System for Non-Contact Ultrasonic Study of Mediums and Materials Intended for Embedding into Automated Manufacturing Systems

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Abstract: *The main feature of ultrasound waves is their high frequency, allowing to be broadcast in the form of a narrow beam of rays and their distribution to be examined by the methods of geometrical optics. This allows ultrasound to be used for scientific and applied research. By the nature of distribution and absorption in gases, liquids and solids can be obtained valuable information about the structure and properties of substances. This article examines the use of hardware-software system designed for non-contact ultrasonic study of mediums and materials.*

Key words: *Computer Systems and Technologies, Model, Microprogramming Unit for Operation Control.*

INTRODUCTION

In various industrial processes there is requirement for registration and studying of substances, materials, mediums and conditions with the purpose to improve the production quality. For this purpose are used various contact and non-contact methods which allow to be automated the execution of these activities. One of them is non-contact ultrasonic method which is based on the effect of reflection. It is one of the base methods applied in conventional non-destructive control among with radiography, magnetic-particle methods, methods with penetrating liquids, and etc.

When passing through a given medium the ultrasound reduces its intensity, leading to its weakening. This is due to phenomena such as scattering, absorption, reflection, refraction and ray divergence. The absorption of ultrasonic energy from the medium in which ultrasound is spread depends on the characteristics of that medium (density and elasticity) and also from the frequency of the used ultrasound. As a result, the characteristic parameters of the reflected acoustic wave in the direction of its spread are modified. Thus, the ultrasonic signal carries information about the characteristics of the medium between the transmitter and the receiver [4]. The developed intelligent sensor system extracts this information and allow to be studied the controllable object.

Applied scientific idea underlying in this development lies in the use of non-contact ultrasonic method for determining the status of objects and mediums with the purpose of their identification and classification of their production phases in real time.

EXPOSITION

There are two main functional schemes for the construction of an ultrasonic sensor system for non-contact measurement (when the sensors for transmission and reception of acoustic waves are on the same side of the controlled medium and when they are mounted at a certain distance from one another). In the first, an ultrasonic piezoelectric sensor actively transmits acoustic waves and after their reflection they reaching the receiver and are processed. In this scheme it is possible to be used the same piezoelectric sensor for converting of an electrical signal into a sound wave and vice versa. This saves hardware resources at the expense of some increase of the zone of insensitivity (it is necessary time for readjustment of the piezoelement from mode of transmission of the mode of receiving). In the second scheme solution there are used two piezoelements, transmitter and receiver. These elements are mounted against each other and between them is the studied medium or material. This scheme is appropriate to be uses in the studying of gaseous or liquid mediums, as well as for finished products. In the current paper the sensors are located on the same side of the studied object. This type of formulation of the task has the following advantages:

1. The ultrasound directly contact with the object for studying whether it is in liquid or solid aggregate state;
2. It is eliminated the influence of intermediate barriers such as walls of the vessel into which are set the liquid substances;
3. To implement the measurement is not necessary to have special equipment and propulsion;
4. The process of calibration of the system is simple enough for implementation, and etc;

Structure of the system

Common architecture of hardware-software system is shown in Fig. 2.

