Journal of Sensor Technology, 2014, 4, 148-153
Published Online September 2014 in SciRes. http://www.scirp.org/journal/jst
http://dx.doi.org/10.4236/jst.2014.43014

A Piezoelectric Sensor-Based System for Objective Analyzing of the Preparation of Fluid Foods

Hajime Iwamori, Ichiro Ashida, Yozo Miyaoka

Department of Health and Nutrition, Niigata University of Health and Welfare, Niigata, Japan
Email: iwamori@nuhw.ac.jp

Received 28 June 2014; revised 28 July 2014; accepted 27 August 2014

Abstract

A monitoring system using a piezoelectric sensor was developed for the quantitative analysis of the stirring process in which a mixture of a thickener with water was prepared. A thin piezoelectric sensor film was attached to the inside of a glass container in which the mixture was stirred and connected to a recorder. Seven healthy young participants were asked to conduct stirring for 90 s at three cycles per second (3 Hz). A triphasic wave with a large upward peak was recorded in each cycle of stirring. The average period across the seven participants was 0.337 s (n = 613 cycles), and statistical analysis revealed no significant difference between the average value and the expected value of 0.333 s. Video images captured during stirring were analyzed, and the analysis showed that the peak of the large upward wave appeared approximately 0.12 s (approximately 36% of the average period) after the time when the spoon head for stirring passed near the piezoelectric sensor. The monitoring system developed in this study allows the precise temporal analysis of stirring for the preparation of a mixture.

Keywords

Thickener, Preparation, Stirring, Piezoelectric Sensor, Monitoring

1. Introduction

It is necessary for healthcare practitioners who prepare special foods for dysphagic patients to thoroughly understand the preparation process because inappropriate preparation may cause non-uniform physical and/or textural properties, even lumps, in the prepared foods. Despite the necessity of this understanding, few studies have used suitable tools and methods for analysis of the process. First, practitioners need to observe and record the process

How to cite this paper: Iwamori, H., Ashida, I. and Miyaoka, Y. (2014) A Piezoelectric Sensor-Based System for Objective Analyzing of the Preparation of Fluid Foods. *Journal of Sensor Technology*, **4**, 148-153.
http://dx.doi.org/10.4236/jst.2014.43014

precisely.

Piezoelectricity is the electric potential that some materials generate in response to applied mechanical stress, and piezoelectric sensors are popular in both industrial (e.g., microphones) and medical fields (e.g., ultrasonic transducers). Moreover, piezoelectric sensors are useful for recording physiological events such as swallowing [1]-[4], breathing [5] [6], and speech [7]. For example, a piezoelectric sensor can be attached to the surface of the front of the neck to record the laryngeal movement associated with swallowing [2].

This study was designed to develop a simple recording system using a piezoelectric sensor for monitoring the stirring of a mixture consisting of a thickener and water. The recording system was developed only for the analysis of the temporal, not the magnitudinal, aspect of the waves produced by stirring. The validity and reliability of the temporal aspect of the recording system were examined using video image analysis.

2. Materials and Methods

2.1. Participants

Seven healthy young adults (one male and six females, 20.6 ± 0.79 years) were recruited as participants in this study after providing informed consent. The participants were naïve for the stirring task in this study (see below), and all of the participants were right-handed.

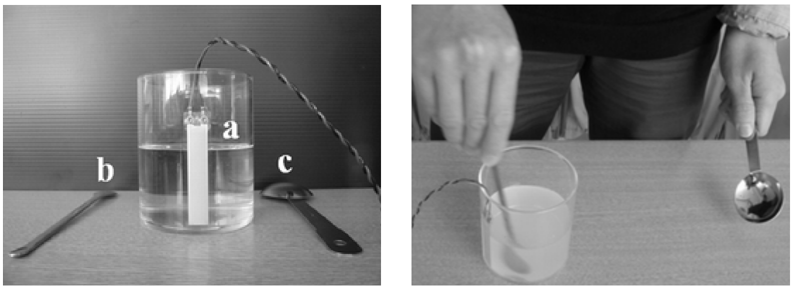
2.2. Preparing the Mixture and Video Recording

