A method of determining cut position of automatic stem removal system for salted wakame

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Abstract: In the wakame production procedure, the manual operation process of stem removal is known as a hindrance to the wakame production. In order to solve this problem, we aspire to develop an automatic wakame stem removal system. The purpose of this paper is to propose a cut position determination method for the system by picking up the characteristic changes that appear at the cross section of the wakame. In this method, with the utilization of exposure control, two images are captured from the same cross section that is made by a developed device. These images are used in the segmentation of the cross section. The positions where the stem should be cut can then be determined through the examination of the thickness of the cross section. To verify the feasibility of the proposed method in developing an automatic removal system, 100 cross sections were generated from the roots of 10 samples of the salt-preserved wakame with an interval of 20 mm. In the experiments, the success rate was 76% with the width selection of 1.5mm allowable part of the stem left on the leaves, and it increased with the extension of the allowable part.

Keywords: Marine algae, wakame, automation, stem removal, exposure control and segmentation.

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1 Introduction

Marine algae (seaweeds) are prolific around the coasts of Japan, and have long been used as food as well as industrial products, and have been played an important role in the maintenance of health as a source of supply of vitamins and minerals. Consequently, the consumption and production of seaweed in Japan are highest in the world (Murata et al., 2001). Common edible seaweed in Japan include Nori (Porphyra), Wakame (Undariapinnatifida), Kombu (Saccharina japonica) and Hiziki (Sargassumfusiforme), etc. Among them, wakame, as illustrated in Figure 1, is one of the most popular edible seaweed and widely used in soup, salad and noodle, etc. The main part of this seaweed used for cooking is the sterile leaf of the asexual generation. Before the basic resources become the finished products, the processing system of wakame production requires many processing steps. Currently, almost all of the wakame products are produced from cultivated wakame seaweed, and the processing steps of cultivated wakame for marketing include harvesting, boiling, cooling, salting and stem removing (Hasegawa et al., 2005). The season for harvesting cultivated wakame usually starts from the month of February and goes up to the end of April, and during this season the fishery workers spend their busiest time to gather their harvests with excessively heavy loads. Every time the fisheries finish unloading their harvests on coasts, boiling, cooling and salting processes are carried out at the unloaded place. In the first process, boiling, the

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harvested wakame is briefly boiled in sea water, and this is the process that makes brown wakame change its color to bright green. After boiling, wakame is refrigerated, then mixed with salt and preserved overnight in a highly-saturated salt water solution. The salted blades are then drained and allowed to dehydrate for several days, after which the mid-ribs are removed (Yamanaka et al., 1993).

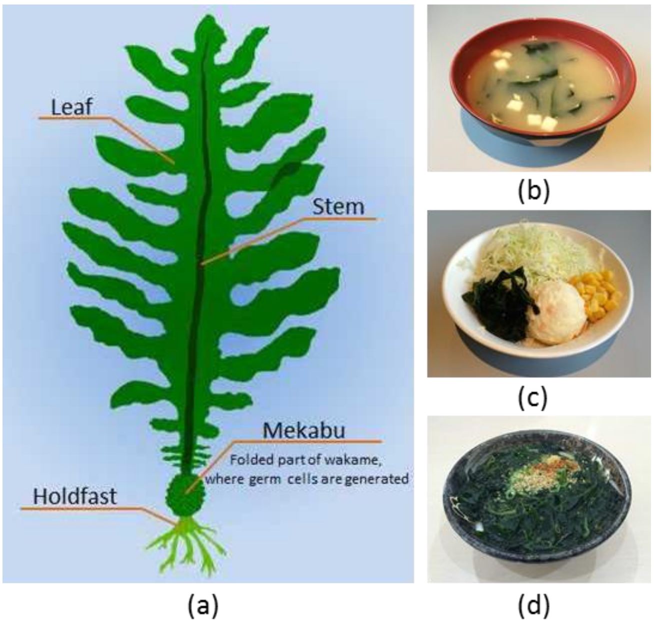

Figure 1 General structure of wakame (a); and Japanese cuisine made with wakame:(b) Miso soup, (c) salad, (d) wakame noodle.

The total amount of the wakame harvested in 2010 was about 50 thousand tons (Ministry of Agriculture, Forestry and Fisheries of Japan); however, it was only capable of filling about 20% of the domestic demand. The other part of domestic use was filled with the importation from Korea and China. The amount of harvested wakame has decreased over the years, and it causes an increase in importation. The problems of the decrease of the wakame production can be considered from several viewpoints. But, the main reasons are the following ones: (i) decrease in the number of employees, which is caused by the problem of low birth rate and aging population; (ii) quality improvement and low price of the imported wakame products as compared to the domestic products.

