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Air-coupled ultrasonic evaluation of food materials

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Abstract: This paper describes the use of air-coupled ultrasound for food quality assessment. A major study has been performed, in collaboration with four industrial food companies, to investigate the use of air-coupled ultrasound to both detect foreign bodies, and to measure certain parameters of interest, such as the amount of a certain additive.

The research has demonstrated that air-coupled ultrasound can be used in on-line situations, measuring food materials such as chocolate and cheese. It is also capable of performing measurements on moving sealed metal cans containing food, and is able to detect foreign bodies with the top removed, as encountered just before sealing.

Key words: Food quality assessment, air-coupled ultrasound, foreign body detection.

A. Introduction

In many areas of food production, it is important to be able to monitor the quality of the product at various points along the production process. Ultrasound has been proposed for this, and there are many publications which describe its use for measuring the properties of food (e.g. [1]-[2]). A disadvantage of many ultrasonic techniques is the need for physical contact to the food or container. This is often undesirable; the use of a couplant is not possible with many foods, as the couplant would contaminate the product. In addition, food material on a production line is often moving, and hence any solution involving a conventional transducer is not often possible. While certain approaches such as the use of wheel probes might be possible in certain circumstances, it would be far better if there was no contact at all to the food material.

Air-coupled ultrasound has been described for some time [3] and use it is often used in conjunction with some form of signal processing to increase the signal to noise ratio (SNR). The SNR is usually low, because of the large losses at the air/solid boundaries. For this reason, pulse compression has become a popular technique. Here, some form of coded signal, often a swept frequency or chirp waveform, is transmitted, and a cross-correlation with a replica waveform used to improve detectability. This approach requires a wide bandwidth, and in theory the cross-correlation result improves with a wider bandwidth of transmitted signal [4]. This is turn has required the development of wide bandwidth transducers, capable of reproducing such waveforms. One approach is to use a matching layer to air with a piezoelectric element [5]. Here, we use capacitive or electrostatic transducers that are more naturally matched to air, and which have an excellent bandwidth and sensitivity for air-coupled ultrasound.

In this paper, the technique has been used in a wide-ranging investigation to measure the properties of food materials. This formed part of a project, funded by the Department of Food, Rural Affairs and Agriculture (DEFRA) of the UK government, and involved four industrial partners. The aim was to determine the applicability of air-coupled ultrasound in an industrial environment, and to examine whether the technique is suitable for on-line measurements. In the following, examples are given of the use of air-coupled ultrasound in the detection of foreign bodies, and in the imaging of the internal contents of many types of food.

B. Apparatus

The transducers used for this work have been described previously [3], and an example is shown schematically in Fig. 1. They use thin Mylar membranes attached to a rigid micromachined silicon backplate.

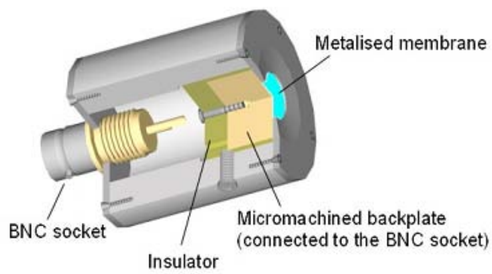

Fig.1 A wide bandwidth capacitive transducer for use in air.

Using such transducers, it is possible to generate ultrasonic signals across a range of frequencies, within the 100 kHz to 1 MHz range, which is ideal for the testing of food materials. Absorption and scattering within foods is often much higher than in most nondestructive evaluation and medical imaging applications, and hence a relatively low frequency range must be used. In some materials, such as bread dough, the loss of signal is still too high, and much lower frequencies must sometimes be used.

The above transducers have been used with a custom built Labview based pulse compression unit. Pair of capacitive transducers were aligned in through transmission mode and mounted on a x-y stage for image

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scanning, Figure 2. All aspects of signal generation, acquisition and stage control were performed using PXI system by National Instruments. Signal conditioning and pulse compression algorithms were implemented using a custom built Labview based software. Signal was amplified using a 40W broadband amplifier before being fed to the transmitter.