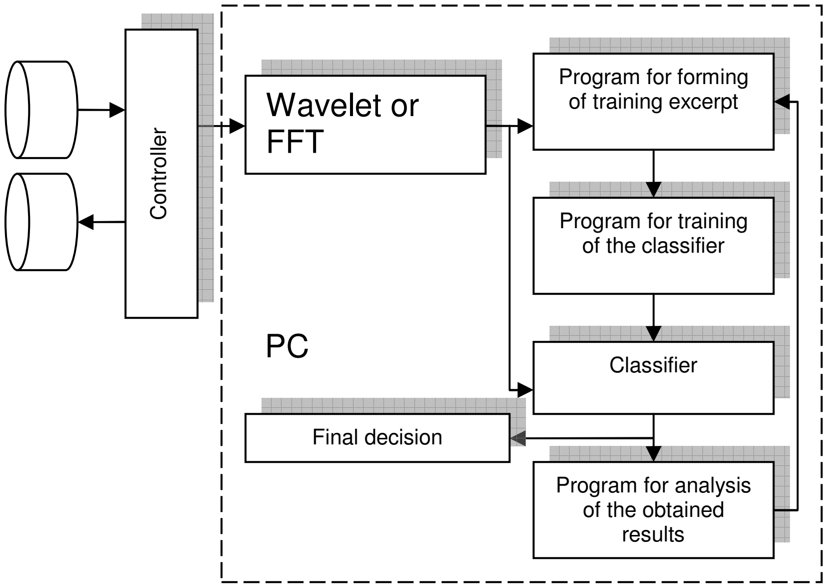


Fig. 2. Block scheme of the work setting

The system is made up of two functionally distinct subsystems:

- Measuring subsystem (Fig. 3.);
- Recognition subsystem.

Measuring subsystem

The process of measuring and storing of information is realized on the basis of the modules of National Instruments.

The system is built on three levels. The first level (sensor module) (Fig. 4) is designed to generate an ultrasonic signal which is

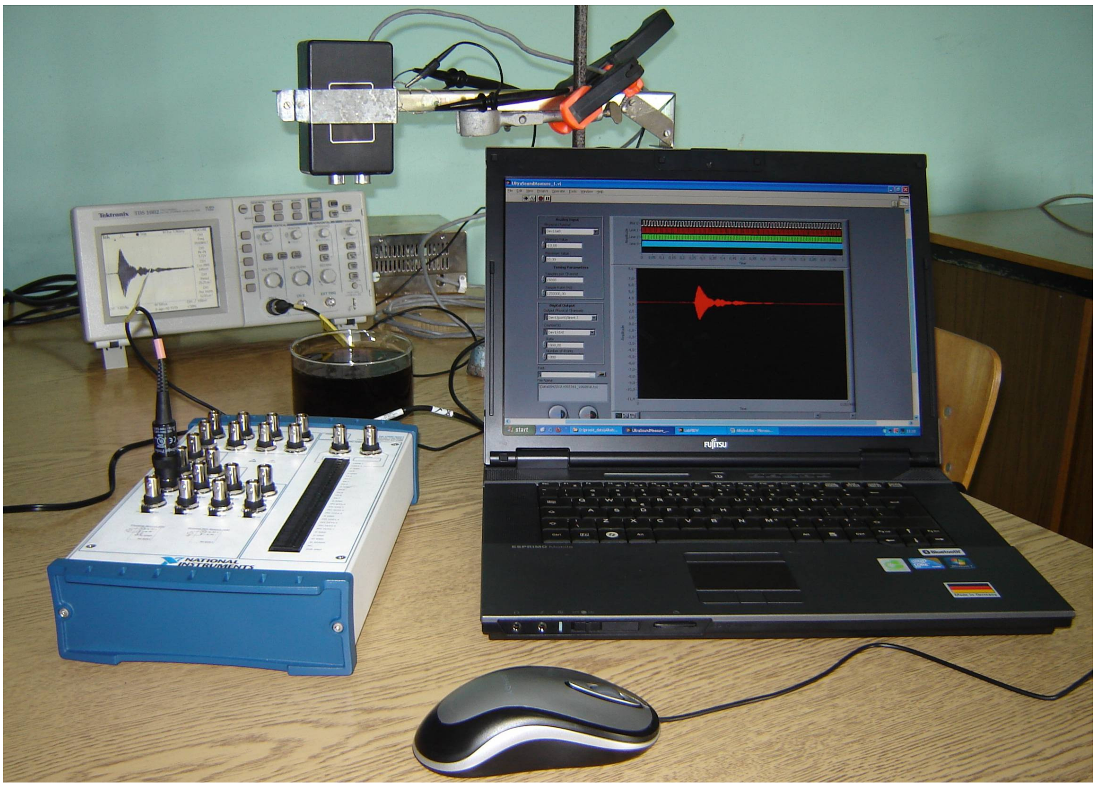


Fig. 3. Measuring subsystem

spread in the medium and to receive the reflected wave, converts it into an electrical signal and amplify it to a level suitable for processing.

