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Development of an Automatic Cherry Sorting System Using HSL Color Model

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***Abstract*— The sorting operations of cherry are conducted manually by cherry farmers; however, they require skillful workers to examine each fruit, and evaluation is subject to variation. This study analyzed the performance of an automatic cherry sorting system. The key to sorting cherries is to sort the fruits accurately without producing damage, along with quick size estimation and grade identification. An image analysis system using the hue saturation lightness (HSL) color model to identify the grade of cherries was implemented. Size was estimated by the equator diameter of the fruit, and grade was determined by the percentage of colored area on the surface of the fruit. A prototype system for automatic cherry sorting into three grades was developed. A second version of the prototype was developed to include size estimation. In both prototypes, an air eject mechanism with individual collection bins were prepared for a non-invasive handling of the fruits. A stable accuracy of 72.4% for size estimation and 82.5% for grade identification were achieved. The findings favor the use of automatic systems for the sorting of cherries according to fruit grade in combination with fruit size.**

***Keywords*— image processing, cherry, grade, size, HSL color model**

I. Introduction

Since the last decade, Japan has been the twenty sixth largest producer of cherries in the world, topped in the first three places by Turkey, the United States of America, and Chile [1]. In Japan, the Yamanashi Prefecture ranks third for cherry yield amount, after the Yamagata Prefecture and Hokkaido [2]. Consumers place a high value on aesthetics, which includes consistent fruit color and size, vivid color, shiny skin devoid of flaws, and stems that retain their fresh, vibrant green color without browning or discoloring [3]. The size of cherries is estimated by the equator diameter of the fruit. In addition, the grade is determined by the percentage of coloring area on the surface of the fruit. For example, in Yamagata Prefecture, there are six sizes (M, L, 2L, 3L, 4L, and 5L) and three grades (Marushu, Shu, and Tokushu) [4] to commercialize cherries.

Fig. 1. Example of a reference plate for manual size sorting of cherries.

The grading of cherries is performed visually, by checking each fruit for scratches, molds, bruises, or any other imperfections. The sorting of cherries is conducted manually before shipping, measured for size using a reference plate shown in Fig. 1, while simultaneously inspecting for defects and fragile stems [5]. An indicator of the expanding relevance of cherries in the horticulture and food industry is its increase of value in the market, overall production and total harvested area [6]. The lack of skilled workers and the variability in evaluation, due to the decrease in number of cherry farmers, have risen the necessity for solutions in sorting automation.

Different methods have been used to analyze the color composition of the surface of cherries for sorting and classification. An Artificial Neural Network (ANN) combined with image processing techniques was used to determine the color parameters l^*, a^*, b^* of cherries during the different stages of ripening [7]. Another approach for the ripening stage is the use of the Red Green Blue (RGB) values obtained through a series of image processing algorithms [8], in which cherries were segmented from images using the Canny algorithm to detect the borders of the cherry, the Hough transformation to detect the circular shape of the cherry, and finally obtaining the RGB values of the final image, with a processing time of 4.3048s per image. A YOLOv5 model was trained to detect the different qualities of diverse cherries [9]. The results show that four different qualities of cherries were distinguished with an accuracy rate of 99.6% in the 20th epoch from an image dataset extracted using the flooding filling algorithm. Even though automated quality and grade identification has also been studied for commercializing cherries [10], methods corresponding the Japanese standards have not been established yet.

Previous studies about automatic fruit sorting systems have shown positive results [11]-[13]. Color and defects were inspected on cherry tomatoes while they were sorted into designated quality groups [11]. Results show a grade accuracy of 80% with a sorting rate of 360kg per hour using a novel mechanical sorting unit. Mango fruits were sorted according to their maturity level using four solenoid valves with their respective drivers [12]. A paddle wheel feeder actuator was designed for automatic sorting of date fruits based on their ripeness, divided into three grades, obtaining results similar to that performed by humans [13].

In this study, cherries are labeled by image processing using the hue, saturation, lightness (HSL) color model for the purpose of visualizing the size estimation and grade identification. Both parameters, size and grade, will follow the Yamagata Prefecture's shipping standards for cherries [4]. Furthermore, two versions of a prototype system are built to automate the cherry sorting process and to implement the size and grade labeling.

