.K., S.-J.H. and J.-S.N.; visualization, S.-J.K. and H.-S.L.; supervision, J.-H.K., M.-K.J. and J.-S.N.; project administration, S.-J.K., J.-H.K. and M.-K.J.; funding acquisition, S.-J.H. and J.-S.N. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Korea Institute of Planning and Evaluation for Technology in Food, Agriculture and Forestry (IPET) through Machinery Mechanization Technology Development Program for Field Farming Program, funded by Ministry of Agriculture, Food and Rural Affairs (MAFRA) (RS-2023-00235957).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The data are not publicly available due to privacy.

Conflicts of Interest: The authors have no conflict of interest to declare.

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