A tasteless and odorless thickening agent (Neo-High Toromeal III®, Food-care, Inc., Tokyo, Japan) developed especially for dysphagic patients, was used for preparing a mixture. The thickening agent has xanthan gum as the main ingredient, and xanthan gum shows the following characteristics: 1) high viscosity with even a small amount added to water, 2) high heat resistance, and 3) high stability of physical properties after the completion of preparation. A piezoelectric sensor film (DT2-028K/L, 16.0 × 73.0 mm, Tokyo Sensor Co., Tokyo, Japan) was attached to the inside of the container to monitor the waves produced by stirring the mixture ("a" in **Figure 1(A)**). Approximately 50 mm of the sensor film was soaked in the mixture, and two fine electric wires fixed to the other end of the film were directly attached to two recorders. One recorder was a data logger (midi LOGGER GL220, Graphtec Inc., Yokohama, Japan), and the other was a PowerLab system (AD Instruments Pty Ltd., PowerLab/8sp, Bella Vista, Australia). Digital data of the detected waves were stored directly or indirectly (*i.e.*, via the data logger) on the PowerLab system for recording. A digital notch filter was applied to the electrical signals of the recorded waves at 50 Hzon the PowerLab system to eliminate the noise of the alternating current.

A video camera (DCR-DVD101, SONY, Tokyo, Japan) was used to record the stirring. The camera was mounted on a tripod with the bottom 46.5 cm away from the top of the glass container that was filled with "the mixture". A cross and a circle were drawn on a piece of white paper as reference points for analysis, and the glass container was placed on the paper and adjusted to be positioned at the center of the cross (**Figure 2**). The video recorded by the camera was captured and fed into a personal computer to be converted to the MPEG file format for further analysis. A box containing a light-emitting diode (LED) with a battery was placed near the glass container. The LED was used for synchronizing the signal captured by the video camera, which was delivered when the light was turned on, with a rectangular electrical pulse from the battery on the PowerLab system.

2.3. Procedures

A glass container with a diameter of 80 mm and a height of 100 mm and distilled water (DW) were presented to each participant, who stood near a table on which the container with DW was placed. Two spoons were also presented to the participant: a stainless steel spoon with a diameter of 5 mm ("b" in **Figure 1(A)**) for stirring and a 15 ml stainless steel spoon ("c") for adding the thickening agent. An experimenter initially demonstrated the stirring to each participant and allowed her/him to ask questions about the stirring. Then, the participant was asked to stir the mixture as regularly as possible at approximately 3 Hz (three times per second) for 90 s. The thickening agent was added to the water immediately after the start of stirring. One 90 s trial was conducted for each participant, and the data for seven trials were collected in total. The collected data were separated into three (initial, middle, and last) stages (10 s each), and three groups of 10 s of data (in total, 30 s data) were analyzed individually.



(A) (B)

Figure 1. Setup to measure stirring. (A) The tools used for the measurements. a, a piezoelectric sensor attached to the inside of a glass container; b, one spoon for stirring the mixture of a thickener and water; and c, a second spoon for adding the thickener. (B) Stirring after the addition of the thickener. The participant stirred the mixture using the smaller spoon. The piezoelectric sensor film was connected to the recorder. See the text for details.

The thickener and DW were mixed by one of the experimenters, and the mixing was recorded by the videocamera only for video image analysis. The preparation was conducted by the experimenter in the exact manner same as the participants. Prior to the preparation, the LED light was turned on to synchronize the videocamera pictures with the data from the PowerLab system (see above).

2.4. Data and Statistical Analyses

A specific parameter was used in this study to analyze the mixing process: the period between two peaks of consecutive waves associated with stirring detected by the piezoelectric sensor (“a” in **Figure 2(A)**). The “cycle calculation” tool of the PowerLab system was used to measure the period according to the following steps: 1) the highest point of each wave was identified, 2) the identified point was converted into a pulse of 1.0 ms width, and 3) a time interval between two consecutive pulses was measured as the period. The frequency was calculated as the reciprocal of the period.

The periods calculated from the waves were averaged for each participant. The number of stirring motions was counted from the start to the end of each trial. The null hypothesis for statistical examination was that the overall average of the periods did not differ significantly from the expected value, 0.333 s (the reciprocal of 3.0 Hz). A one-sample t-test was used to test the null hypothesis, and a level of $P < 0.05$ was set for statistical significance.