The module consists of three blocks. Block generator is designed to generate an analog signal for excitation of the transmitter. Sensor block consisting of two piezoelements transmitter and receiver. The third block is a precision high-frequency amplifier designed to amplify the signal received from the receiver.

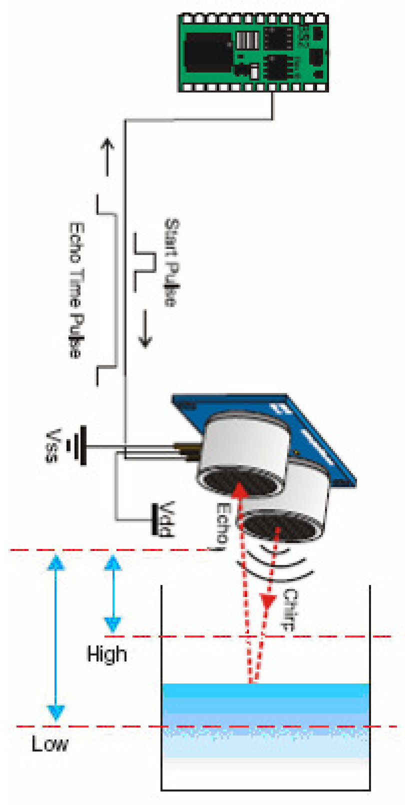


Fig. 4. Sensor module

The second level is constructed on the basis of multifunctional module NI USB-6251 M Series production of the company National Instruments (Fig. 5) having the following specifics:

- Up to 16 differential BNC analog inputs at 16 bits, 1.25 MS/s (1 MS/s scanning)
- Up to 4 BNC analog outputs at 16 bits, 2.86 MS/s
- Up to 48 TTL/CMOS digital I/O lines (8 BNC, up to 32 hardware-timed at up to 1 MHz)
- Two 32-bit, 80 MHz counter/timers
- Analog and digital triggering supported; power supply included
- NI-PGIA 2 and NI-MCal calibration technology for improved measurement accuracy
- NI signal streaming for 4 high-speed data streams on USB
- NI-DAQmx driver software and LabVIEW SignalExpress LE included

Fig. 5. Measuring module NI USB-6251 M Series

In the realized measurement system are used three analogue channels and one digital channel. At the first analogue channel is connected the "sensor module". From this channel is made the measurement of the signal received from the ultrasonic sensor. At the other two channels are connected a temperature sensor and a humidity sensor. These two signals are used to introduce coefficients for corrections.

The third level is a virtual instrument built in an environment of LabView. The implementation was made in an environment of LabView 9 (Fig. 6) and operates in the following algorithm:

1. Measurement and storage of the environment temperature.
2. Measurement and storage of the environment humidity.
3. Generating of a sequence from 6 or more pulses with a frequency determined by the type of ultrasonic sensor.
4. Measuring the signal received by the ultrasonic sensor for a predetermined period of time.
5. Saving of the data into a file.