Up till now, a lot of research has been done to improve the wakame processing, and some of them have even been used in the production line (Fujii and Korenaga, 2000; Onodera and Ishimura, 2007). Those research documents include each process from cultivating to stem removing. Comparing with the procedure held before, the productivity of harvesting and salt-preserved processing has been increased with production scale for household. However, the productivity of stem separating operation is still extremely low. Because this process is depended entirely on manual operation, that is, the stemsare manually removed one by one, and this is why it becomes a bottleneck to the improvement of total production. For this reason, Inoue et al.(2004) developed an automated production system that can separate the stem and leaves of wakame by guiding two special blades. In their method, the wakame is pulled by clutching the root edge of it to a rotation drum. The leaves are separated from the stem by the two cutting blades which are set on the both sides of a stem, while the stem is wound onto the drum. However, their machine was not widely used in production line due to the several limitations, e.g., before grasping the root of wakame to the drum, the stem should be manually separated with certain distance on the both side of the stem, so that it consumes a little time before finishing the removal.

Thus, making an automatic stem separation system is very important to increase the wakame productivity. Therefore, we are engaging in developing such a system that can automatically detect cut positions on both sides of the stem, and then on the basis of those results separate the stem from the leaves. At the present stage, we have developed a prototype cross section generation devicefor carrying out the detection.After making a cross section two types of images are grabbed from the same cross section by controlling exposure. Then these images are segmented to extract the overall cross section of wakame.

Finally the cut positions are obtained by using the variation of thickness of the cross section.

In this paper, discussions will be made mainly on the cut position determination for the stem removal system. The rest of this paper is organized as follows: in section 2, we first briefly explain the conceptual functions of stem removal process and present a prototype device that is developed for generating the cross section. Then, we provide a detailed explanation about how the image capturing process is performed and about how to identify the cut positions.Following these, in section 3, the effectiveness and usefulness of the proposed method will be verified by experiments, and finally conclusion and future worksare presented in section 4.

2Materials and methods

2.1 Stem removal system and cross section generating device

By observing the manual stem separation, it can be found that there are three main steps in the process. The procedure begins with identification of the best point at which to separate. Stage two involves cutting slits at the chosen points, and creating a leaver from the roots of the wakame which is a place to be grasped by the worker. Finally the stem is removed from the leaves. The leaver is pulled to separate the leaves and the stem from the rest of the wakame using the thumb and the index finger. Because the stem has a high fiber content it is stronger than the leaves, which will therefore break away easily where they are slit at the connecting point. This is the principle on which the system devised by Inoue et al was based.

According to the above, taking the functions of these three steps into consideration, it is very important to develop an automatic wakame stem removal system, in other words, these functions can be thought of as the basic requirements for the system to be developed. Therefore, the main parts of a typical stem removal system consist of an image processing system to determine the cut position with regard to the determination made by visual observation, a slit generator to cut both sides of stem on the basis of the determined cut position, and a stem remover to separate the leaves. Among them, the determination of the cut position is the most important part of the system. Generally, when made by worker the decision of where to cut is based on the color difference and the tangible difference in the thickness at the boundaries of stem and leaves, as well as, on intuition developed through experience. Obviously, it is imposable to provide a detection method that can find the right points in the same way as humans do, but from manual determination process we can find a similar way to do that, that is, utilizing the color difference being caused by the reflection on the cross section and the perceptible thickness variation of the cross section. Therefore, cross section generation is a process that needs to be done before the detection. Most importantly, validating the feasibility of the detection method is an efficient way to develop a system before the integration. As a first stage of our work, we constructed a prototype cross section generating device with two degrees of freedom (DOF) as shown in Figure 2. It has designed functions to fix the wakame by pressing down the handle ①, and to make a cross section by cutting the wakame through sliding the rotary blade ②. An example image of cross section that was generated by the device is shown in Figure 3.

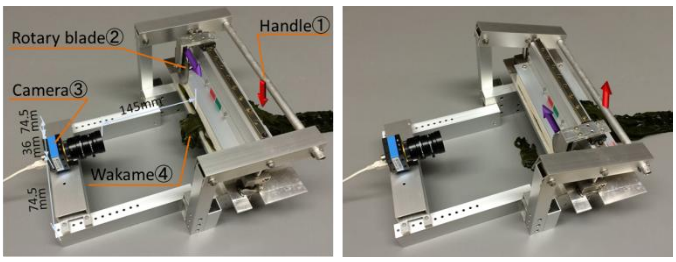

Figure 2 Prototype device and generating process of cross section.

