ORIGINAL ARTICLE

Texture Analysis based on Ultrasound Elastography for Food Design

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Abstract: The food industry makes an effort for development of food products to satisfy various needs of consumers. They must evaluate foods from various viewpoints to satisfy the sensibility of consumers: a physical characteristic, a chemical, nourishment, price, seasoning, temperature, etc. To secure reproducibility by evaluating the features of the food product quantitatively and objectively is useful to establish the manufacturing method of the food product. We pay attention to the food index that the quantitative and objective evaluation with the machinery has not been carried out although the panel test has been carried out, and suggest a new method to mechanize this. We focus on chewy texture that are important property to decide the taste, and suggest a method to check hard/soft distribution in an elastic food. In this article, we explain an application method of the new technique for an example by the design of rice noodle.

Keywords: Food design, Ultrasound elastography, Texture

1. INTRODUCTION

Human sensibility for foods includes various kinds. Physical quantities or chemical properties, such as taste on our tongue surface, a smell, heat, coldness, weight, etc. occur to us immediately, which can be measured as instantaneous values. On the other hand, there are chewy texture (resistance to the teeth), drinkability (feeling in a throat when drinking), feeling on the tongue, the sight information, etc. as indices of the sensibilities. In history of cooking technology of the human, a huge amount of knowledge has been saved as science of cooking about techniques to design a part of food taste such as chewy texture, drinkability, feeling on the tongue, etc. until now. In this article, we focus on chewability and feeling on the tongue. Particularly, about noodles, which difference in chewability and feeling on the tongue affect the taste directly, we suggest a new food measurement technique to help food texture design. In cooking science, probably there are no study that the attempt to measure hard/soft distribution in the food influencing chewability and feeling on the tongue and to visualize it as a 2D image. In this respect, our suggestion is an attempt to get the new index of the food evaluation. We think that it is in a useful tool to produce food products in response to the food consumers' needs. Our method gets an idea from a medical technology and uses an ultrasound diagnostic equipment which is a famous medical instrument. In this article, we show the design of rice noodles of several millimeters in diameter as an application example of the proposed technique.

Although rice is the only staple food grown in Japan, the consumption of rice in Japan has decreased with the Westernization of food in recent years; the share of rice as a staple food is being eroded by various foods made from wheat. Nevertheless, rice remains an important staple food in Japan. Japanese people most often eat rice cooked by itself as a staple food. In addition, cooked rice is eaten in a range of foods in which it remains recognizable. Regardless, Japanese people usually eat rice in its original form. On the other hand, many processed foods made of rice also exist in Japan and are familiar to Japanese people. Although rice noodles remain relatively unpopular in Japan, their different texture makes them a novel delicacy. Therefore, the spread of rice noodles is expected. The texture qualities that consumers who like rice noodles consider important include "chewiness" and "over a throat." When evaluating foods with elasticity, chewiness, over a throat, texture, overall taste, aroma, and temperature must be taken into account. These characteristics make elastic foods unique. These sensations are considered to be attributable to the food's texture and are actively studied in sensitivity engineering and food processing [1-5]. Various noodles dishes exist worldwide. Noodles are made from the powder of cereals. People who enjoy the over the throat and chewiness of noodles produce and cook noodles worldwide. As noodles are mainly made from the granular materials of cereals, it is relatively easy to create new methods for processing or cooking noodles. Even when using the same material, it is possible to make noodles with completely different texts depending on the production method or recipe. In food product design in Japan, sensory evaluation by panels is used to evaluate the levels of the chewiness and

over a throat. As humans actually eat samples, this is a very effective way to enhance the texture design of food.

We propose a method of visualizing the distribution of hard and soft areas inside elastic foods and evaluating food texture on the basis of this information. The distribution of hard and soft areas inside foods was estimated by processing tomographic images (i.e., B-mode images), which can be recorded by ultrasound diagnostic equipment using in medicine. The principle used as the foundation of the proposed method is called ultrasound elastography [6-13]. It is put into practical use in medical diagnostics to non-invasively examine malignant tumors [14, 15]. Additionally, there are some researches in the use of ultrasound elastography in objects besides the human body. However, although some studies have evaluated the application of ultrasound elastography in pieces of meat [16-18], research on elastic foods such as rice noodles has not been performed using this technique. Furthermore, as special hardware is needed for ultrasound elastography, its introductory cost is unrealistic for use in food design. Therefore, we propose a method for estimating the distribution of hard and soft areas inside elastic foods using only tomographic images (i.e., B-mode images), which can be recorded with the comparatively cheap and widespread ultrasound diagnostic equipment. The technology proposed herein is applicable to the design of not only noodles, but also many other elastic foods.