The obtained in this way data is processed, demodulated and evaluated by the specialized software. These measurements make sense when the parameters of state of

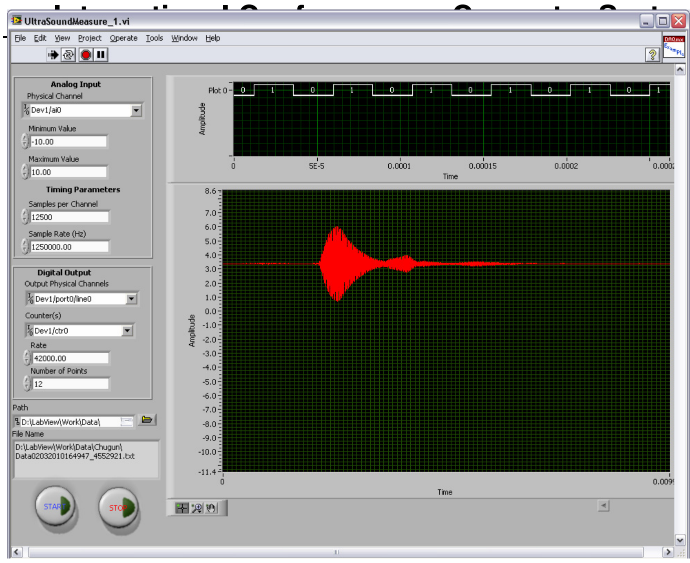


Fig. 6. LabView virtual module

the environment such as temperature, pressure, etc. are measured simultaneously with ultrasonic parameters and also with high accuracy. The next step is to use algorithms to calculate the parameters of interest. They are based on the laws for the spreading of waves and include the interaction of acoustic waves with studied (controlled) medium. Knowing of these relationships is necessary for the development of new applications of ultrasonic sensors (such as elements of control systems), for example, for recognition of mediums and materials, into the control of processes, for specific measurements of distance, and etc.

Recognition subsystem

The recognition process (Fig. 2) has two phases: Phase of training and phase of recognition.

During the training phase the system is feed with known training signals – the purpose is to be trained the system for recognition.

The sequence of actions for training is as follows:

- Sending of short series of ultrasound waves generated by piezoelectric transducer (transmitter) to the object of study (Fig. 4);
- Receiving, detection and buffering of the reflected signal from the studied object;
- From the received signal using Discrete Wavelet Transform (DWT) or Fast Fourier Transform (FFT) are extracted information-bearing elements carrying information for the studied object;
- Forming of a training excerpt based on the made studying;
- From experience and from statistical information are determined the target vectors of the recognition system;
- The chosen classifier is trained with data obtained from measurement and the target vector;
- Comparing of obtained data with the accumulated database;
- Taking of a decision for membership to a particular class.

The second phase is the phase of identification and classification of the studied signals.

The sequence of actions in recognition are:

- Sending of high-frequency ultrasound packet of pulses to the object;
- Receiving and buffering the reflected signal from the object of study;
- From the received signal using Discrete Wavelet Transform (DWT) or Fast Fourier Transform (FFT) are extracted information-bearing elements carrying information for the studied object;
- Comparing of obtained data with the accumulated database;
- Taking of a decision for membership to a particular class.
- Print out the appropriate information for the site of the studied object.

With the developed hardware-software system are intended to be carried out several experiments on the basis of which will be developed a mobile device for identification of substances. Some of the directions are:

- Research of the change of speed of sound as a function of the temperature and the composition of the medium and the influence over the accuracy of measurement and creation of a hardware or a software model;
- Study modification of the length of the sound wave as a function of the speed of sound and the frequency over the accuracy, the minimal size of the ultrasonic sensor, minimal and maximal allowable distance and depth of measurement into the studied medium;
- Study the influence of the structure of the material from the change of volume of the sound as a function of frequency and humidity, and choice of the distance between the sensor and the measured medium;
- Study the influence of changing the angle of radiation over the maximal distance for measurement and the power of the reflected wave;
- Research the change of the reflected signal amplitude as a function of the distance, geometry, surface, size, and choice of the distance between sensor and the object of study;
- Research of change in phase angle of the reflected signals according to the transmitted signal depending on the studied substance and the medium for spreading;
- Study the feasibility of fast Fourier transform (FFT) at the recognition of substances;
- Study the feasibility of compact-wave transform of the signals at recognition of substances, and etc.