The movies recorded by the video camera were reproduced using computer software (TMPEGEnc MPEG Editor version 3.0.5, PEGASYS, Tokyo, Japan) and separated frame-by-frame (33.3 ms per frame) into freeze-frame pictures. The image of the spoon moved from one frame to the next during stirring, and the spoon passed the four bars of the cross regularly. The relative location of the spoon to the four bars was depicted as a trajectory of stirring by plotting them as points from the sequential frames and by connecting the points consecutively with lines.

3. Results

Figure 2(A) presents a trajectory of the changes in electrical potential recorded by a piezoelectric sensor during a stirring cycle of a period of approximately 0.33 s, while **Figure 2(B)** depicts a series of sample pictures captured by the video camera during the cycle. A triphasic wave presented in **Figure 2(A)** started from an upward peak (“a_1”) at which the spoon head passed near the piezoelectric sensor (“a_1” in **Figure 2(B)**). The trajectory showed a downward slope approximately 0.06 s after the peak, followed by a larger upward peak (“P”). The larger upward peak, which was used as a signal for measurement of a period, appeared approximately 0.12 s after the start (“a_1”). The trajectory returned to the baseline (“b”) and ended with a period of approximately 0.33 s (“a_2”) after negligible peaks and valleys.

Figure 3 shows superimposed traces of five randomly sampled stirring cycles. Despite some variations among the traces, the locations of upward and downward peaks were similar to each other. Five peaks of the

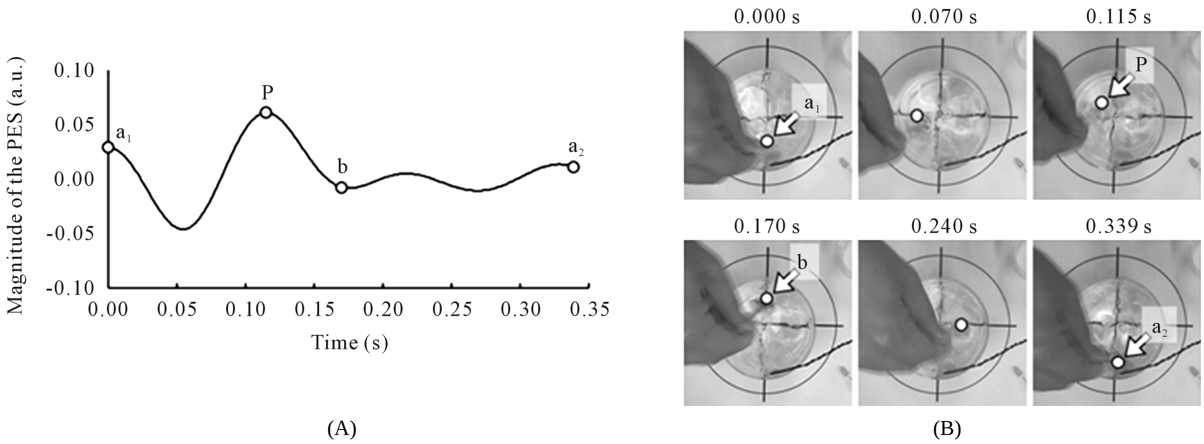


Figure 2. Sample video images and recordings of changes in electric potential by the piezoelectric sensor during stirring. (A) A trajectory recorded during a stirring cycle with the piezoelectric sensor. The six pictures from "a_1" to "a_2" correspond to the time points from "a_1" to "a_2", respectively, in the video images in B. (B) Images from the video recorded during the stirring cycle. The numbers indicate the time after the start of the stirring cycle. The open circles in "a_1" to "a_2" show the location of the spoon head, and the white arrows indicate the corresponding points from "a_1" to "a_2" in **Figure 1(A)**. The piezoelectric sensor was attached to the inside of the glass container at the bottom of each picture. The spoon rotated in the clockwise direction. See the text for details.

second upward group, which were used for measuring the periods between two consecutive waves, were narrowly tuned (see the group of arrows in **Figure 3**). Note that the present study was not sensitive to variations in the magnitudes of the traces. The overall average period during stirring was 0.337 ± 0.105 s (mean ± SD; n = 613 cycles). Statistical analysis with the one-sample t-test revealed that the average period did not differ significantly from the expected value, 0.333 s, and the 95 percent confidence interval was 0.329 s.

