The IInd International Conference «Advanced Information Systems and Technologies», AIST 2013
21-24 May 2013, Sumy, Ukraine

In vivo verification of an intelligent system for accurate measurement of intima-media thicknesses

M.Mani, A.N.Kalashnikov
Department of Electrical and Electronic Engineering
The University of Nottingham, Nottingham, NG7 2RD, UK
eexmhm2@nottingham.ac.uk, alexander.kalashnikov@nottingham.ac.uk

***Abstract* – The paper describes further progress in the development of an intelligent system for accurate measurement of intima-media thicknesses (IMTs, which was introduced at the previous conference [1]. The system was commissioned in an electronics laboratory, and both electrocardiogram and ultrasonic A-scans were taken in vivo, following a custom measurement protocol. Several waveforms recorded at the same phase of the heart cycle showed good consistency for the estimated diameter of the lumen and agreed well with literature data.**

INTRODUCTION

An intelligent system for accurate measurement of IMT aims to overcome some complications associated with conventional ultrasonic IMT measurement (namely insufficient resolution of the IMT estimates and their dependence on the phase of the heart cycle) by using a high-resolution ultrasonic A-scanner that is triggered after a set delay from the electrocardiogram (ECG) R-wave. The ECG itself is taken by a battery powered ECG monitor, and is transmitted wirelessly to the ECG processor using infrared (IR) communication. This approach largely eliminates any concerns for the safety of the patient, as no mains powered equipment is connected to her/him. Additionally, the approach eliminates any radio frequency (RF) emissions that could affect other medical equipment in close proximity. *In vivo* verification of the custom-designed ECG monitor already has been reported by the current authors [2]; the high-resolution capability of the previously developed ultrasonic A-scanner was verified experimentally by ultrasonic measurements in aqueous solutions [3]; and the algorithm for R-wave detection implemented by the ECG processor firmware was verified previously [1].

In this paper, we describe the integration of the above-mentioned separate devices into a complete system, discuss *in vivo* measurement protocol and present experimental results that show consistency among waveforms taken consecutively at the same trigger delays with respect to the R-wave.

SYSTEM CONNECTIONS AND OPERATION

Fig.1 shows the connection diagram for the system. The data acquisition (DAQ) board produces excitation pulses at the pulse repetition rate of 10 kHz. These pulses are routed through the ECG processor board, where their level is changed from 0/1 V to 0/5 V, into the ultrasonic pulser-receiver (UPR, NDT Solutions Ltd). Each excitation pulse results in a high-voltage pulse applied to a particular ultrasonic transducer from a conventional ultrasonic array that is selected using wire jumpers. The width of this pulse equals the half-period of the resonant frequency of the transducer. The pulse forces generation of an ultrasonic wave that propagates into the patient and is partially reflected back at interfaces of different body tissues and/or fluids. The receiver part of the UPR amplifies the echo signal before the ADC input of the DAQ board. However, the board records the waveform only if triggered by the ECG processor at a set phase of the heart cycle. The waveform is stored in a personal computer for further offline analysis. The oscilloscope (LeCroy 9450) shown in fig.1

is used to check and trace various signals during setup of the system, and for selecting a transducer that produces the most appropriate echo waveform during measurement.

IN VIVO EXPERIMENTAL PROTOCOL

The protocol was developed by taking into account the following constraints:

- Measurement would be conducted in an electronic laboratory;
- Only one experimenter would be available for setting the instrumentation, selecting a particular transducer and manually controllimg waveform acquisition and storage.

Every experimental session included the following procedural steps:

1) Attaching the ECG electrodes to the patient, verifying the presence of the correct ECG signal at the output of the ECG front end and triggering pulses at the output of the ECG processor;
2) Setting up and checking correct operation of the DAQ board and UPR;
3) Finding the right external carotid artery on the patient's neck, close to the right ear, by palpation and placing the ultrasonic array perpendicular to it; the array was held in place by the patient throughout the examination;
4) Selecting a particular transducer to be used for acquiring the echo waveforms;
5) Collecting the ultrasonic echo waveforms at different trigger delays with respect to the ECG R-wave.

