Egg Surface Inspection Using Infrared Transmitted Light Images

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***Abstract*—Factories that mass-produce boiled eggs do not use eggs with minute surface irregularities as out-of-spec eggs in order to reduce the risk of damage during transportation. The inspection is performed visually by human workers to check for abnormalities, but this is a heavy burden on the workers because of the number of eggs they handle. In this study, a method to detect minute irregularities in eggshells using transmitted infrared light was attempted. By using an infrared camera to capture images of infrared light transmitted into the egg, we were able to detect areas where the shell was locally thicker. In the future, we plan to try deep learning to detect irregularities distributed on the sides near parallel to the optical axis of the camera by matching the three-dimensional shape of the shell measured by a 3D scanner with the transmitted infrared light image.**

Keywords-boiled eggs; surface inspection; infrared light; protrusions; image processing.

I. INTRODUCTION

Currently, boiled eggs are produced and shipped in large quantities daily as a food product. In addition to preventing eggs from being damaged during transportation, the surface of boiled eggs as a product must be free of blemishes and stains to maintain their good appearance as a product. For example, if the surface of the shell has a different color than the rest of the shell, it is out-of-spec as having stains. Similarly, any unevenness on the surface of the shell that exceeds the standard is called “Zara” (which means roughness) and is considered out-of-spec. Figure 1 shows the uneven surface of an egg, which has many protrusions. These out-of-spec eggs are removed before boiling and used as raw materials for other egg products. Thus, the quality inspection of eggs for the production of boiled eggs requires a more detailed inspection of the surface texture, unlike the inspection for cracks and stains on the shell, which is conducted to guarantee food safety.

Thus, in producing boiled eggs, it is necessary to remove off-spec eggs before processing them according to the established standards. Currently, workers visually inspect the eggs to remove out-of-spec. However, in a certain boiled egg production plant, the process is not as thorough as it should be. A certain boiled egg factory produces 150,000 boiled eggs per day, and a larger number of them must be inspected in advance. This is a heavy burden for even the most experienced workers. In addition, the temperature and humidity inside the boiling egg factory are high due to the handling of boiling water, and the workers are fatigued when they work in clean clothing. As described above, the high workload, including environmental aspects, may affect the accuracy of the inspection. In response to the above issues, we believe that if the detecting and removing process could be automated, it would not only improve the efficiency of boiled egg production but also solve the problems caused by the shortage of human resources.

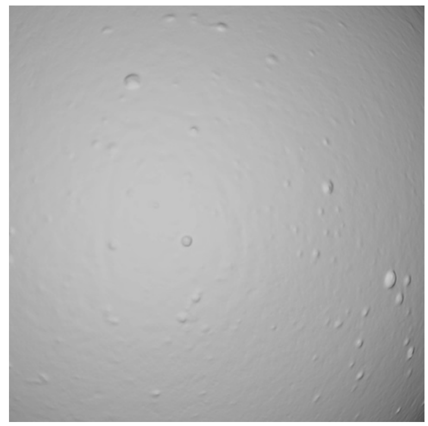

Figure 1. Protrusions on the egg surface.

This study focuses on the inspection of egg surface irregularities and aims to develop a method to automate the process of removing out-of-spec. Specifically, we propose a method to inspect the surface of the shell from an image of the egg taken by infrared transmitted light and to detect out-of-spec eggs when the number of irregularities exceeds a standard.

The rest of this study is organized as follows: Section II describes the existing methods for egg quality inspection; Section III describes the egg surface inspection method used in this study; Section IV describes the relationship between the image features obtained by the proposed method and the egg surface features. Section V summarizes this study and discusses prospects.

II. RELATED WORKS

Visual inspection has been used in the egg inspection process. The main purpose of this method is to assure the quality of food products by checking whether there are any abnormalities on the surface or inside. However, the accuracy of this method, which relies on human skill, depends on the skill and fatigue of the inspector and the environment of the inspection site. Therefore, attempts have been made to automate the inspection process and sort out eggs that do not meet a certain level of quality.

