TECHNICAL NOTE:

RAPID MEASUREMENT OF PHYSICAL PROPERTIES OF CHEDDAR CHEESE USING A NON-CONTACT ULTRASOUND TECHNIQUE

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ABSTRACT. *This article discusses the first known application of the non-contact piezoelectric ultrasound system for physical property measurement of food with specific application to cheese. A non-contact ultrasound parameter called the relative attenuation and the ultrasound velocity were measured and correlated with the physical properties of Cheddar cheese (such as failure strain, failure stress, Young's modulus, and toughness) using a multi-linear neural network analysis. When the relative attenuation, velocity, and cheese types were used as inputs to the neural network, the squared correlation values for the prediction of failure strain, failure stress, secant madulus, and toughness of Cheddar cheese were 0.836, 0.947, 0.625, and 0.956, respectively. Results indicated that the non-contact ultrasound technique has excellent potential for rapid and automatic quality measurement of the physical properties of Cheddar cheese.*

Keywords. *Non-contact ultrasound, Physical property, Cheddar cheese, Neural networks.*

Ultrasound has been used to characterize food materials due to its nondestructive and rapid measurement capability. However, the present contact ultrasound procedure has a significant limitation in that it uses a coupling medium between the transducer and test specimen owing to extremely high attenuation of ultrasound by air. For ultrasound to propagate through a test specimen effectively, coupling liquids (such as oil or gels) or an immersion method (which consists of placing the specimen in a water bath) has been used. The use of coupling liquids and water immersion methods is undesirable in food quality measurement and process control since it might change or destroy the liquid-sensitive, porous, and continuously formed food materials due to absorption or interaction of liquid couplants with the food system analyzed.

Acoustic waves are affected by microstructure, texture, and composition. Since acoustic scattering is dependant on density, components, particle size, and shape of media, acoustic parameters, such as velocity, amplitude attenuation, and frequency spectrum are good indicators of the food physical properties, such as structure, texture, and physical state of the components of the media (Povey and McClements, 1988). Among the acoustic parameters, velocity is the most widely used parameter because it is simple to measure (Povey and McClements, 1988). The distance traveled by the wave must be measured accurately in velocity measurement. In addition to velocity measurement, the attenuation parameter has been used for foods. The attenuation parameter is mostly used for the detection of defect and microstructure of foods. However, this technique is restricted to food products with low attenuation characteristics.

With the improvement in sensor technology, applications in the area of nondestructive food quality assessment have increased for meats, fruits, and dairy products. However, all of the past research dealt with conventional contact ultrasound measurement. Lee et al. (1992) reported that ultrasound spectra analysis has the potential for the estimation of rheological properties and structural changes in cheese. Gunasekaran and Ay (1996) demonstrated that ultrasound attenuation can predict the optimum cutting time of cheese based on the degree of coagulation of milk. Benedito et al. (1999) utilized ultrasound propagation velocity as an indicator of cheese maturity by measuring moisture and texture with linear correlations of 86% and 93%, respectively. In their study, olive oil was used as a couplant to minimize the energy losses at the cheese-transducer interface. The use of a couplant is undesirable because it promotes an indirect contact of the sensor with the food. This limitation has been overcome by a recent novel automatic thickness measurement method using air-coupled transducers as well as by development of effective air-coupled transducers (Bhardwaj, 2000). Recently, Bhardwaj (1997, 1998) developed novel acoustic matching layers using soft polymers to optimize ultrasound transmission in air using 100 kHz to 5 MHz frequency transducers.

Article was submitted for review in January 2001; approved for publication by the Food & Process Engineering Institute of ASAE in August 2001.