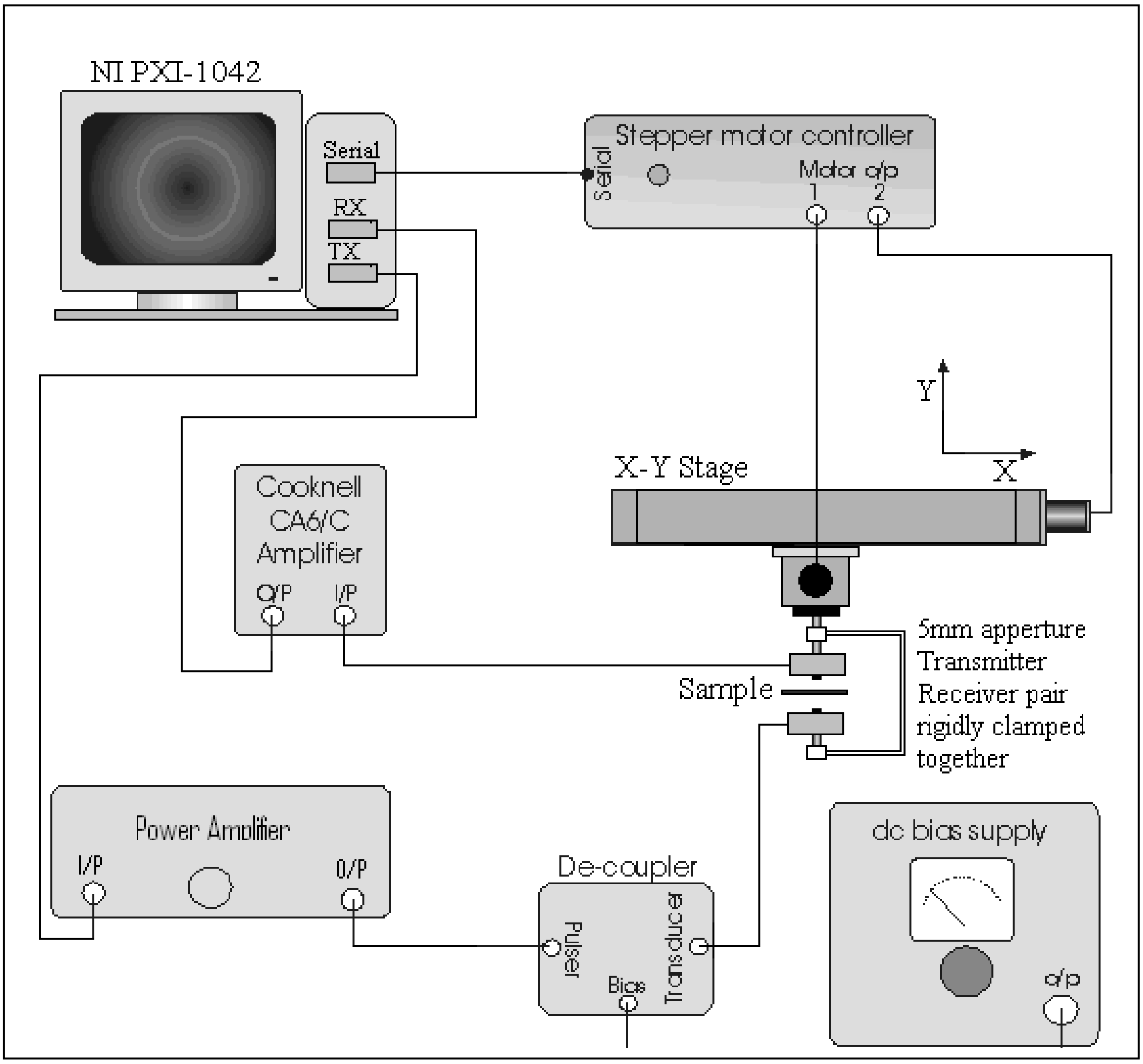

Fig.2. The apparatus used to obtain air-coupled ultrasonic images of food products.

Signals from the receiver transducer are received first by a Cooknell CA6/C charge amplifier, which supplies the required DC bias voltage, before being passed back to the receiver part of the pulse compression unit. Signals are then recorded for later processing. The transmitter and receiver pair were scanned over the object under test using an X-Y stage with stepper motors, controlled by the PXI system. Typically this was moved in 1 mm increments, and a pulse compression waveform recorded in each location with the motors turned off to reduce electromagnetic interference.

Note that many types of waveform can be used, and the result also depends on the type of window used during the cross-correlation process. In our work, we have investigated many windowing functions, and have found that a new approach, the Elliptical-Tukey window, gives very good results.

C. Imaging for various food products

C.1. Detection of foreign bodies in cheese

An example of a food material in which ultrasonic foreign body detection is important is cheese. Here, metal detection is only partially successful, because the food is also partially conducting; in addition, non-metallic contaminants cannot be detected. Hence, air-coupled ultrasound is an excellent choice.

An example of the type of images that can be produced is shown in Fig. 3. Here, images have been produced of a 2mm wide piece of wood, which has been deliberately placed within the block of cheese, kindly provided by Kerrygold Ltd. Images are shown as a result of both received amplitude (left) and ultrasonic propagation time variations (right). The wood samples show up as the darker areas identified within the white dotted boxes.