Figure 3 Sample image of cross section.

Evidently the developed prototype device is only capable of generating the cross section to test the performance of the proposed detection method. However, the final goal of our system is to make a separation of the whole stem from the leaves in a fully automatic process after simply setting the wakame and the functions of this device will be applied to the automatic system in our next work.

2.2 Detection unit setup

Images of wakame were acquired using a color CMOS camera (Imaging Source DFK 42AUC03).The camera has a lens with a focal length of 6 mm, mounted in the front of the device.The view field of camera has a width of 116mm and a height of 87mm at a distance of 145 mm from itself and the cross section of wakame. A single pixel represents approximately 0.1mm.The setup for image capturing is also shown in Figure 2, and a sample image captured by the setup can be seen in Figure 3. The environment for collecting data is chosen as normal office environment with fluorescent lighting source. To deal with distortion of the image, a typical problem caused by the lens system, calibration,a process of estimating intrinsic and external parameters to minimize the discrepancy between the observed image features and their theoretical positions, is carried out. In the present work, the camera is calibrated using a method proposed by Zhang (2000), and undistortionisapplied to the captured image.

2.3Exposure control

In order to find the separating positions between the stem and the leaves, it is crucial to identify the variation of thickness. For this, however, the most important is to accurately segment the overall cross section of wakame. Considering the segmentation, setting a 'good background,' from which the cross section can be easily extracted, is a simple and effective way to be used. However, directly applying a conventional segmentation method to the image even with the 'good background' does not guarantee the accuracy of the extraction due to several problems, e.g., reflection appeared around the cross section of wakame and noise of camera, etc. In this work, we have focused on a segmentation method with the use of controlling 'Exposure,' which is an important part of camera and controlling it is an essential process of photographic light sources. By default settings, most digital cameras generally implement an automatic exposure adjustment algorithm to compensate for overall scene light level changes such as going between lit and unlit environments (O'Malley et al., 2010). Exposure can also be manually controlled by changing any of three parameters, which are shutter speed (exposure time), F-number (aperture) and ISO value (sensitivity). Most of the industrial cameras are available for programmable exposure control. For these cameras, exposure is usually controlled by changing shutter speed.

Along with setting the configuration of a camera with higher shutter speed, the target will gradually appear dark, such that the image detail can be lost in the end. On the contrary, with slower shutter speed, the intensity of the bright target can cause saturation in the image, such that color and shape information can be lost. Since we are only interested in accurately segmenting comparatively dark-colored object, wakame, losing the shape and color of other parts is beneficial to our work. The result of making lower shutter speed loses high intensity detail in the resultant scene, which is not of interest to this system. Therefore, further reduction in high intensity parts of the image can simplify the wakame segmentation process. Some of the sample images captured with different configurations of shutter speed are shown in Figure 4.

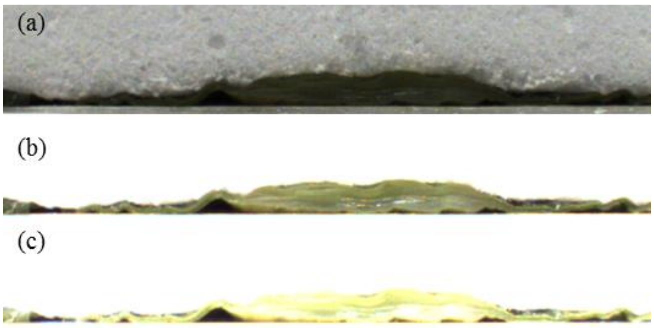

Figure 4 Sample images with different configuration of shutter speed: (a) automatic exposure control, (b)exposure time is 0.143 s and (c) exposure time is 0.321 s

As shown in Figure 4, along with slowing the shutter speed, the background is gradually lost its detail and becomes white, at the same time the cross section of the wakame also changes its color from dark to light. In the present work we utilize this phenomenon to extract the cross section. Therefore, we firstly need to establish a way to automatically choose proper exposure configurations, because the exposure time is mostly relative to the light condition. In different environments, e.g. different rooms or different place in the same room, the images captured with the same exposure time may be slightly different even with an installed illumination device. A solution for this problem is to apply a tuning process with the start of the system. By this way the system can also perform an automatic calibration of the exposure time.