In this paper, we propose a new food design technology and analyzed the distribution of hard and soft areas inside noodles made from rice flour as the main material. Furthermore, we explored the possibility of the practical use of the method to non-destructively evaluate food quality in the processing of rice noodles.

2. MATERIALS AND METHODS

2.1 Method to estimate distribution of hard and soft area inside a food

The procedure of the proposed method, which uses the principle of ultrasound elastography (Fig. 1) to estimate the distribution of hard and soft areas inside noodles, is as follows.

- 1) First, a technician acquires the B-mode images of boiled noodles by using ultrasound diagnostic equipment. The noodles are placed on a hard table, and pressure is applied from the top down, slightly altering the noodles. B-mode images are recorded before and after pressure is applied.
- 2) Next, the region of interest for analysis in the acquired B-mode image is specified. In this study, the range

Figure 1: Principle of elastography

Although many methods were proposed as elastography, in speckle tracking of B-mode image used for this research, hard and soft distribution was estimated based on modification of each small domain inside a food.

from the probe to the floor is clipped to a rectangle. Furthermore, in order to unify the size of the region of interest before and after pressure application, alignment reduction of the clipping figure before pressure is performed in the direction of the pressure.

- 3) The particle image flow velocity measuring method, termed particle image velocimetry (PIV) is applied to the B-mode images before and after pressure is applied in step (2). The small spotted pattern called speckling is generally easy to observe in the B-mode images obtained from targets with varying acoustic impedance. In this process, PIV processing analyzes these speckle movements. The size of the search range in PIV processing and its analysis window is set to correspond to the magnitude of the modification caused by pressure. The vector diagram describing the movement of speckles is obtained by PIV processing. The PIV processing used in the present study was a plug-in for ImageJ image processing software. "ImageJ" is a freely available java-based public-domain image processing and analysis program developed at the National Institutes of Health (NIH) [19].
- 4) Next, a domain with the following features is searched for in the obtained vector diagram: (A) the domains in which vectors of similar length align (i.e., the pressure direction or anti-pressure direction) and forms the group; (B) the domains where the vector group applicable to (A) forms an orderly layer in the vertical direction; (C) The domain where a vector group of a certain size faces in either the left or right direction (horizontal direction) in the vector diagram; (D) the domains in which each vector in a vector group has not aligned; (E) the domains in which the vector group is not formed.
- 5) Finally, soft and hard areas in each domain are manually labeled with respect to conditions (A)–(E) above. The judgment of hard versus soft is subjective.

Here, we explain the details of steps (4) and (5). A hard portion is expanded parallel to the pressure direction. Meanwhile, a soft portion is reduced along the pressure direction. However, this is not realized when there is only a domain that does not have a hard/soft difference on the axis parallel to the pressure direction. Horizontal particle movement occurs inside the food near the boundary of 2 domains that have a large difference in hardness. In addition, when the pressure grade in the pressure direction is too large compared to the sample size, the same phenomenon occurs. However, the soft portion also moves substantially horizontally in contrast to a hard portion. In the domains in which the elastic limit is exceeded when pressed, the movement directions of each particle in B-mode images are easy to be separated. The movement of particles also becomes disorderly when the area of each hard and soft domain is comparatively small and the hard and soft parts become intertwined.

The abovementioned judging standard is summarized in Fig. 2; Fig. 2(A) and (B) are mimetic diagrams of foods with 2 layers (hard and soft portions) that are obtained in step (2). When the figure in which the original image is reduced vertically is compared to that obtained by pressing the sample from the top down, the compression ratio of the hard part is small and the soft part will be compressed greatly. In the hard part, the vector diagram showing the situation of movement of speckling inside the B-mode images is expressed as a vector group that tries to spread in the vertical direction, and the other is drawn as a vector group that tries to be shortened in the vertical direction in the soft part. The tendency is similar to that shown in Fig. 2(C) and (D), which shows a more complicated structure. Furthermore, in both cases, in the domains of the hard and soft parts, which can be considered locally homogeneous, a continuous change in the vertical direction of vector length should occur. However, in the case of Fig. 2, we assume an elastic food that has sufficient size to the compression ratio based on pressure and the probe size of the measurement apparatus. When analyzing small thin foods and foods that reach their elastic limit with a small amount of compression, the abovementioned problems are also likely to arise.