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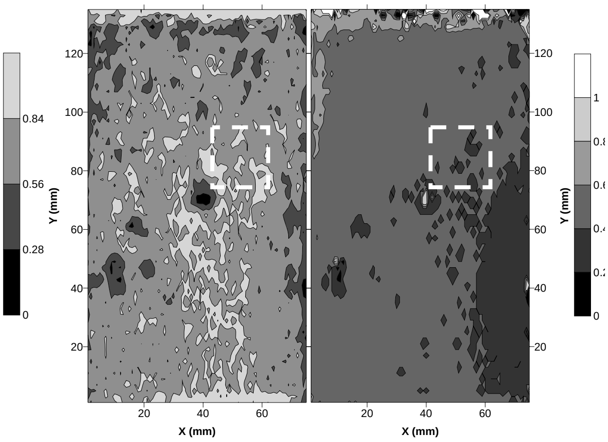

Fig.3 Examples of images obtained in cheese samples containing a 2mm wide wood fragment, showing variations in amplitude (left) and time of flight (right).

In addition, images can be formed by amalgamating data from both amplitude and propagation time data. Fig. 4 shows such a composite image for a 2 mm wide piece of glass, again inserted deliberately into the cheese. The glass has been detected successfully by the air-coupled ultrasound technique.

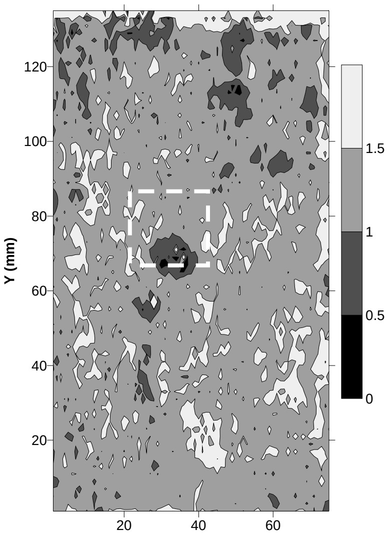

Fig.4 Ultrasonic image of a cheese sample containing a 2mm wide glass fragment, obtained by combining spatial variations in both amplitude and time of flight.

C.2. Imaging of chocolate samples

In many foods, it is of interest to be able to detect the quantity of different ingredients present in the product. One such food material is chocolate, where nuts, raisins, and other types of content are added in various quantities. Because ultrasound is sensitive to small changes in acoustic impedance, the air-coupled technique can be used to differentiate between different samples. In such cases, an "at-line" system would be of interest, so that continuous monitoring of the content of the chocolate can be obtained.

Fig. 5 shows the apparatus developed for this purpose, containing a holder for specific chocolate samples kindly provide by Cadburys Ltd. A miniature X-Y stage is used to traverse the sample, to image either the whole bar of chocolate, or a smaller area.

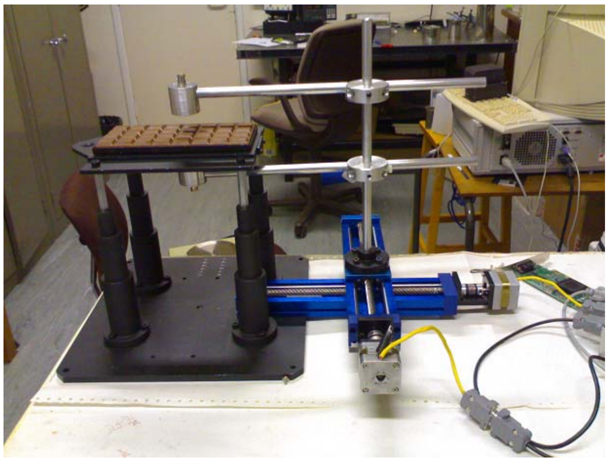

Fig.5 A scanning system for chocolate bars.

An example of this type of scan is shown in Fig. 6, where images of amplitude and time of flight are shown for a chocolate bar containing a single hazel nut. This is clearly visible in both images, and it would be a simple matter to determine the size and location of this nut from such images.

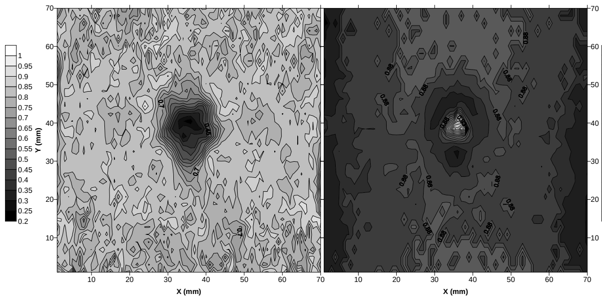

Fig.6 Examples of images obtained in cheese samples containing a 2mm wide wood fragment, showing variations in amplitude (left) and time of flight (right).