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  ISSN 0001-2351

The most important element in air–coupled transducer is the matching layer, which determines the efficiency of ultrasound transmission from piezoelectric material to medium. For perfect transmission of ultrasound, a specific matching layer should be developed. The thickness of the matching layer should be a quarter of a wavelength and a specific acoustic impedance of 0.1 Mrayls is required (Hayward, 1997). Fox et al. (1983) utilized silicon rubber as the matching layer for 1 MHz and 2 MHz frequency transducers. They reported that the transducers were able to measure the distance in air from 20 mm to 400 mm with an accuracy of 0.5 mm. Haller et al. (1992) improved the ultrasound transmission efficiency using a specially designed matching layer with tiny glass spheres in the matrix of silicone rubber. To overcome the high acoustic impedance mismatch between air and the test sample, highly sensitive transducers were developed (Bhardwaj, 2000). The non–contact transducers provide ultrasound energy transfer from the transducer to air from –54 dB to –58 dB, which is approximately 30 dB below the sensitivity of conventional contact transducers. Such sensitivity might have the potential for improved estimation of ultrasound parameters.

Texture is considered as one of the most important sensory attributes of cheese for consumer acceptability and quality (McEwan et al., 1989). Texture in cheese is determined by the composition and complex interaction of components, such as casein, fat, moisture, and other minor elements. Usually, the cheese made from reduced fat milk is harder and drier than that made from whole milk due to an increase in structural matrix per unit cross–sectional area (Emmons et al., 1980). Hence, the types of cheese, its components, and the state of ripening are significantly related to acoustic parameters. The goal of this research is to determine the physical properties of cheese using a novel non–contact piezoelectric transducer and explore its potential for rapid and automatic measurement of cheese quality.

The objectives of this study were to: (1) investigate sampling procedures using the non–contact ultrasound transducer for measurement of the physical property of cheese, (2) calibrate the data using standard mechanical properties obtained from the Instron testing machine, and (3) demonstrate a non–contact ultrasound technique using artificial neural network for rapid, and automatic measurement of the physical properties of cheese.

Materials and Methods

Materials

Five kinds of Cheddar cheese (Kraft foods Inc. Glenview, Ill.) were purchased from the local grocery store: 2% milk sharp, sharp, 2% milk extra sharp, extra sharp, and New York aged reserve Cheddar cheese. Samples of size 45 × 45 × 25 mm were cut from each block of cheese (0.28 kg) using a specially designed wire cutter and stored at 8°C in an ice box. Eighty pieces of cheese were prepared from the five different types of cheddar cheese. Each sample was wrapped in a plastic film and stored at 4°C until measurement.

Non–Contact Ultrasound Transducer System

A non–contact ultrasound system (NCA 1000) from SecondWave System Inc. (Boalsburg, Pa.) was used to examine the ultrasound wave propagation velocity and the relative attenuation. The analyzer is designed to use a computer–generated chirp with the best attributes of non–contact transducers. Synthetic aperture imaging technique is adapted for the signal processing in the NCA 1000. The analyzer can measure the time–of–flight within an accuracy of ±50 ns under ambient air and ±1 ns under closed conditions.

After simple calibration for air velocity and time–of–flight in air column and from sample surface, the thickness and ultrasound velocity of sample can be determined automatically by the following equations (Bhardwaj, 2000):

$$D_m = V_a \times [t_a - (t_1 + t_2) / 2] \tag{1}$$

$$V_m = D_m / [t_a - (t_1 + t_2) / 2] - (t_a - t_c) \tag{2}$$

where

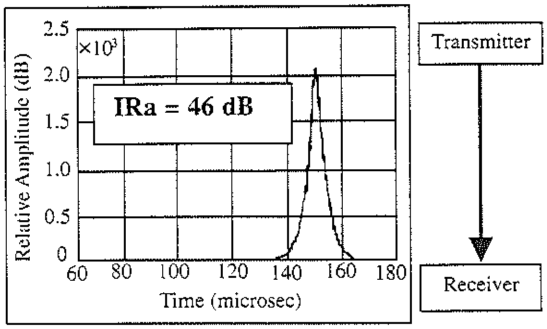
D_m = sample thickness
V_a and V_m = respective velocities of ultrasound in air and through the sample
t_a = time–of–flight between transmitter and receiver in air
t_c = time–of–flight between transmitter and receiver with sample
t_1 = time–of–flight between the transmitter and sample
t_2 = time–of–flight between the sample and receiver.