EXPERIMENTAL WAVEFORMS AND THEIR PROCESSING

Fig.2 shows an example of the experimental waveform recorded at the equivalent sampling frequency of 1 GHz (100 MHz ADC, interleaving factor of 10, no averaging). The excitation starts at about 5 µs, and the echoes feature both noise and multiple reflections. The waveforms were filtered using a low pass digital filter (order 100, cutoff frequency 30 MHz), and their analysis showed that proximal reflection from the lumen occurred soon after 12.5 µs, and the distal reflection started at around 17.5 µs. Fig.3 presents five superimposed waveforms recorded at the same trigger delay with respect to the ECG R-wave about 30 s apart; the reflections from the lumen for individual records were displaced vertically in the bottom part of the figure for clarity.

DISCUSSION AND CONCLUSION

Processed waveforms shown in fig.3 exhibit good consistency. Although the time positions for reflections in different waveforms are slightly different, the time differences between the peaks marked in fig.3, estimated for subsequent records, are quite consistent at 4.95, 4.94, 4.93, 4.91 and 4.89 µs from the bottom to the top, respectively. These estimates comply with the data reported in the literature. We attribute the observed differences in the positions of the peaks to differences in pressure exerted by the patient on the ultrasonic array, which also resulted in slight changes to the estimated ultrasound time-of-flight in the lumen.

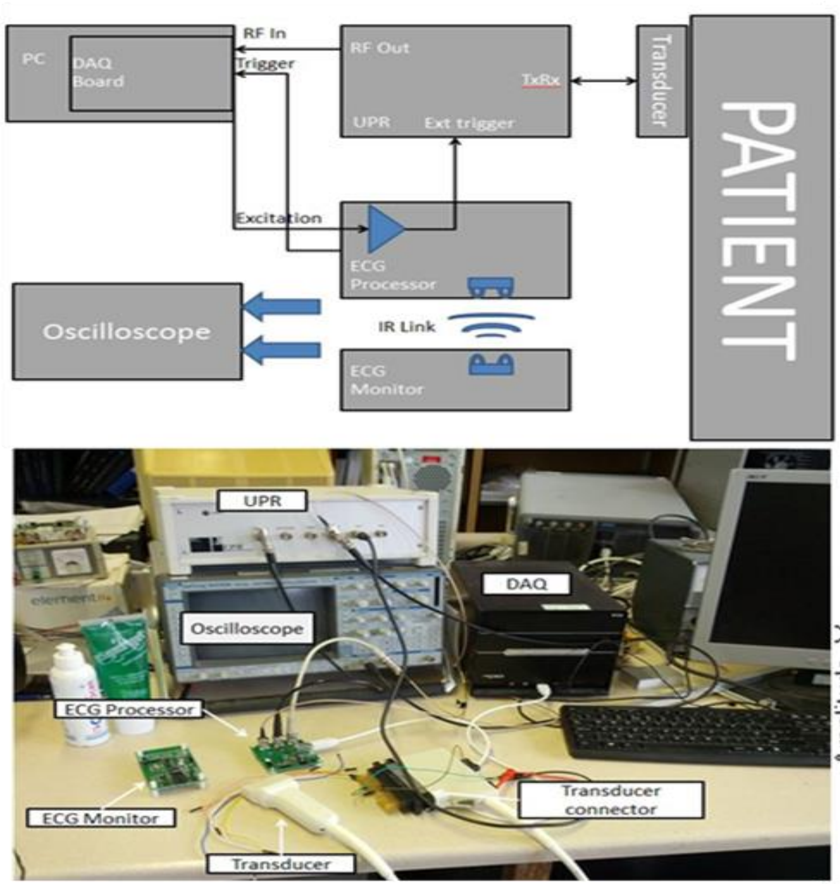
These results show that the developed IMT measurement system allowed recording of high-resolution ultrasonic waveforms at a particular phase of the heart cycle, which was its development aim. Future work will include extracting IMT estimates from recorded waveforms.