The scanning system shown in the photograph of Fig. 5 can also be used to image whole bars of chocolate. An example of such an image is shown in Fig.7, where now a bar containing many nuts has been scanned. The nuts show up as the darker regions. Such a scan is useful, as with additional image processing, the number of nuts per unit volume of chocolate can be calculated, and used as information which could be used to control the production process.

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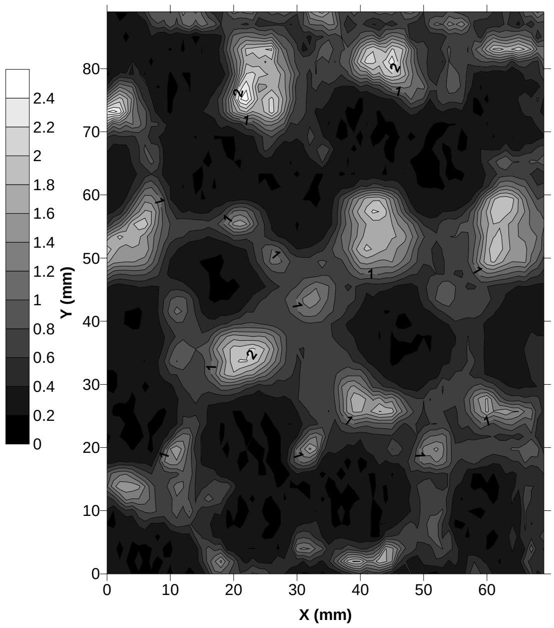

Fig.7 Ultrasonic amplitude image of a chocolate bar containing nuts, which show up as the darker areas.

C.3. Experiments on canned products

Air-coupled ultrasound is of interest here, as canned products can be tested on the production line, potentially at high speeds. Of interest is whether the contents of the can is up to specifications in terms of content and/or fill level. Both can be determined using the technique. Fig. 8 shows the air-coupled system used to inspect cans in a lab-based mock-up of a production line, with the transducers aligned horizontally.

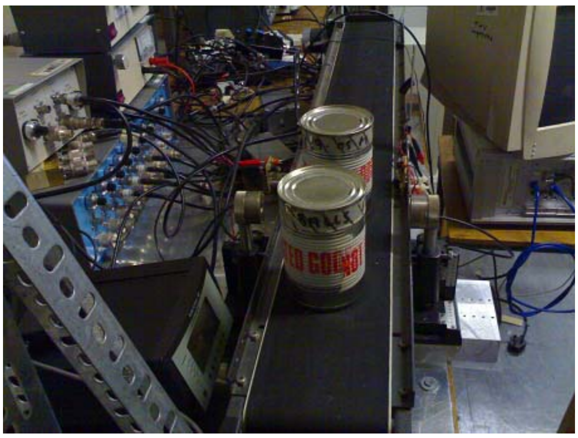

Fig.8 A scanning system for canned products on a conveyor belt.

This apparatus has been used to scan canned products kindly provided by Westler Foods Ltd. Typical output waveforms are shown in Fig. 9. It can be seen that the signal through the can has arrived sooner, due to the higher velocity in the can than in air, and such signals can be used to determine the properties of the food in the can, even if it is moving past the transducers.

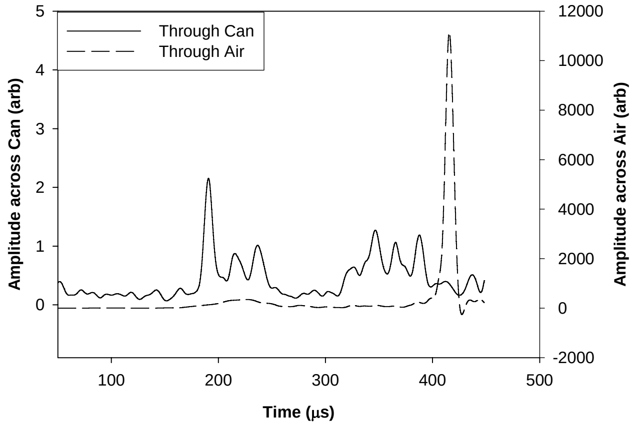

Fig.9 Pulse compression signals transmitted across a can in air (solid line) and across air only (dotted line).

D. Conclusions

This paper has demonstrated that air-coupled ultrasound can be used to make a range of measurements of interest to the food industry. The technique, using capacitive transducers, has sufficient sensitivity and bandwidth to enable many of these measurements to be made on a production line, using the non-contact nature of the instrumentation.

E. Acknowledgements

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F. Literature

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