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II. METHODOLOGY

A. Dataset Acquisition

In a previous study [14], cherries were sampled for an image dataset consisting of the percentages of varieties of Sato Nishiki (77%), Benishuho (18%), and Nanyo (6%). Moreover, the total dataset was also divided into the grades, following the standard grade system in Japan, as follows: Tokushu (Excellent), 30%; Shu (Very Good), 36%; Marushu (Good), 13%; Hanedashi (Not good), 11%; and Suteru (Discard), 10%. This study uses the same database for the realization of the image processing methodology. The grades are determined according to the respective ratio of red coloration present on the surface of each cherry, utilizing the following scale: Tokushu, 70% or more; Shu, 60% or more; Marushu, 50% or more; Hanedashi, less than 50%; and cherries with defects are considered Discard. Images for the dataset were previously acquired using a constructed device for collecting images of different cherries under the same position and lightning conditions from four different angles (top, down, left, right). From a total of 1,839 cherries, 97% of the total were sampled successfully. Histograms of the corresponding HSL values of each variety and grade were prepared and analyzed for grade identification of cherries, yet data were targeted for the Sato Nishiki variety as being the largest variety in the dataset. An image matrix for the five grades of the Sato Nishiki variety is shown in Fig. 2.

The acquired images revealed that there is a large difference in the coloration of fruits within the same grade. Reasons for this include the sorting of surplus fruit into lower grades when packed in boxes for shipping, and damage and ripening during the period between fruit collection at the farms and image acquisition. The images of fruits with high percentage of coloring within the Tokushu grade were obtained from a survey conducted by the National Agriculture and Food Research Organization (NARO) [15]. Therefore, a human expert visually examined the coloring percentage and excluded images that deviated significantly from each grade. These data were used as the representative images for each grade.

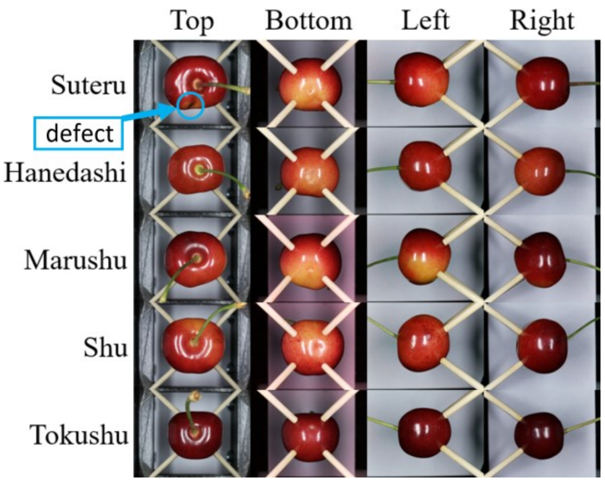

Fig. 2. Collected images of the Sato Nishiki variety having five different grades.

B. Sorting System

The performance of the two sorting systems (assigned the names of "Unit 1" for the first version and "Unit 2" for the upgraded version) was evaluated. The general appearance of both prototype sorting systems are shown in Fig. 3. Due to the brief distribution period of cherries [16], pseudo-fruits were used to verify the operation of the systems. The pseudo-fruits were produced by embedding weights into artificial cherries.

The cherries are transported in a conveyor belt, passed through an image acquisition area, and are finally ejected by air to the target collection bin. The length of the conveyor belt is 1.3m for Unit 1 and 2m for Unit 2, respectively. In both units, cherries are analyzed in real-time inside a chamber with three cameras (upper, left, and right views) for image analysis of the fruits while being transported. The cameras are a Brio C1000eR webcam with direct USB connection to a PC for real-time image processing, and the angle of view and focus can be configured on the PC. The cameras are equipped with tape LED strings for indirect lighting to ensure uniform illumination of the 270mm long image acquisition area.

The PC constantly detects the fruit in the three-camera images and identifies the grade when the fruit passes through the center of the angle of view. Therefore, real-time processing for the sequence of three images is required, drastically increasing the execution time. However, reduction of time is achieved by acquiring images from the camera in 384 x 216 pixels, and using multi-threading to process the images in parallel. ON/OFF control of solenoid valves is performed in a separate thread to shorten the cycle time of the main thread.

Based on the identification results, the number of the solenoid valve and the timing of air jetting are determined, and scheduling is performed. Each air solenoid valve is controlled by a USB relay, and the cameras and USB relays are operated from a PC. By controlling the USB relay according to the schedule, air is sprayed when the fruit passes the specified solenoid valve, and the fruit is ejected to the target collection bin. The air jet timing is based on the time from when the fruit passes through the center of the image until it reaches the air nozzle. Air pressure is adjusted using a regulator to prevent fruits from colliding with the walls of the collection bin or other fruits.