The proposed tuning process is carried out by matching colors of the particular regions in the captured image to the pre-specified colors. The colors used for matching are obtained from two color marks, red and green, which are attached to the device as shown in Figure 2. In our work, since the segmentation of the cross section is accomplished by exploiting two images captured with two different exposure configurations, we need to set two exposure times, E1 and E2. The main steps of tuning process of E1 are described as follows:

(1) Initialize E1 as the default exposure time (which is obtain by the automatic exposure control)

(2) Capture an image and compute the average intensity ave_R of the specified region in the green mark of that image by following Equation 1:

$$ave_R = \sum_{j=-N/2}^{N/2} \sum_{i=-M/2}^{M/2} f(x_R + i, y_R + j) \Big/ MN \quad (1)$$

whereMN is the size of a window in the green mark and (x_R, y_R) is the location of the window in the captured image.

(3) Calculate the stop condition Q_R as in Equation 2:

$$Q_R = \begin{cases} true, & if \quad |ave_R - d_R| \le \varepsilon_R \\ false, & otherwise \end{cases} \quad (2)$$

where ε_R isabsolute error, and d_R is a constant value and found by trial and error from pre-experiments of tuning process.

(4) Repeat steps (2) and (3) with (E1 + Δτ1) until the stop condition Q_R becomes true.

The exposure time E2 can also be acquired by a tuning process in accordance with the same principle as the use of green mark. In this case, however, the red mark is used to tune exposure, and the initial value of E2 is set as E1 + Δτ2.

2.4 Cut position determination

After obtaining the appropriate exposure times (E1 and E2) at the startup of the system, the camera is configured with E1 and the system waits for the detection request. The detection algorithm includes: image acquisition, segmentation, thickness calculation, decision of cut positions and configuration of camera. The flowchart of this algorithm is given Figure 5.

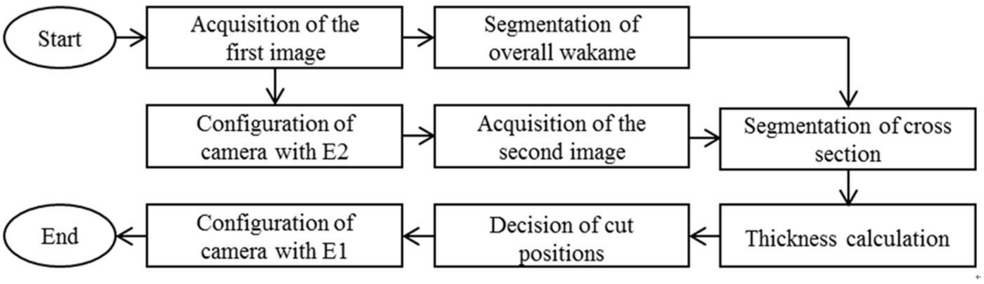

Figure 5 Flowchart of the present work

As shown in Figure 5, the image acquisition of this algorithm includes two parts: the first is for segmenting the whole area of the wakame, the other is for extracting the cross section from the result of the first by a synthesis process. When the system receives the request, it captures the first image with the pre-configured E1. The first image is then transformed from RGB color space to Lab color space.Here, we apply Otsu's thresholding technique (Otsu, 1979) to the L component of Lab color space to segment the wakame region. The image captured with E1 is shown in Figure 6(a) and the segmentation result is depicted in Figure 6(b). And then, the camera is configured with E2 and captures the second image, as shown in Figure 6(c). It is clear that the cross section in the second image became brighter than that of the first image. In the other regions, however, there was less of a change in the intensity than in the cross section. We considered that these changes can be used in effectively extracting the cross section. To achieve this, the second image is firstly segmented by a simple thresholding method. The thresholding method uses two components (red and green) of the second image, and the segmented image is obtained by following Equation 3:

$$g(x,y)=\begin{cases}1, & if \quad f_R(x,y)>T_R \quad and \quad f_G(x,y)>T_G \\ 0, & otherwise\end{cases} \qquad (3)$$

where $f_R(x,y)$ and $f_G(x,y)$ are the intensity values of R and G components of the second image, and T_R and T_G are threshold values, respectively. In the present work, T_R and T_G are set as 200 and 150, experimentally.

After these two segmentations, the results of them are combined by a simple logical 'AND' operator to extract the cross section. The extracted result obtained from Figure 6(a) and (c) is illustrated in Figure 6(d). Following these, the thickness is calculated by counting the minimum lengths of straight line segments that pass through the pixels of interest and cross the edges of extracted cross section. Here, the pixels of interest indicate the pixels on the centerline of the extracted cross section. The centerline is obtained by implementing Hilditch's thinning algorithm (Gonzalez and Woods, 1992) to the synthesized binary image.