4. Discussion

This study presented a simple recording system that uses a piezoelectric sensor to monitor stirring. The recording system can provide temporal data about stirring, and the data are likely to be useful for quantitative analysis of the time course of stirring. Previous studies rarely analyzed the time course and often described almost nothing about sample preparation. Details of preparation were described in several studies: e.g., 1) "All solutions were made by mixing … for 30 s at…", 2) (a mixture)… (was) stirred for 30 s until a smooth consistency was achieved…", and 3) "(a mixture)… (was) continuously stirred for 20 s (or until completely dissolved) using a Cimarec 2 magnetic stirring device..." [8]-[10]. Even in these studies, it is difficult to understand the time course of stirring for 20 s or for 30 s due to the lack of frequency data. The situation suggests the possibility of relatively little attention being given to the time course or the process of sample preparation.

Each of the recorded waves (**Figure 2** and **Figure 3**) had two components, temporal (cyclic) and magnitudinal (amplitude), but this study paid attention only to the temporal component because the present authors did not know whether there were any consistent (e.g., linear) relationships between the degree of distortion of the sensor and the magnitude of the wave. Thus, it would have been inappropriate to analyze such a situation, for example, if a larger wave resulted from greater distortion of the sensor by stirring. In clinical sites in Japan, and likely in other countries, the preparation of a mixture of a thickener with fluids (water, juice, and others) is generally performed manually, not instrumentally. Analysis of the time course may reveal that some practitioners stir the mixture regularly and that others do so less regularly. The difference in stirring between practitioners can affect the physical or textural properties of the mixture. These possible effects indicate the importance of monitoring the preparation during stirring to assure that the required properties are achieved.

The video image analysis seems to verify the present recording system. The analysis indicated three major peaks, two upward and one downward, of the recorded wave (**Figure 2(A)**). The three peaks were derived from the flow of the mixture, which was detected by a piezoelectric sensor during stirring. The first upward peak appeared just after the spoon head passed near the sensor, suggesting that the flow of water drove the positive electricity by deformation of the sensor as the upward peak. The downward peak that followed may represent

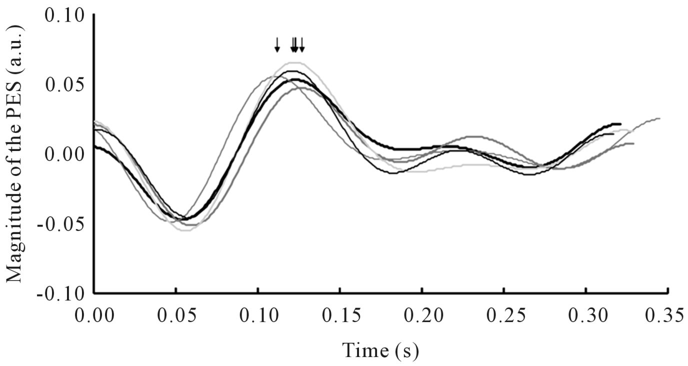


Figure 3. Five waveforms recorded with the piezoelectric sensor. The cycle durations (from the start to the end of each cycle) and locations of peaks of trajectories were similar. The average period of the stirring cycle was approximately 0.33 s, and the second and larger upward peaks appeared at approximately 0.12 s after the start of the cycle. Each arrow indicates the location of the peak in each trajectory. Note that the five second and larger upward peaks are narrowly tuned. A thicker and darker trajectory is identical to that in **Figure 2(A)**.

the negative electricity of the sensor, which appears inevitably after positive electricity [11]. Although it is not the goal of this study to physically explain the recorded waves, the flow of water during stirring may be more complicated than our supposition. The present study did not visualize the flow using suitable techniques (e.g., using pigment). Complicated flow might produce the second upward peak, but it is necessary to conduct experiments with visualization of the flow and video image analysis to reach such a conclusion.