The sorting in Unit 1 is performed for three grades: Tokushu, Shu, and Others. A total of three collection bins were placed alongside the conveyor belt. Hanedashi and Suteru cherries are classified as Others. Fruit sorting in Unit 2 is carried out for the grades Tokushu, Shu, and Marushu. Additionally, size estimation is implemented. Each grade is further divided according to size into medium or smaller (M), large (L), extra-large or bigger (LL). An additional Others bin is also included. A total of ten collection bins were placed alongside a conveyor belt to store the sorted cherries. The collection bins were increased in capacity and a door was added in Unit 2 for farther manual collection.

A distance measuring module is used to determine the height from the surface of the cherries to the edge of the collection bin in Unit 2, denoted as the free capacity of the bin. An ESP32-WROOM-32E microcontroller is used to control status LEDs for capacity indication, and, taking scalability into account, can be connected to a PC, smartphone, or linked through Wi-Fi.

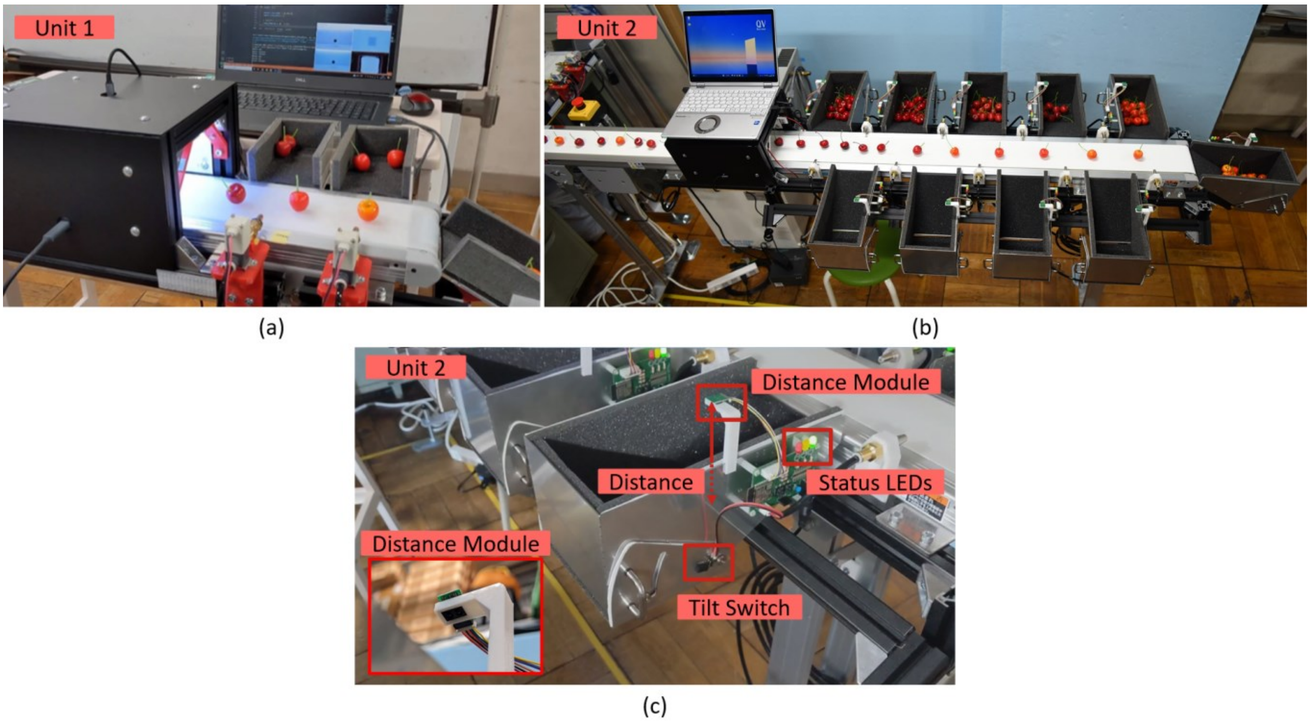

Fig. 3. Prototypes of automatic cherry sorting systems. Unit 1 (a), Unit 2 (b), and capacity indicators and sensors for Unit 2 (c).

