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Method of Determining the Envelope of the Blood Flow Velocity Curve in Spectral Doppler Ultrasound

Jarosław Majewski[1], *Krzysztof J. Opieliński*[2], *Andrzej Wiktorowicz*[1]
[1] *DRAMIŃSKI S.A., Wiktora Steffena 21, 11-036 Sząbruk, Poland,*
[2] *Department of Acoustics, Multimedia and Signal Processing, Faculty of Electronics, Photonics and Microsystems, Wroclaw University of Science and Technology, Wyb. Wyspiańskiego 27, 50-370 Wrocław, Poland*
krzysztof.opielinski@pwr.edu.pl

Summary:

The method for automatic calculation of the envelope of the blood flow velocity curve in spectral Doppler imaging has been implemented in the prototype 128-channel ultramobile ultrasound B-mode scanner under the research project POIR.01.01.01-00-1462/19. Based on the determined envelopes, algorithms were developed for automatic determination of the most important characteristic points of the Doppler blood flow waveform in the Pulsed Wave Doppler imaging mode and the most relevant blood flow parameters. Sufficiently good repeatability and precision with low computational complexity were obtained.

Keywords: spectral Doppler ultrasound, Color Flow Mapping (CFM), Pulsed Wave Doppler (PWD), blood flow velocity envelope, blood flow pulsation indices

Introduction

Spectral Doppler ultrasound methods are among the primary methods for diagnosing vascular disease, as they allow finding the site and assessing the extent of lesions atherosclerosis [1]. Blood flow velocity is recorded in the form of a Doppler spectrum from which the envelope of instantaneous maximum and minimum blood flow velocity is determined, as well as pulsation and flow resistance indices - characteristic quantities indicative of progressive blood vessel changes. The accuracy of determining these parameters is significantly affected by the accuracy of determining the envelope and characteristic points of the Doppler blood flow waveform.

Within the framework of this work, a method for automatic calculation of the envelope of the blood flow velocity curve was developed in spectral Doppler imaging. It is characterised by sufficiently good repeatability and precision, as well as low computational complexity, making it possible to draw it on the fly during measurements. The method developed was implemented in the prototype 128-channel ultramobile ultrasound scanner developed under the research project POIR.01.01.01-00-1462/19 funded by the National Center for Research and Development (NCBR) with funds from the European Union.

Description of the Method

A method based on short-time Fourier Transform (STFT) analysis with additional filtering using Gaussian filters [2,3] was used to calculate the blood flow velocity spectrum (the so-called Doppler blood flow waveform). The developed method for automatically determining the envelope of the time course of this spectrum is based on the selection of the threshold parameter using variance analysis. Two options for envelope smoothness settings were developed in the envelope determination algorithm: LOW and HIGH. The degree of smoothing in both options can be adjusted to improve the user experience of the algorithm for the ultrasound scanner user. The algorithm was further refined toward the ability to determine the envelope of instantaneous maximum (*Max* – red) and minimum (*Min* - green) velocities (see Fig. 1).

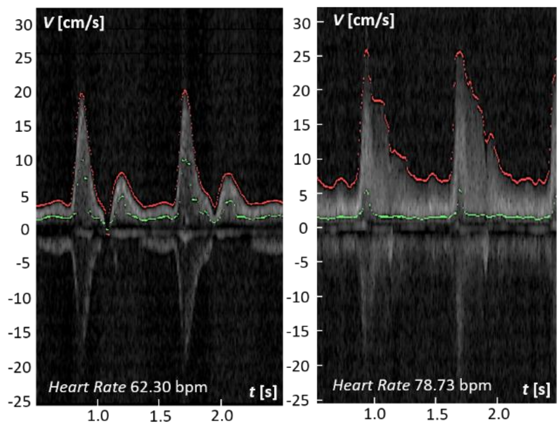

Fig. 1. Example results of the algorithm developed for automatic calculation of the flow velocity spectrum envelope (STFT spectrograms).

Both envelopes can be determined in one of three modes: lower, upper, or both halves of the velocity spectrum waveform. In the latter, the envelope is determined at any given time for only one half. The choice of the half is made automatically by the algorithm based on the statistical distribution of the velocity spectrum calculated for both halves. The selection of modes is made by the operator.