2.2 Preliminary experiment using a tofu

The distribution of hard and soft areas inside the sample is visualized according to the process described above. To evaluate the proposed method, a preliminary experiment was conducted. The proposed technique was applied to a sample comprising layered tofu with varying hardness. A Smooth fine-grained tofu (soft tofu) was put on a cotton

Figure 2: Schematic view of the internal structure of pressed foods

tofu (hard tofu). Each tofu was approximately 3 cm thick. This sample food was placed on a horizontal stand. Pressure was then directly applied with the ultrasound probe from the top down, and the B-mode images were obtained.

2.3 Main experiment using rice noodles

Next, as main experiment, the texture analyses of flat noodles made from rice and wheat flour was carried out using two kinds of noodles which were different with respect to the content of rice flour. For the noodles containing more rice flour, the weight ratio of rice flour and wheat flour was 8:2. For the other kind of noodle, the ratio was 7:3. The sample comprised 105-120, 30-45, 60, and 3 g, rice flour, wheat flour, distilled water, and salt, respectively. Most of the rice flour was gelatinized in advance and was used to make dough. Two pieces of dough were made without initially mixing wheat and rice flour; the rice flour dough, which was gelatinized, and wheat flour dough were combined and kneaded. The dough was subsequently blended. For each kind of noodles above mentioned, two kinds of noodles were created with respect to the length of time to knead the dough. The ratio of the length was 1:2 (approximately

2 minutes versus 4 minutes) between the two kinds of noodles. The dough which kneaded during shorter time was barely formed to noodles. The dough was prolonged in order to make it a fixed thickness (approximately 3 mm); it was then cut into 6-mm-wide sections to form the noodles. Both kinds of noodles were boiled in four kinds of boil time (3, 7, 10, and 11 minutes).

After boiling, the noodles were drained, covered with cellophane to retain moisture, and allowed to cool to room temperature (25°C). The sample was cut into 40-mm-long sections and fixed on the table, and B-mode images were recorded.

The following comparisons were made in the main experiment. First, 2 kinds of rice noodles containing 30% wheat flour by weight as a binding agent with different kneading times were compared after boiling for 10 minutes. Each length of time to knead the two kinds of dough was 2 and 4 minutes. In addition, a similar experiment was conducted after boiling for 11 minutes. Next, rice noodles containing 20% wheat flour by weight as a binding agent with the same kneading time were compared after boiling for 3, 7, or 10 minutes.

3. RESULTS

The estimation of the distribution of hard and soft areas inside the 2-layer tofu is shown in Fig. 3. Figure 3 (A), (B), and (C) are the B-mode images before pressure, the vector flow chart showing speckle movement, and the distribution of hard and soft areas estimated by using the vector flow chart, respectively.

The distribution of hard and soft areas of rice flour noodles (30% wheat flour blend) is shown in Fig. 4. Figure 4 (A) and (B) show the analysis results of noodles with short and long kneading times, respectively. In Fig. 4 (A) and (B), both samples were boiled for 10 minutes. In Fig. 4 (C) and (D), the samples were boiled for 11 minutes. In Fig. 4 (A)–(D) the upper, middle, and lower rows show the B-mode images before pressure, the vector diagram from the PIV processing results, and the distribution of hard and soft areas, which were read on the basis of the vector diagram, respectively. The distribution of hard and soft areas was labeled manually in consideration of the steps (4) and (5) of the method described above. In both analyses of the noodles kneaded 200 times, the vector group was disorderly. On the other hand, there were many portions where the direction of the vectors was regular in 1 of the 2 analysis results of the noodles kneaded 400 times (Fig. 4(D)). This indicates that the distribution of hard and soft areas inside the noodles kneaded many

Figure 3: Distribution of hard and soft area inside the sample food (tofu)

(A) B-mod image expressing a cross section perpendicular to the height direction. (B) Result of PIV processing. (C) Distribution of hard and soft area estimated based on the result of PIV processing (B).

times was more homogeneous than that of the noodles kneaded less. However, this tendency was not observed at all the parts of the noodle, including Fig. 4 (A) and (C). This suggests the influence of the difference in the measured part of a noodle is greater than the length of time the noodle is boiled.