REFERENCES

[1] M.Mani, O.Bener, A.Bener and A.N.Kalashnikov, “Intelligent system for accurate measurement of intima-media thicknesses as markers for artherosaclerosis”, Advanced information systems and technologies (AIST-2012), Sumy, Ukraine, 2012, pp.180-183.

[2] O.Bener, M.Mani, O.Sonbul, O.Bener and A.Kalashnikov, “Intrinsically safe and RF interference free device for synchronisation of ultrasonic scans with the heart activity”, Sensor Electronics and Microsystems Technology (SEMST-4), Odessa, Ukraine, 2010, p.133.

[3] A.N. Kalashnikov, V. Ivchenko, R. E. Challis and B. R. Hayes-Gill, “High Accuracy Data Acquisition Architectures for Ultrasonic Imaging”, IEEE Trans. Ultrason., Ferroel. and Freq. Contr., vol.54, 2007, pp.1596-1605.



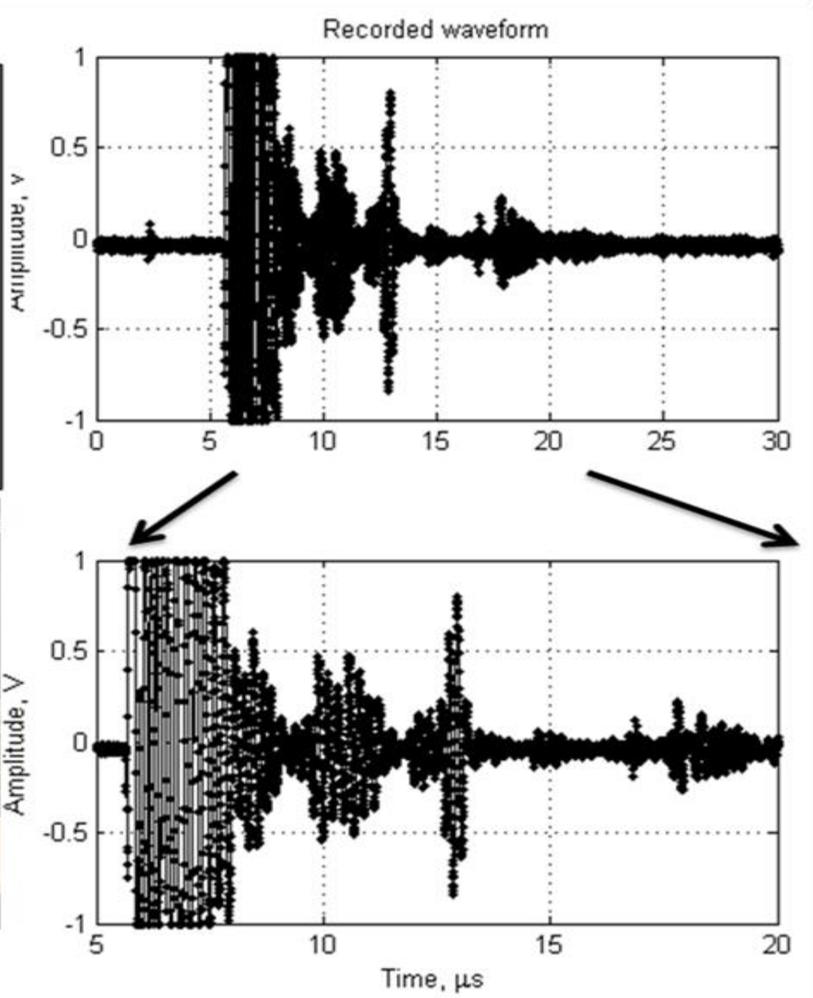


Fig.1. Block diagram of the developed IMT measurement system

Fig.2. An example of the recorded wavefor

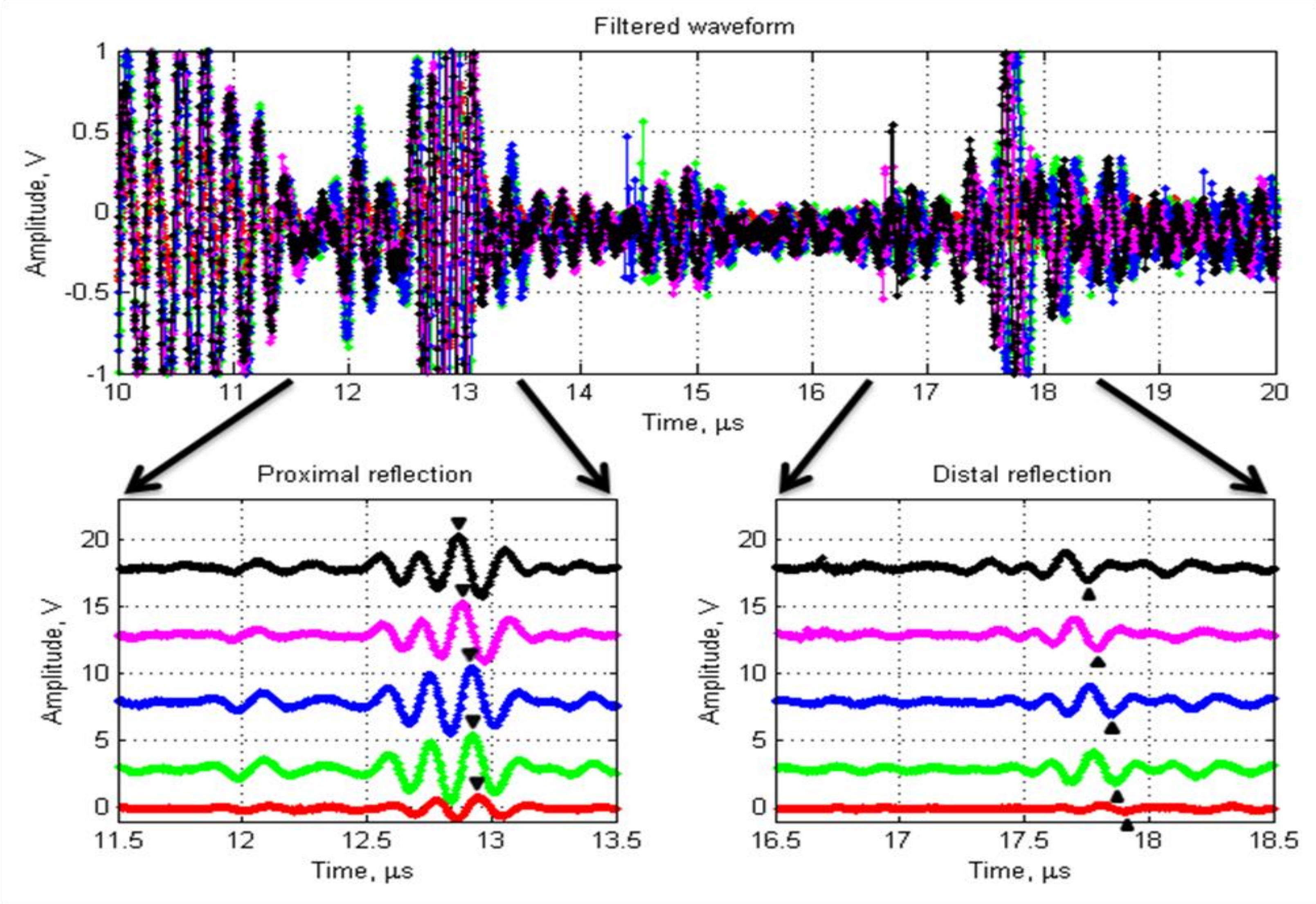


Fig.3. Filtered waveforms superimposed (top) and their parts related to the proximal reflection bottom left) and distal reflection (bottom right), with the triangular black marks indicating positions used for calculating time-of-flight in the lumen