The work also included the development of an algorithm for finding the most important characteristic points of the determined envelope of the blood flow spectrum, as well as an algorithm for measuring heart rate (HR) based on the spectral analysis of the envelope waveform. The algorithm determines fully automatically the points of PSV (Peak Systolic Velocity), EDV (End Diastolic Velocity) and the point used to determine the AT (Acceleration Time) parameter (Fig. 2).

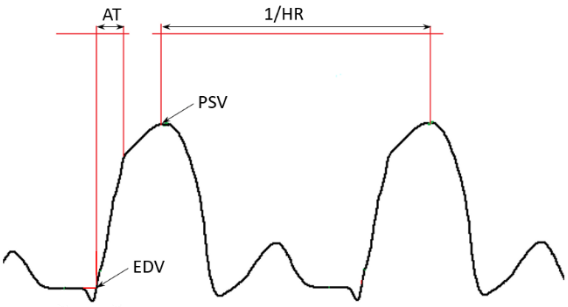

Fig. 2. Illustration of how to automatically determine the most important characteristic points of the flow velocity spectrum envelope.

Based on the characteristic points of the envelope of the spectral blood flow graph, algorithms have also been developed to determine the indices parameterizing the recorded blood flow velocity curves using a single number (including the PI pulsation index and the RI resistance index) [1]. Increasing atherosclerotic lesions induce a decrease in the pulsation of the Doppler blood flow waveform, as reflected by a decrease in the PI index. This index is independent of the frequency of the transmitted waveform or the propagation angle of the ultrasound beam. The RI index in the normal common carotid artery has values of 0.55 - 0.75. An increase in the index indicates a decrease in cerebral flow. A too small RI value can indicate abnormal arteriovenous connections or arteriovenous malformations.

Results

An algorithm for Doppler imaging of blood flow in PWD mode with automatic determination of the envelope of the flow velocity spectrum and measurement of flow parameters was implemented in the prototype ultrasound B-mode scanner developed within the framework of the research project. PWD imaging tests were performed on an appropriately programmed ATS Cardiac Doppler Flow Phantom Model 523 stimulated with a Doppler Flow Pump Model 769 (see Fig. 3).

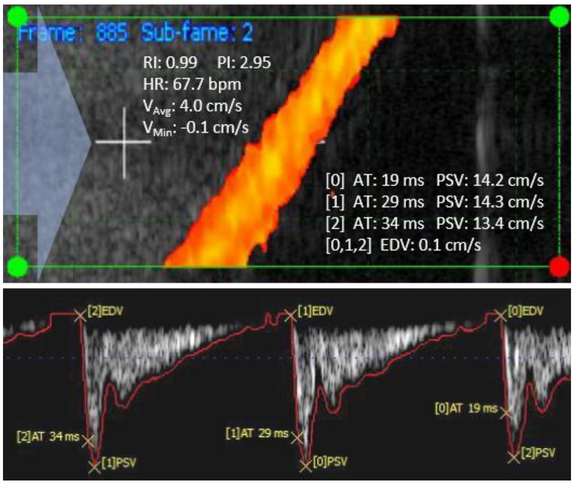

Fig. 3. An example of the performance of the developed CFM+PWD Doppler imaging algorithm implemented in the prototype 128-channel ultramobile ultrasound B-mode scanner.

The test results showed +/- 10% accuracy in volume measurement relative to manual measurement, as well as measurement of blood flow parameters with +/- 10% accuracy relative to manual measurement, for the parameters: peak diastolic velocity, peak systolic velocity, average velocity, RI and PI coefficients.

Summary and Conclusions

As a result of the tests, the performance of the method developed for automatic calculation of the envelope of the blood flow velocity curve in spectral Doppler imaging was sufficiently good in terms of repeatability and precision. The low computational complexity of the developed algorithm implemented in the prototype 128-channel ultramobile ultrasound B-mode scanner means that it does not burden the memory resources and FPGAs used for the device and is fast in operation.

References

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