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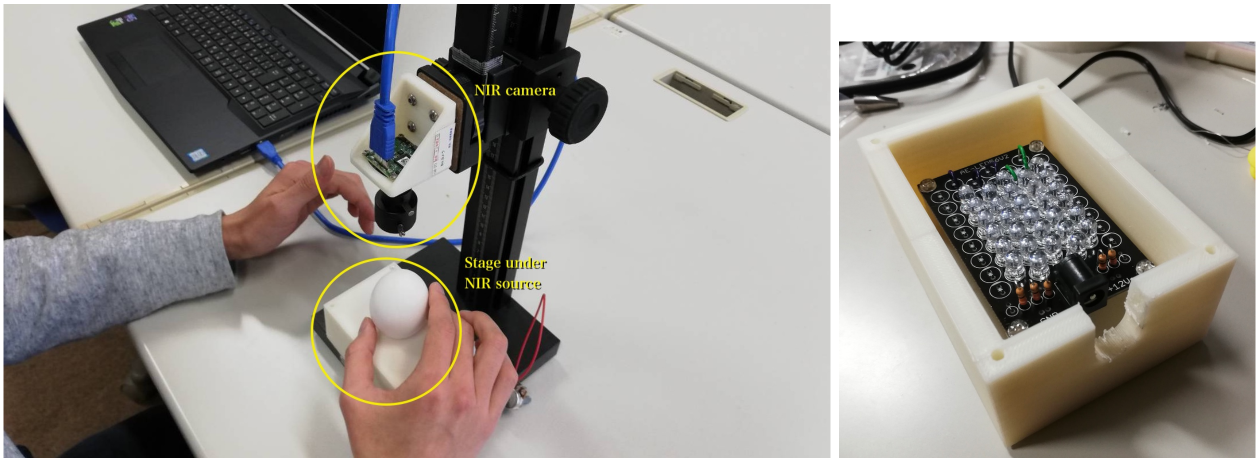

Figure 2. The device for NIR imaging.

A typical inspection method is candling. The method of checking freshness by shining light on eggs and using the color of the yolk inside as a guide [1] has been used for many years. Liu *et al.* [2] developed a method to inspect freshness by measuring the spectrum of light transmitted through the interior of the egg. They used the ultraviolet and visible (UV/VIS 200–800 nm) spectrum as the light source. On the other hand, De Katelaere *et al.* [3] proposed a method for detecting cracks on the surface using the analysis of frequency response by acoustic measurement when the shell is subjected to mechanical impact. For inspecting surface conditions, Wang *et al.* [4] used the surface image of the eggshell to detect black spots, and Wang *et al.* [5] examined a neural network to detect contamination.

These previous studies aimed to ensure the safety of eggs as food by detecting blood or meat spots inside or by inspecting relatively large cracks or stains on the surface. On the other hand, eggs that have passed these inspections are received at the plant where boiled eggs are produced, and it is required to detect even finer irregularities. This is because the protrusions on the surface of the shell are easily affected by vibration during transportation, and there is a high risk of cracking. To reduce the risk of product breakage, only eggs with smooth surfaces should be used as material. Furthermore, eggs with even a slight lack of smoothness in appearance will be shunned by consumers because of their poor appearance. There are no existing studies aimed at detecting the fine texture of eggs that meet these conditions.

III. METHODS

In this study, we focus on the wide application of near-infrared light to food analysis, based on various sample presentation techniques [6]. In addition to reflection, Near-Infrared Ray (NIR) absorbed and transmitted from the sample may be used to detect the internal state of the eggshell. Here, we attempt to analyze the surface shape of the shell by photographing the NIR transmitted through the egg.

A. Image Acquisition

The device for NIR imaging in this study is shown in Figure 2. As shown on the right side of the figure, the NIR light source is under the stage where the eggs are placed, and the NIR light transmitted from the light source through the eggs is captured by a camera mounted directly above the stage. Near-infrared LEDs with a wavelength of 840 nm were used as light sources. The eggs were photographed in two ways: face up or face down. Therefore, the image acquired in this case was always centered directly above or below the egg, with the sides of the egg at the periphery.

Figure 3 and Figure 4 show examples of images captured by this device. The brightness of each pixel is determined by the thickness of the eggshell, not by the egg's internal structure. High brightness areas indicate that the shell is relatively thin, while low brightness areas indicate that the shell is thicker than the surrounding area.

Figure 3 shows an image of a good surface quality egg with an even texture. Although there are differences in brightness and darkness, the brightness is within a certain range. On the other hand, Figure 4 is an image of the surface of a substandard egg with deep irregularities. There are some darker areas in the image, as indicated by circles. Those areas are where the shell is thicker, indicating the appearance of protrusions on the surface.

B. Thresholding

Areas with large changes in shell thickness are deeply uneven and have a coarse texture. Using this feature, the size of the area occupied by areas with large changes in brightness can be used as a criterion for judging whether an egg is out-of-spec or not.