Figure 6 Imaged wakame and segmented results: (a) acquired image with red mark, (b) segmented result of (a), (c) acquired image with green mark, (d) segmented result of (c), and (e) extracted cross section of wakame

Finally, the identification of where to separate the stem from leaves is achieved by using the calculated thickness. In this case, two approaches can be considered as common ways to be adopted: finding a characteristic thickness change around the boundaries or investigating the distribution of the thickness of the boundaries. For the first one, it is difficult to find that characteristic due to the irregular change from the leaves to stem. In addition, the shape of each sample is different from the other. Therefore, in the present work, we have measured the thickness of roots over many salted wakame samples. The measurement was performed at an interval of 20 mm for each sample by generating the cross section. We found that the thickness of the boundary regions is distributed around 1mm, and is mostly related to the thickness and width of the stems. Consequently, for our work we simply selected a 1mm (approximately 11 pixels) thickness as a boundary point. This means if the thickness is less than 11 pixels then they will be treated as the leaves. The extracted stem area of Figure 6(a) is shown in Figure 6(e). This figure is only illustrated to visualize the positions at where it should be cut, but for the final system it is limited to return a feedback of cut positions corresponding to the origin.

3 Results and discussion

In order to evaluate the performance of the proposed detection method, 10 samples of salted wakame were used in the experiments. All of the samples were harvested from Sanriku region, the largest wakame culturing place in Japan. The root width of the stem varies from 10mm to 43mm, and length of them varies from 500mm to 1800mm. Generally, the stem can be smoothly removed from the leaves (from root to tip) if the leaves do not break-off during the separation. In some cases, however, the leaves may break-off and the re-removing process will be necessary to carry out again from where the separation failed. Considering the failed process and making the experiments on different breadths, the cross sections were generated at interval of 20mm for each sample in this work. Consequently, the total of 100 cross sections was generated from 10 wakame samples. In order to compare the detected results with the observed positions, 2 fine wires with diameter of 0.1 mm were vertically set in front of the boundaries of stem and leaves, wherein the set positions were decided by visual observation. The positions indicated by 2 wires were then used as ground truths (GTs) to calculate the differences between detected positions and GTs. An example of setting set wires is illustrated in Figure 7(a), and (b) shows the experimental result of detected cut positions that correspond to the GTs, in which two vertical red lines indicate the detected positions.

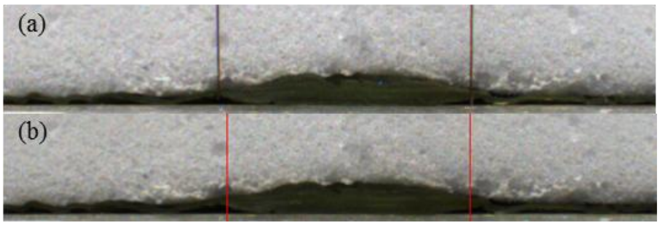

Figure 7 (a)Observed positions indicated by two wires, (b) detected positions indicated by two vertical red lines.

In this work, the absolute differences between detected positions and GTs were calculated respectively with regard to the right and left side of the stem, and the distributions for each wakame sample are plotted in Figure 8 andFigure 9, respectively. The x axis shows the absolute difference, and the y axis indicates the number of samples. The measurements for each sample are shown as box plot (Moses, 1987), in which the median values are shown as thin horizontal lines. The box covers the range between the twenty-fifth and seventy-fifth percentile, and the whiskers outside the box are extended to the maximum and minimum values within 1.5 times the interquartile range. Points outside the whiskers are outliers and extremes that indicate the incorrect detection. Observing the parts that are over 2mm line, we can easily find that most of the incorrect detections were occurred on the sample #5. This sample was the largest wakame among the given samples, and the average width and height of the cross sections generated from this sample were 45mm and 4mm, respectively. In addition to the thickness of cross section that exceeded the pre-set thickness condition, the uneven surface of the cross section can be considered as the reasons for the incorrect detections.