CONCLUSIONS AND FUTURE WORK

The developed hardware-software environment allows for non-contact non-destructive analysis of materials. Studies were made of alcohols with different content of alcohol in them (Fig. 7), iron and cast iron (Fig. 8) showing the efficiency of the set.

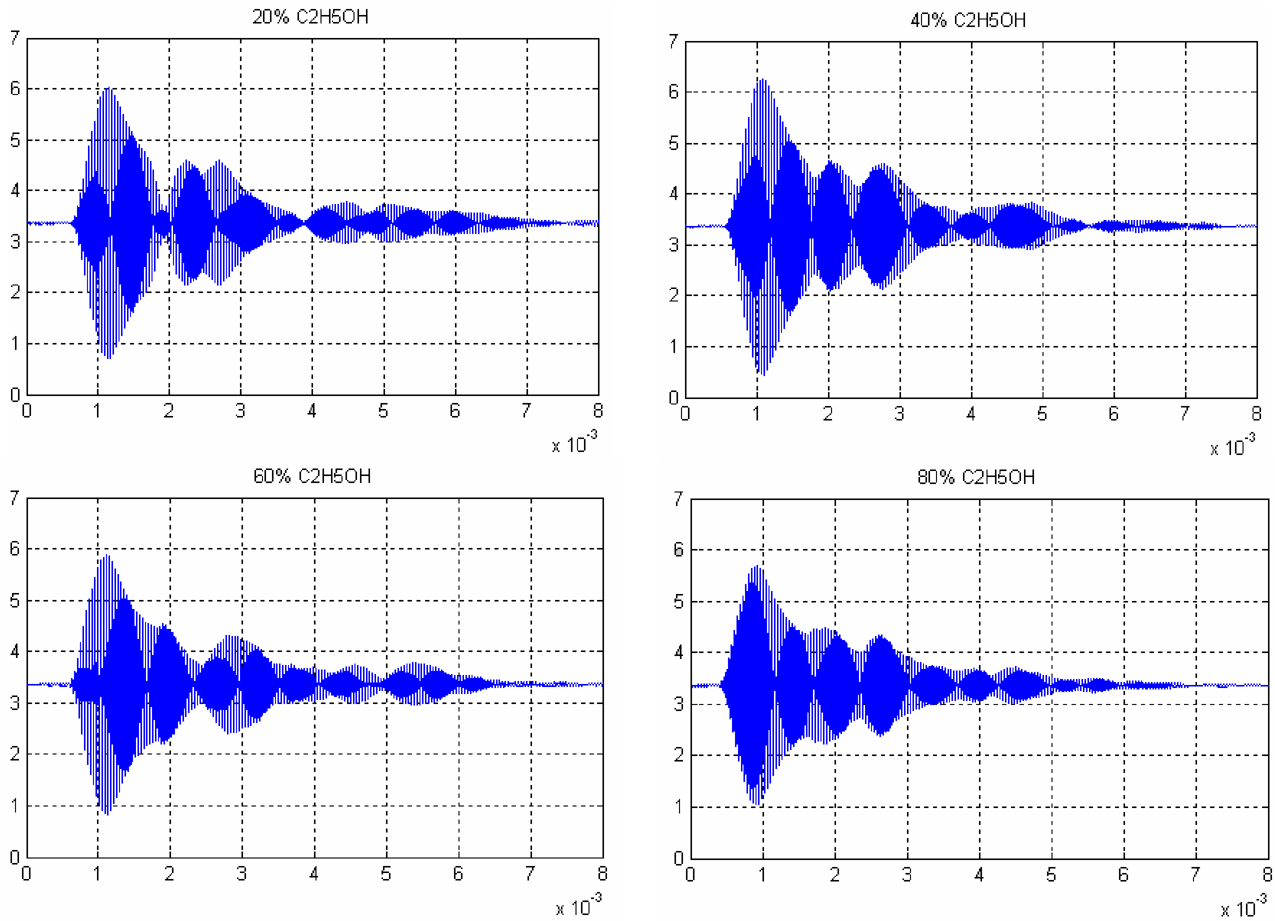
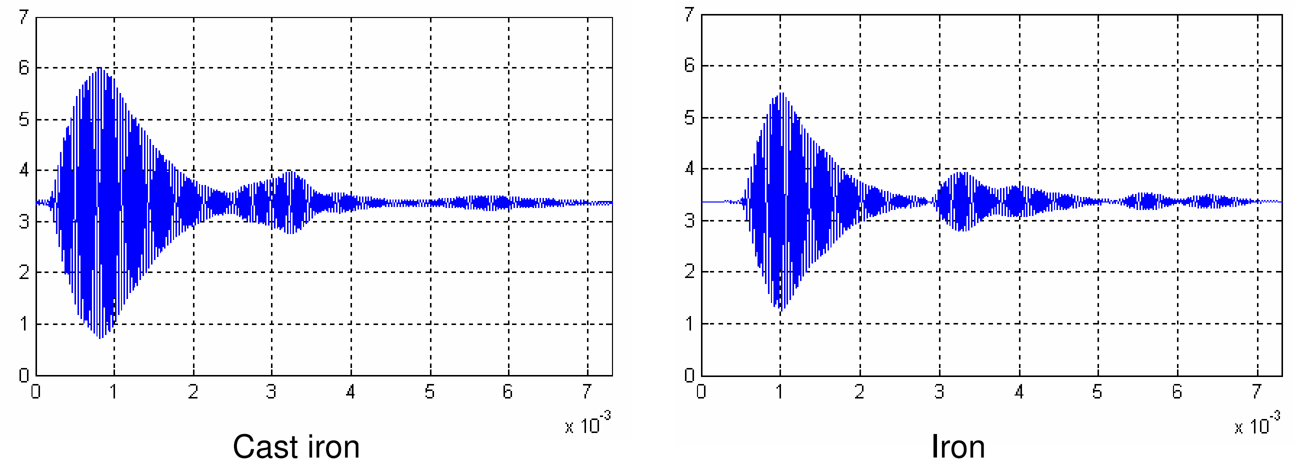