C. Grade Identification

Pixels from the fruit's surface area from the most representative images of all the grades were acquired, and two-dimensional histograms of hue-lightness, hue-saturation, and saturation-lightness for each grade were prepared for analysis. The HSL value range of the coloring area was set by focusing on the distribution of pixels for each grade in the two-dimensional histogram of saturation-lightness.

Although the HSL model is an excellent representation of how humans perceive colors, it is less uniform and the color manipulation becomes complex for image processing compared to its HSV (hue, saturation, value) relative [17]. HSV color masks with set value ranges for each grade were defined to identify the grade of the cherries. The area of pixels within each value range are compared, and the grade with the largest similarity is designated as the grade of the fruit. Fig.4 exhibits the resulting images obtained from each mask, while Table I shows the HSV values of each range of colors. By comparing the areas, it is possible to identify the grade of the cherry fruits.

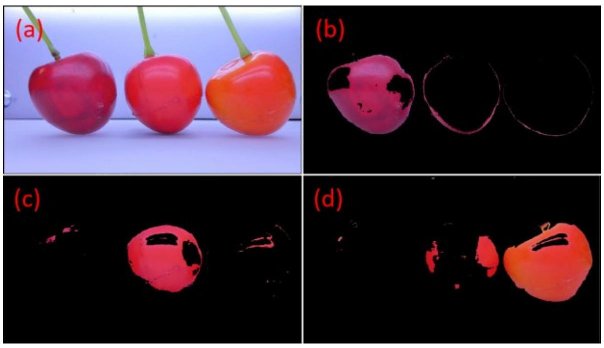

Fig. 4. Defined HSV masks from original image of pseudo-fruits (a): Tokushu (b), Shu (c), and Hanedashi (d).

TABLE I. CHERRY HSV MASK VALUES

	Tokushu	Shu	Hanedashi
H	152~170	160~178	0~10, 177~179
S	120~255	168~255	0~255
V	0~200	190~255	0~255

D. Size Estimation

To obtain an estimate of the cherry size, first the outline of the cherry area was obtained from the resulting HSV mask in the section C of this chapter, then an equatorial line was drawn through the center of the mask area, thus converting the length of the resulting equatorial line between the ends of the mask into the diameter of the fruit. Furthermore, to obtain the direction of the cherry, the stem root coordinate was obtained by creating a new HSV mask to detect the green color from the camera input, tracing the contour of the area of the mask, obtaining the coordinates of this trace, and finally calculating the shortest distance from the center of the equatorial line to the coordinates of the stem. The HSV values utilized for the detection of stems are shown in Table II. This resulting distance is used to calculate the fruit stem root, otherwise, if the value is zero or excessive, it is considered that there is no stem present on the fruit.

The coordinates of the center of the fruit surface area and the coordinates of the fruit stem root are connected by a straight line, and therefore taken as the orientation of the fruit. In addition, the length of the equatorial diameter is obtained in the direction perpendicular to the direction of the fruit, passing through the center coordinate of the surface area of the fruit. The average of the equatorial diameters, acquired by the upper, left and right cameras, is used as the final equatorial diameter of the target fruit for size estimation. Table III shows the values used for size estimation, in accordance with the standards the Yamagata Prefecture, using the final equatorial diameter d^* for further classification, and Fig. 5 shows how the algorithm draws the resulting diameter lines according to the estimated direction of the cherry from the center of the area of the fruit.

TABLE II. STEM HSV MASK VALUES

	Min	Max
H	90	100
S	50	255
V	150	210

TABLE III. SIZE ESTIMATION VALUES

Size	Equatorial diameter d (mm)
LL	$d \geq 25$
L	$22 \leq d < 25$
M	$d < 22$


Fig. 5. Size estimation method on pseudo-cherries.

III. RESULTS AND DISCUSSIONS

Fig. 6, Fig. 7, and Fig. 8 demonstrate the two-dimensional saturation-lightness from the cherry grades Tokushu, Shu, and Marushu, respectively, obtained from the representative images of each grade. The set value range was used to obtain the coloring percentage of the fruit image for grade identification.