In addition to measurement of the thickness and velocity through the sample, the NCA 1000 can also estimate the integrated response. The integrated response is a measurement of the area underneath the most significant peak (plot of time vs. relative amplitude response from NCA 1000 shown in fig. 1) of the transmitted signal in power units, which is an indicator of the relative attenuation at a particular frequency (Bhadwaj, 2000). The relative attenuation is then calculated by subtracting the integrated response of the transmitted signal through the sample (IR_m) from that of air column (IR_a). The relative attenuation can be defined as the amount of ultrasound energy transmitted into the test material from ambient air as the ultrasound carrier medium.

The cheese sample was placed in between the transmitting and receiving transducers at a distance of 3 cm from the each other and the ultrasound velocity and integrated response of transmitted signal were measured in less than 30 seconds. Each data point was an average of four measurements and each measurement is an average of 20 readings.

Physical Property Measurement

The physical properties of Cheddar cheese, such as failure strain, failure stress, secant modulus (failure stress / failure strain) at failure, and toughness (failure stress × failure strain /2) were measured using an Instron testing machine (Model 4444, Instron, Canton, Mass.). Cylindrical cheese samples, 10 mm in diameter and 18 mm in height obtained from the same location as the non–contact ultrasound measurements, were used for testing. The Instron crosshead (55 mm in diameter) speed was set at 10 mm/min. The load was applied at one end and the force–deformation curve was obtained and recorded using LabView software (Version 5.0, National Instruments, Austin, Tex.). From the force–deformation curve, the physical parameters, such as failure strain, failure stress, secant modulus and toughness were determined (Mohsenin, 1986).



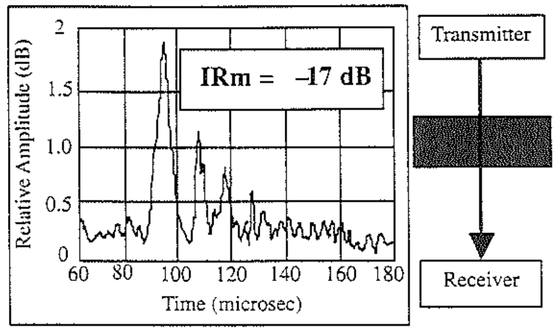


Figure 1. Integrated response (IR) of transmitted signal through (a) air and (b) air and sample; Relative attenuation = $IR_m - IR_a$ = –17 – 46 = –63 dB.

After the ultrasound measurement, the physical properties of cheese, such as failure strain, failure stress, secant modulus, and toughness were obtained from the Instron experiment to validate the results obtained from the non–contact ultrasound system. In this study, a neural network software (NeuroShell release 2.0, Ward System Group, Inc., Frederick, Md.) was used for multi layer neural network (MLNN) analysis.

Results and Discussion

Table 1 shows the R–square and the standard deviation of error between the actual values and predicted values from the MLNN analysis. The velocity, the relative attenuation, and cheese types were used as input to the neural network. The validation correlation coefficients were 0.836, 0.947, 0.625, and 0.956 for failure strain, failure stress, secant modulus and toughness, respectively. This compares well with the results of Benedito et al. (1999).

The structure and texture of cheese depends upon its constituents (Lawrence and Gillies, 1987). Consequently, the changes in texture occur depending upon the type (full fat, reduced fat) and variety (Cheddar, Mozzarella, Swiss, etc.) of cheese. Initial results indicate that the texture of different types of cheese could be predicted with reasonable accuracy using the parameters from non–contact ultrasound measurement. Advantages of MLNN are its ability to simultaneously predict multiple properties and model the non–linear behavior of physical systems.

Although the prediction of some physical properties of cheese, such as failure strain, failure stress, and toughness with the ultrasound velocity, the relative attenuation, and types of cheese showed high accuracy (83.6%, 94.7%, and 95.6%, respectively), the secant modulus had a high variation (62.5%). Figure 2 shows the predicted vs. actual values of failure strain, stress, secant modulus, and toughness. One possible reason for the weak correlation of the secant modulus might be due to the variability in the structure and porosity of cheese. Another factor could be the variability in temperature. A variation of approximately ±2.5°C was observed during measurement. Previous research (Benedito et al., 2000) showed the high variation of the velocity with different sample storage temperatures. Further research needs to be conducted to examine the structural and temperature effects. However, this research demonstrates the feasibility of this approach and introduces a non–contact ultrasound method that has not been known to be used before.