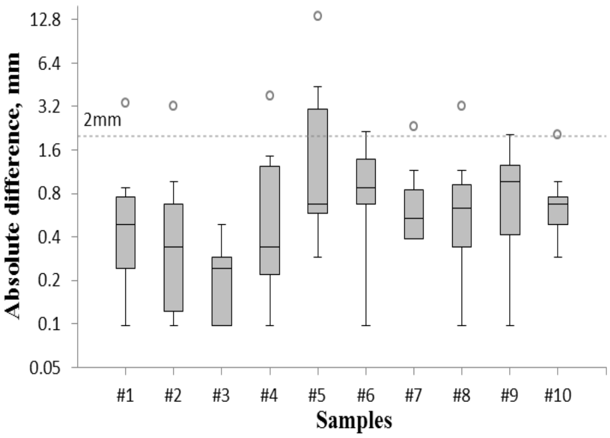

Figure 8Box plot of absolute differences between detected positions and observed positions for the left side of all samples.

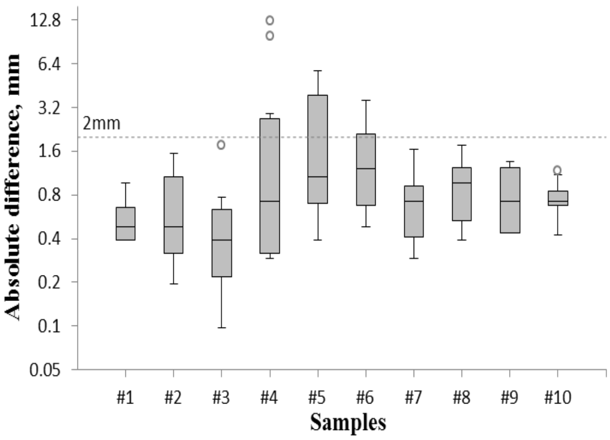

Figure 9Box plot of absolute differences between detected positions and observed positions for the right side of all samples.

To better understand the relation between detection rate and allowable absolute difference range (AADR), we calculated the detection rates corresponding to different AADRs, and illustrated them in Figure 10. From the figure, it can be known that the detection rate was only 25% while AADR was selected as 0.5 mm, and it increased along with extension of the AADR. By manual separation, however, it is said that there is an average of 1.5 mm part of stems left on leaves. Accordingly, the detection rate can be considered as 76%. Moreover, in our method pre-set thickness condition was simply selected as 1mm, and it did not give a good detection especially for the thick wakame as like the sample #5. Therefore, the detection rate can be improved by employing a dynamic selection of thickness condition corresponding to the thickness and width of cross-section.

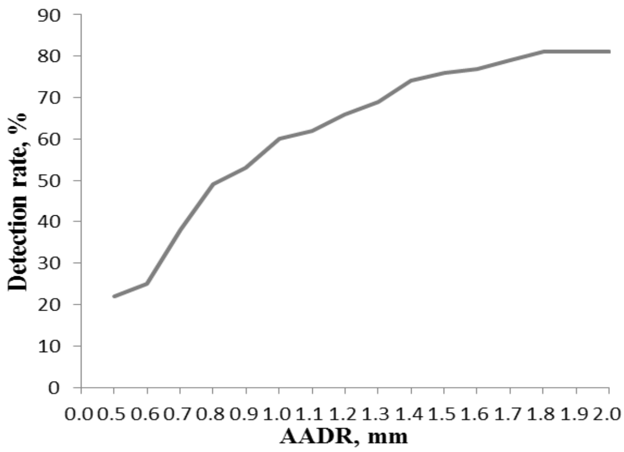

Figure 10 Detection rate corresponding to the allowable absolute difference range.

In the proposed method, computational time is a major problem that should be dealt with in our future work, because it takes an average of 1 s to accomplish the detection. The reason for this problem is that the method needs to capture 2 images in accordance with the changed exposure time, and the time taken by them accounts for more than half of the total computational time. One of the solutions to deal with this problem may be the utilization of two cameras, that is, configuring two cameras with two proper exposure times (with regard to the red and green marks) after applying the tuning process as the system starts; otherwise, finding a direct way (without controlling exposure time) to perform stable segmentation would be the best way to solve this problem.

4 Conclusions and future work

In light of the strong need to develop a new system for wakame production, we developed a method that detects the positions of where the robot should automatically separate the stem from the leaves. In the proposed method, corresponding to two exposure configurations, two images were captured from the same cross section of wakame that is made by a developed cross section generation device. These images werethen utilized in the segmentation of the cross section. Finally, the cut positions are determined by using the thickness of the cross section. Performance tests of the proposed method showed that it can give good results for finding the positions. Future works will involve that to establish a dynamic thickness condition in accordance with the change of the width and thickness of the cross section and to find much more effective way of not only reducing the processing time but also accurately segmenting the cross section.

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