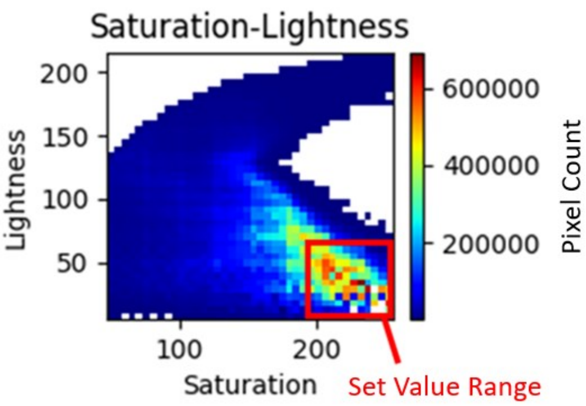

Fig. 6. Two-dimensional histogram of Saturation-Lightness (Tokushu).

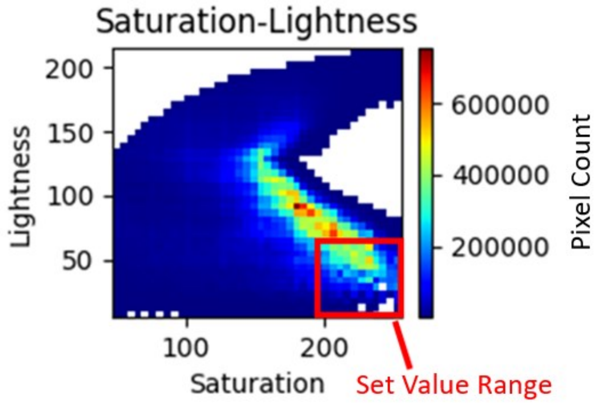

Fig. 7. Two-dimensional histogram of Saturation-Lightness (Shu).

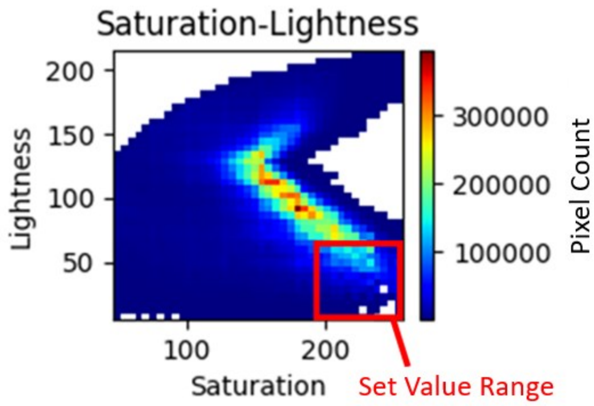

Fig. 8. Two-dimensional histogram of Saturation-Lightness (Marushu).

The presented system was able to sort 2 cherries per second, 7,200 per hour, and 57,600 in 8 hours (about 8g per cherry), at a maximum of three grades and three sizes. The speed of the sorting system was restricted due to the performance of the image processing, consequently having to reduce the maximum speed of the conveyor belt. Collection bins in Unit 1 held approximately 15 cherries per bin, while the bins from Unit 2 held an average of 120 cherries per bin.

The sorting system achieved an accuracy of 72.4% for size estimation using the equatorial diameter and 82.5% for grade identification using coloring ratio. The cherries are constantly moving in batches, and are detected through the cameras and processed through real-time video as soon as the entire body of each fruit is fully seen, mostly being when the cherry is close to the center of the video from the cameras. Fig. 9 shows a breakdown of the grade identification results, in which 10 of the 157 Tokushu cherries were identified as Shu, however none were identified as Marushu; out of the 157 Shu cherries, 13 cherries were identified as Tokushu and 14 cherries as Marushu; and out of the 74 Marushu cherries, 2 cherries were identified as Tokushu, and 29 cherries were identified as Shu. Likewise, Fig. 10 shows the result screen for the grade identification, labeling present cherries as Hanedashi, Tokushu and Shu from left to right. Additionally, the result screen for size estimation of a LL cherry, viewed from the three cameras, can be seen in Fig. 11.

Studies have shown that the use of different image processing methods achieve different accuracies [18]-[19]. This research tested grade identification from obtained color values and size estimation using the HSL model by maximizing the fruit processing line at an efficient speed. In one study, the use of a convolutional neural network (CNN) showed a significant increase in size detection for cherries, obtaining an accuracy of 95.18% at a detection speed of 59 cherries per second even though the fruits were not physically sorted by the system [18]. While in another study, the hue saturation intensity color model (HIS, another name given to the HSL model) was used for analyzing the coloring area of lemons, resulting in an average accuracy of 94.04% for three grade levels, however, the fruits were not fed automatically, therefore, no resulting classification speed was obtained [19]. These results indicate that the use of neural networks as well as the use of the HSL model allow us to obtain results above 90% accuracy, and in turn indicate that the proposed identification and estimation algorithm can be improved, while avoiding compromising the line speed, to increase the resulting percentage of correct detection. However, a great advantage that the developed system presents is that it allows the use of image processing while performing a dedicated fruit sorting.