Fig. 7. Experimental data from measurements of alcohols



Cast iron Iron

Fig. 8. Experimental data from measurements of cast iron and iron

Under development is a mobile device intended for embedding into automated manufacturing systems, which require rapid and accurate determination of the type and condition of substances, content of mixtures, physical mediums and of their manufacturing phases.

REFERENCES

[1] Baltes, H., W. Göpel, J. Hesse. Sensors Update. Volume 3. Sensor Technology-Applications-Markets. Weinheim-Berlin-New York-Chichester- Brisbane-Singapore-Toronto, Wiley-VCH Verlag GmbH, 1998.

[2] Marques de Sa J.P. Pattern recognition concepts, methods, and applications, Springer, 2001.

[3] Daubechies I.,Ten lectures on wavelets, CBMS-NSF conference series in applied mathematics.SIAM Ed., 1992.

[4] Smolencev N. N., Base theory of wavelets. Wavelets in MATLAB, DMK Press, Moscow, 2005.

[5] Karpur, Split-spectrum technique as a preprocessor for enhanced reliability in ultrasonic signal analyses, Material Evaluation/June 1992 , p793.

[6] M. Kitahara, J. D. Achenbach, Q. C. Guo, M. L. Peterson, Neural network for crack-depth determination from ultrasonic backscttering data, Review of Progress in Quantitative Nondestructive Evaluation, Vol. 11, pg. 701.

[7] Dorin Ciobanu , Razvan Ciocan, Artificial neural network for ultrasonic spectroscopy data analysis, Proceedings AROEND Symposium 1996.

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