Figure 5 (A), (B), and (C) show the differences in the distribution of hard and soft areas when the length of boiling time was 3, 7, and 10 minutes, respectively. The maps of the distribution of hard and soft areas show the distribution of hard and soft areas equalizes with increasing boiling time. Increasing boiling time leads to the increasing puffiness, springiness, and resilience characteristic of rice noodles.

4. DISCUSSION

Although the distribution of hard and soft areas of simple forms could be visualized in the preliminary

Figure 4: Estimation of distribution of hard and soft area inside a noodle

(A) A rice noodle kneaded for a short time and boiled 10 minutes. The upper row, the middle row, and the lower row show B-mode image, result of PIV processing, and distribution of hard and soft area, respectively. A solid line, a dashed line, and a dotted line express a hard domain, a middle domain, and a soft domain, respectively. (B) A rice noodle kneaded for a long time and boiled 10 minutes. (C) A rice noodle kneaded for a short time and boiled 11 minutes. (D) A rice noodle kneaded for a long time and boiled 11 minutes.

experiment, the difference in the distribution of hard and soft areas of noodles made under the different conditions could not be sufficiently distinguished in the main experiment. As the speckle tracking accuracy of PIV processing strongly influences the estimated results of the distribution of hard and soft areas inside foods, the accuracy of the PIV processing must be improved. In addition, image recognition technology to identify the hard and soft domains from PIV processing results must be developed.

Moreover, the technique for analyzing the PIV processing results must be refined owing to the complicated movements of speckles in the B-mode images of elastic foods, which become plastic as a result of pressure.

Various elastic foods are eaten worldwide. B-mode images can be used to record virtually anything. As human tissue exhibits characteristic speckle patterns on B-mode images, B-mode image processing technologies using the feature of the speckle patterns have been proposed but is mainly used for medical diagnostics. Ultrasound elastography also analyzes the features of the human body. However, it is difficult to analyze speckle movements in B-mode images of foods, because food often exhibits more variable speckling patterns than human tissue.

Meanwhile, it is necessary to perform the steps (4) and (5) in the proposed technique manually. These steps must be automated in order to put the proposed method into practical use in food design.

Figure 5: Distribution of hard and soft area inside a noodle

(A) Rice noodle including 20 mass % of wheat flour and boiled for 3 minutes. (B) Rice noodle including 20 mass % of wheat flour and boiled for 7 minutes. (C) Rice noodle including 20 mass % of wheat flour and boiled for 10 minutes. In each figure set, the upper section is a B-mode image before the pressure. The middle section shows a vector map stemming from optical flow. The lower is a distribution of hard and soft area.

5. CONCLUSION

We proposed the new technique to help food design. This is the information to strongly influence over chewy texture, feeling on the tongue, and feeling in the throat when drinking. We expect that visualizing this information allows us to design elastic foods with complicated texture, the reproducibility of which is good.

We applied the proposed method to the easy example and examined the validity. Although the hard and soft distribution of simple form was able to be visualized in the preliminary experiment, the difference in the hard and soft distribution of the noodles enough to distinguish clearly the noodles made under the different manufacturing conditions was not able to be confirmed in the main experiment. Since the speckle tracking accuracy in PIV processing greatly influences the estimated result of the hard and soft distribution inside a food, the improvement in accuracy of the PIV processing is needed to be developed. And we also require the image recognition technology to identify the hard and soft domain from a PIV processing result.

Moreover, we have to develop the analytical skills of the PIV processing result of having caught complicated movement of speckle in the B-mode images of an elastic food which becomes a plastic food owing to a little pressure. Furthermore, we have to devise the valuation function which maps hard and soft distribution data to the numerical value indicating the grade of food texture in order to use the result obtained by the proposed method for the quantitative evaluation of food texture. This is also a future subject.

Meanwhile, the food texture measuring method which we proposed is applicable not only to rice noodles which were handled in this paper but also to any food which have the elastic body and can provide B-mode images. The scope of our proposal is very wide. We are going to perform technical improvement of the proposed method, conducting a sensitivity evaluation experiment in parallel on various food including elastic foods made from rice flour.

ACKNOWLEDGEMENTS

This work was partially supported by The Tojuro Iijima Foundation for Food Science and Technology.

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