Conclusions

A new non–contact ultrasound system was utilized to determine the physical properties of Cheddar cheese, such as failure strain, failure stress, secant Young's modulus, and toughness, as a function of ultrasound velocity and relative attenuation using the MLNN method. The physical properties of Cheddar cheese could be predicted with accuracies of 83.6%, 94.7%, 62.5%, and 95.6% for failure strain, failure stress, secant Young's modulus, and toughness, respectively. Results demonstrated that the non–contact ultrasound measurement is a promising technology for rapid physical property measurement of Cheddar cheese. Further, due to its non–contact feature, economic and rapid on–line quality assessment of a wide range of food materials is possible. To the authors' knowledge, this is the first application of non–contact ultrasound in food.

Table 1. R^2 of the training and validation results from MLNN. Standard deviation of error is given in parentheses.

	Failure strain (m/m)		Failure stress (kPa)		Secant modulus (kPa)		Toughness (kPa·m / m)	
Input parameters	Training	Validation	Training	Validation	Training	Validation	Training	Validation
Velocity, relative attenuation (RA)	0.595 (0.045)	0.513 (0.045)	0.385 (32.266)	0.38 (32.386)	0.14 (117.862)	0.177 (115.311)	0.5 (5.56)	0.453 (5.816)
Velocity, types	0.833 (0.032)	0.822 (0.032)	0.952 (9.028)	0.956 (8.67)	0.675 (72.522)	0.659 (74.208)	0.946 (1.823)	0.951 (1.742)
RA, types	0.85 (0.032)	0.839 (0.032)	0.94 (10.082)	0.945 (9.51)	0.57 (83.341)	0.613 (79.11)	0.952 (1.727)	0.951 (1.749)
Velocity, RA, types	0.852 (0.032)	0.836 (0.032)	0.953 (8.955)	0.947 (9.497)	0.677 (72.281)	0.625 (77.847)	0.961 (1.55)	0.956 (1.645)