The waves recorded with the piezoelectric sensor during stirring are reliable to some degree. Stirring the mixture was conducted manually in the present study. The (possibly low) reliability is most likely related to the situation. In other words, mechanical stirring could increase the reliability. It is surprising that after the start of stirring in all five of the cycles, the second and larger upward peaks always appear at approximately 0.12 s within a small range (**Figure 3**). In fact, statistical analysis revealed that the average period (0.337 s) did not differ from the expected value (0.333 s). To evaluate the reliability more precisely in the future, it is necessary to conduct a comparison of the waves recorded with both manual and mechanical stirring.

5. Conclusion

In conclusion, the piezoelectric sensor-based recording system can detect the triphasic waves produced by the flow of a mixture during stirring. The peak of the largest upward wave in each stirring cycle is a useful point for measuring a period between two consecutive cycles. Video image analysis verified the reliability of the recording system by measuring the periods of the repeated stirring cycles.

References

[1] Ashida, I., Miyaoka, S. and Miyaoka, Y. (2009) Comparison of Video-Recorded Laryngeal Movements during Swallowing by Normal Young Men with Piezoelectric Sensor and Electromyographic Signals. *Journal of Medical Engineering and Technology*, **33**, 496-501. http://dx.doi.org/10.1080/03091900902952691

[2] Ertekin, C., Pehlivan, M., Aydogdu, I., Ertas, M., Uludag, B., Celebi, G., Colakoglu, Z., Sagduyu, A. and Yuceyar, N. (1995) An Electrophysiological Investigation of Deglutition in Man. *Muscle Nerve*, **18**, 1177-1186. http://dx.doi.org/10.1002/mus.880181014

[3] Miyaoka, Y., Ashida, I., Kawakami, S., Tamaki, Y. and Miyaoka, S. (2011) Generalization of the Bolus Volume Effect on Piezoelectric Sensor Signals during Pharyngeal Swallowing in Normal Subjects. *Journal of Oral Biosciences*, **53**, 65-71. http://dx.doi.org/10.1016/S1349-0079(11)80037-X

[4] Pehlivan, M., Yuceyar, N., Ertekin, C., Celebi, G., Ertas, M., Kalayci, T. and Aydogdu, I. (1996) An Electronic Device Measuring the Frequency of Spontaneous Swallowing: Digital Phagometer. *Dysphagia*, **11**, 259-264. http://dx.doi.org/10.1007/BF00265212

[5] Siivola, J. and Heikki Lang, A. (1998) Non-Invasive Piezoelectric Transducer for Recording of Respiration at the Lev-

el of Diaphragm. *Electroencephalography and Clinical Neurophysiology*, **106**, 552-553. http://dx.doi.org/10.1016/S0013-4694(98)00019-4

[6] Bu, N., Ueno, N. and Fukuda, O. (2007) Monitoring of Respiration and Heartbeat during Sleep Using a Flexible Piezoelectric Film Sensor and Empirical Mode Decomposition. 29*th Annual International Conference of the IEEE*, *Engineering in Medicine and Biology Society*, Lyon, 22-26 August 2007, 1362-1366.

[7] Miyaoka, Y., Ashida, I., Kawakami, S. and Miyaoka, S. (2009) Applicability of Piezoelectric Sensors for Speech Rehabilitation. *Journal of Medical Engineering and Technology*, **33**, 328-333. http://dx.doi.org/10.1080/03091900802602784

[8] Dewar, R.J. and Joyce, M.J. (2006) Time-Dependent Rheology of Starch Thickeners and the Clinical Implications for Dysphagia Therapy. *Dysphagia*, **21**, 264-269. http://dx.doi.org/10.1007/s00455-006-9050-7

[9] O'Leary, M., Hanson, B. and Smith, C. (2010) Viscosity and Non-Newtonian Features of Thickened Fluids Used for Dysphagia Therapy. *Journal of Food Science*, **75**, E330-E338. http://dx.doi.org/10.1111/j.1750-3841.2010.01673.x

[10] Garcia, J.M., Chambers, E.T., Matta, Z. and Clark, M. (2008) Serving Temperature Viscosity Measurements of Nectar- and Honey-Thick Liquids. *Dysphagia*, **23**, 65-75. http://dx.doi.org/10.1007/s00455-007-9098-z

[11] Cady, W.G. (1964) Piezoelectricity. Dover Publications, Inc., New York.