The acquired NIR image is binarized with predefined threshold L, and then shrunk and expanded to remove noise, leaving blobs. Figure 5 shows the resulting blobs superimposed on the original image. In this figure, the blobs are drawn as yellow areas.

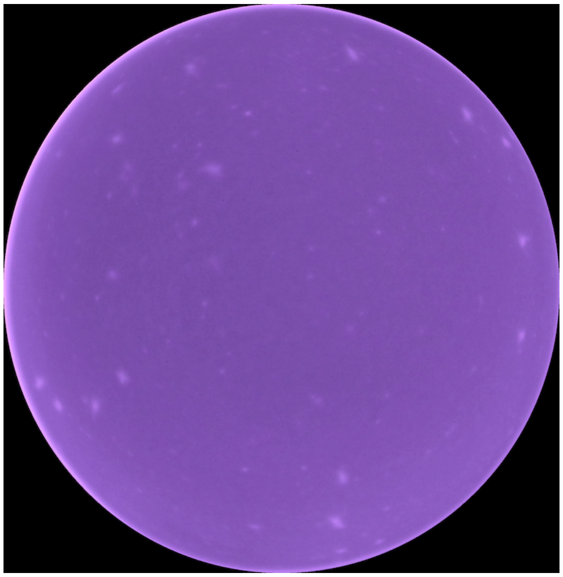

Figure 3. Captured NIR Image of an egg with a good shell.

C. Blob Detection

As shown in Figure 5, the blobs remained in the low-lightness areas annotated in Figure 4, indicating that this process correctly detects out-of-spec eggs. On the other hand, a large blob remains on the left side. This is because the amount of transmitted light was low when the image was taken and the overall image was dark, which resulted in the blob being below the threshold value L. To judge out-of-spec eggs, we define a blob whose area is between S_{min} and S_{max} as a protrusive blob and judge an egg to be out-of-spec when the number of protrusive blobs exceeds the reference value.

IV. Experiments and Results

In this study, 10 eggs with good shells and 30 out-of-spec eggs were prepared, and NIR images were taken from above and below for each. As a result, 20 images were obtained for eggs suitable for producing boiled eggs, and 40 images were obtained for eggs unsuitable for producing boiled eggs. The processing of these images with the proposed method did not stably extract protrusive blobs for all images under the same threshold value L. This may be because the thickness of the shell differs from egg to egg and the amount of transmitted light varied. On the other hand, false positives of protrusive blobs were rarely observed for good eggs.

Figure 6 shows the change in the distribution of blobs as the threshold is varied. The same NIR image is used as the source for binarization in each column, and in each row, images are binarized with thresholds L=0.333, L=0.352, and L=0.376, respectively. These threshold values represent relative amounts when the highest brightness is set to 1. All of these eggs are out-of-spec, and the NIR images contain local dark spots. This figure shows that the percentage of shadow remaining as blobs varies greatly from egg to egg, and that

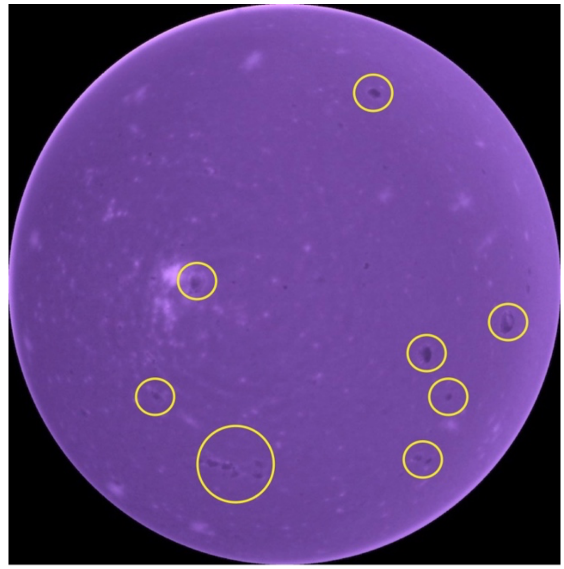

Figure 4. Captured NIR image of a substandard egg.

defining the threshold as a constant does not give good overall results.

As a general trend, blobs distributed in the center of the image were more appropriately detected. This may be because the sides of the shell are inclined to the image plane and occupy a small area in the image, making it difficult to detect their characteristics.