Furthermore, earlier studies have also shown positive results in the use of different techniques for sorting fruits [13], [20]-[21]. A gate-based classifier machine successfully sorted tomatoes at a sorting rate of 0.4 tomatoes per second with an accuracy of 93.33% through a grade detection using a color sensor [20]. Another study used a conveyor belt-based robotic arm aided by a photoelectric sensor to sort strawberries according to the size and shape of the fruit and achieved an accuracy of 98.6% for size estimation at a judgment speed of 0.85 fruits per second [21]. Despite not having high accuracy percentages, the presented system manages to obtain high sorting speeds, indicating that future improvements should be more focused on improving the overall accuracy of the system.

Based on the results, stable grade identification and size estimation were achieved by analyzing the cherries in a light-stable environment. Similarity in coloration of the same grades of cherries was a major cause of failures in successful grade identification. In the case of size estimation, there were cases in which the system failed to detect the difference between the edge of the cherry and the beginning of the stem.

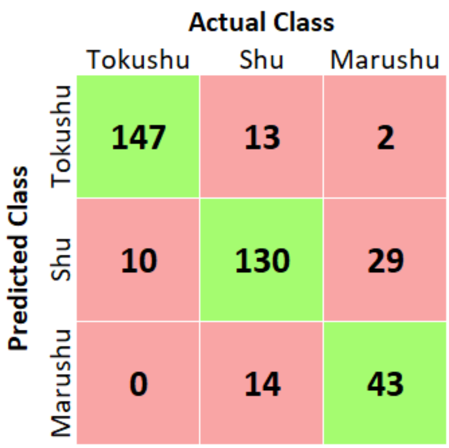

Fig. 9. Confusion Matrix of grade identification for grades Tokushu, Shu, and Marushu.

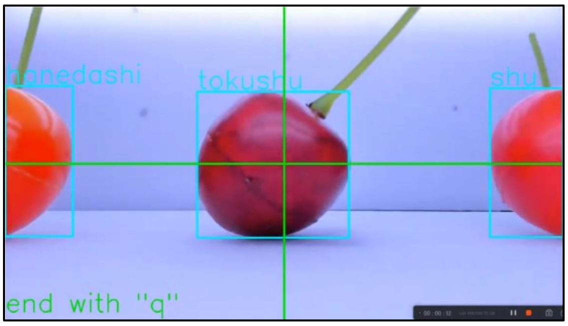

Fig. 10. Result screen for grade identification labeling (Right camera).

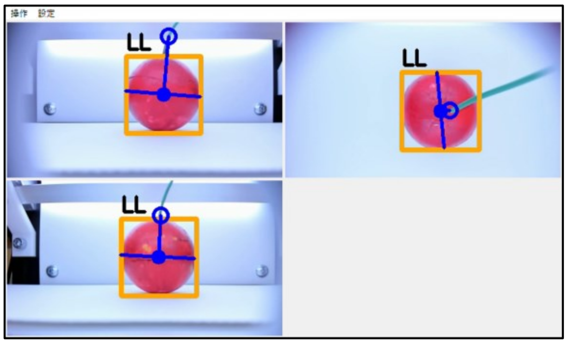

Fig. 11. Result screen for size estimation labeling (Upper, left, and right cameras).

IV. Conclusion

Cherries are sorted manually according to the grade and size of the fruit; however, these methodologies require experience and skills from farmers, causing variations in the results. In this study, a system for sorting cherries in real space was developed using the results from the grade identification utilizing the HSL color model. Furthermore, a second sorting system was built for the addition of size estimation. The performance of both systems using pseudo-cherries was studied for a total of three grades and three sizes for each grade. Accuracy levels of 82.5% for grade identification using coloring ratio and 72.4% for size estimation using the equatorial diameter were attained, indicating room for improvement. Furthermore, using the presented methodology, two cherries could be sorted per second. The results show that the use of machine vision in combination with an air sorting system are sufficient for its implementation in the field Unit 2 is currently under development, focusing on achieving higher accuracy in grade classification and size estimation, and additional tests will be carried out with real cherries for comparison of results. Furthermore, by using machine learning, detection of pest and bird damage will be implemented.

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