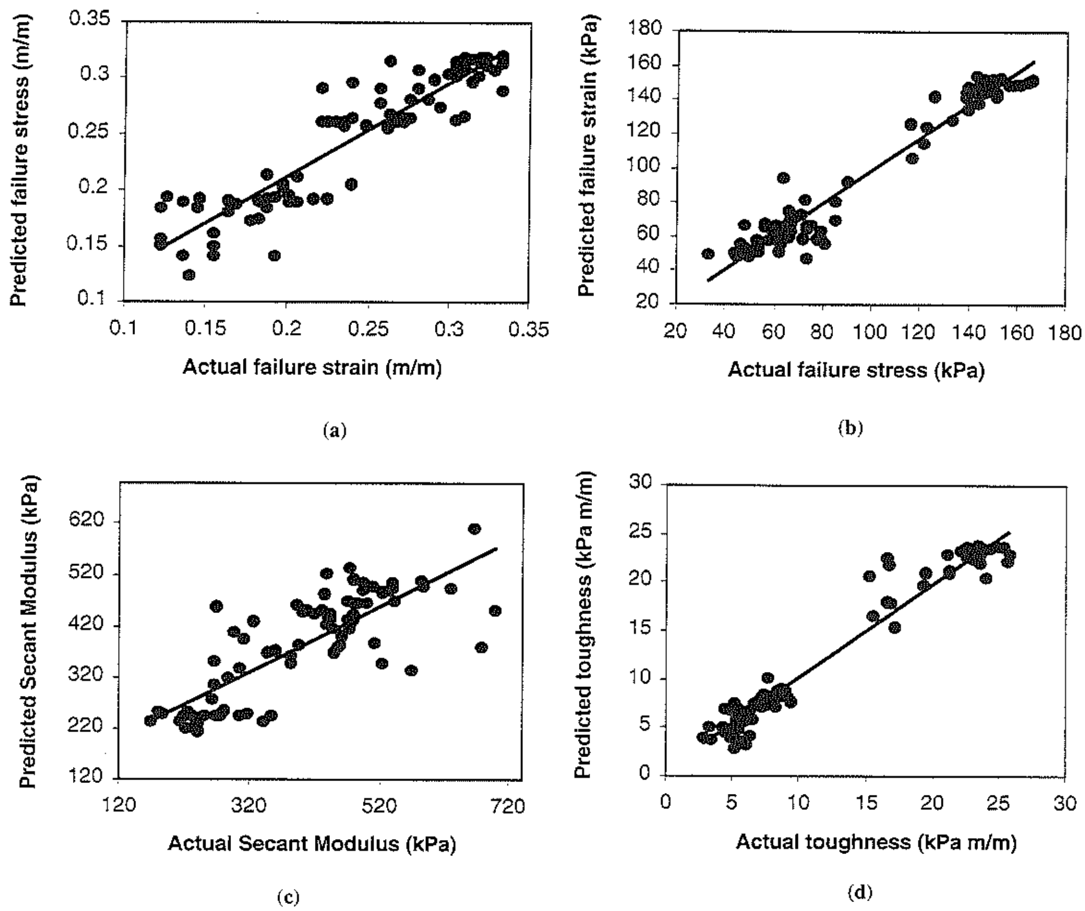


Figure 2. Relationship between actual values, and predicted values of physical properties of Cheddar cheese (a) failure strain, (b) failure stress. (c) secant modulus, and (d) toughness.

REFERENCES

Benedito, J., J. Carcel, G. Clemente, and A. Mulet. 1999. Cheese maturity assessment using ultrasonics. *J. Dairy Sci.* 83(2): 248–254.

Benedito, J., J. Carcel, N. Sanjuan, and A. Mulet. 2000. Use of ultrasound to assess cheddar cheese characteristics. *Ultrasonics* 38(1–8): 727–730.

Bhardwaj, M. C. 1997, 1998. Ultrasonic transducer for high transduction in gases and method for ultrasound non–contact transmission into solid materials, International Patent (In process).

Bhardwaj, M. C. 2000. High transduction piezoelectric transducers and introduction of non–contact analysis. In *The Encyclopedia of Smart Materials*, 12–15. J. A. Harvey, ed. New York, N.Y.: Wiley.

Emmons, D. B., M. E. Larmond, and R. J. Lowrie. 1980. Milk gel structure: X. Texture and microstructure in cheddar cheese made from whole milk and homogenized low fat milk. *J. Texture Studies* 11(1): 15–34.

Fox, J. D., B. T. Khuri–Yakub, and G. S. Kino. 1983. High frequency wave measurements in air. In *IEEE Ultrasonics Symposium,* 581–592. Piscataway, N.J.: IEEE.

Gunasekaran, S., and C. Ay. 1996. Milk coagulation cut–time determination using ultrasonics. *J. Food Processing Eng.* 19(1): 63–73.

Haller, M. I., and B. T. Khuri–Yakub. 1992. 1–3 Composites for ultrasonic air transducer. In *IEEE Ultrasonics Symposium,* 937–939. Piscataway, N.J.: IEEE.

Hayward, G. 1997. Air Coupled NDE: Constraints and solutions for industrial implementation. In *IEEE Ultrasound Symposium,* 665–673. Piscataway, N.J.: IEEE.

Lawrence, R. C., and J. Gilles. 1987. Cheddar cheese and related dry–salted cheese varieties. In *Cheese: Chemistry, Physics, and Microbiology,* Vol. 1, 1–44. P. Fox, ed. New York, N.Y.: Elsevier Applied Science Publishers.

Lee, H. O., H. Luan, and D. G. Daut. 1992. Use of an ultrasonic technique to evaluate the rheological properties of cheese and dough. *J. Food Eng.* 16(2): 127–150.

McEwan, J. A., J. D. Moore, and J. S. Colwill. 1989. The sensory characteristics of cheddar cheese and their relationship with acceptability. *J. Soc. Dairy Tech.* 42(4): 112–117.

Mohsenin, N. N. 1986. *Physical Properties of Plant and Animal Materials.* New York, N.Y.: Gordon and Breach Science Publ.

Povey, M. J. W., and D. J. McClements. 1988. Ultrasonics in food engineering. Part 1: Introduction and experimental methods. *J. Food Eng.* 8(4): 217–245.