V. Conclusion

In this study, we developed a method for detecting

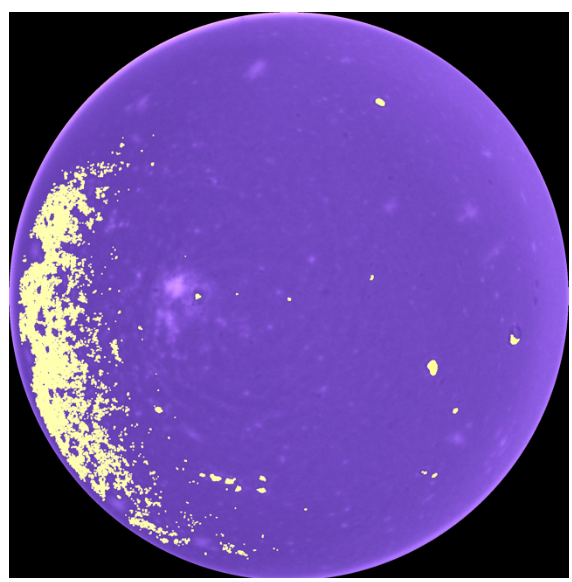

Figure 5. The result after image processing imposes the original.

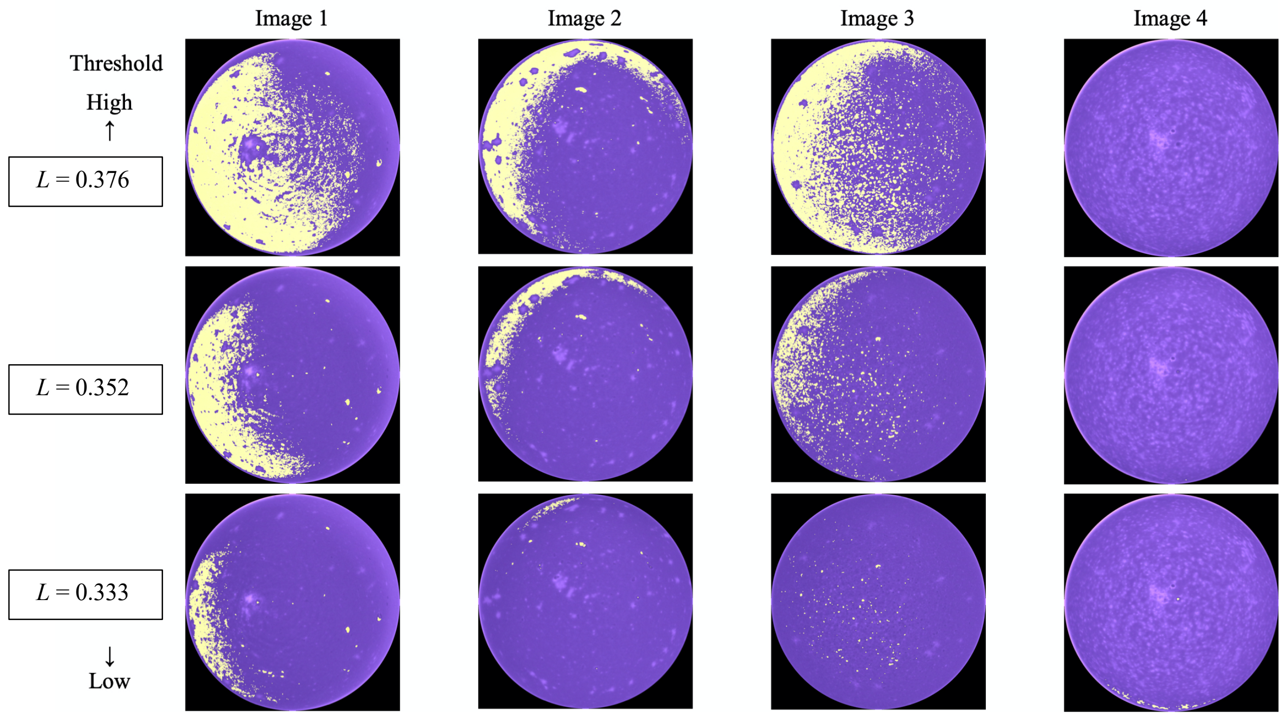

Figure 6. Distribution of blobs with different thresholds in processed NIR images of out-of-spec eggs.

irregularities on the surface of eggshells using transmitted infrared light. By analyzing the shape of the eggshell transmitted by near-infrared light, we were able to detect local thickness variations. In the future, we will try to match the NIR image with the three-dimensional shape of the shell acquired by a 3D scanner to deal with variations in the thickness of the entire shell and to detect protrusions near the sides of the shell. In addition, we will investigate more stable detection methods, including a solution that uses deep learning to estimate the three-dimensional shape of the shell from the infrared transmitted light images.

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