Design and construction of an Ultrasounographic Device Dedicated to the Parietal Rheology Measurement in Human Carotid Artery

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Received: 8 October 2023
Revised: 9 October 2023
Accepted: 11 October 2023

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https://doi.org/10.20428/jst.v28i2.2177

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***Abstract*— We present in this article a detection system of ultrasounographic signal (USG) dedicated to the measurement of parietal rheology in human carotid artery. The aim of this practical work is to develop an ultrasonic method capable of visualizing the localized velocity profile of the carotid artery wall.**

The device produced makes it possible to take the USG signal from carotid wall of the human neck. It comprises an ultrasonic contact probe applied during the measurement (sensor), a signal shaping circuit, an acquisition and digitization interface in conjunction with an RS232 serial communication port and a local computer terminal hosting a graphical user interface (GUI) implemented in Visual Basic integrated development environment enabling the display, archiving and the digital processing of parietal ultrasonic signal.

The aim of this study is to reconnoitering the possibility of using ultrasound for a continuous and non-invasive measurement of the arteries parietal rheology. In this work, a sensor of ultrasound is used to measure the movement and the speed of the carotid artery wall, an image of the arteries parietal rheology.

Keywords— USG, parietal rheology, TEDP, CODEC, microcontroller, RS232, Visual Basic.

I. Introduction

Atherosclerosis is a major cause of cardiovascular mortality and morbidity [15] in a large percentage of the population, patients with hypertension, arterial stiffness, myocardial infarction, diabetes and chronic kidney disease [11, 17].

Numerous studies [12, 18] have demonstrated that hemodynamic changes in arteries have a strong impact on cardiovascular diseases such as atherosclerosis. Elasticity, viscosity, and viscoelasticity can be quantified from mechanical testing techniques that relate the dynamics of a tissue's deformation to an applied load.

For the last fifteen years, ultrasonic velocimetry has been used in rheology, on the one hand for local velocity measurements in standard rheometer experiments and on the other hand, for in-situ rheological measurements in conduits possibly forming part of industrial installations [9].

In October (2016) Richard Tyler Worthing [13], measured the diagonal and the velocity of a blood pulse voyaging through the radial artery, using a non- invasive ultrasound probe. Guerciotti, B.and Vergara, C. (2016) [19] find the influence of non-Newtonian blood rheology in stenosis vessels, for stenotic carotid arteries, velocity and vorticity fields are influenced by blood rheology.

The relations between the measurable quantities and the parameters describing the rheological properties of the material are in general complex, and impose more or less complicated mathematical models, based on approximations which must be all the more realistic as the measurement techniques are more accurate. The validity of these models has been verified experimentally, it is necessary to show whether it is possible to access the parameters describing the properties of the vascular wall from the only entirely traumatic measures currently possible in the cardiovascular system, that is to say the measures using transcutaneous ultrasonic soundings (Doppler velocimetry, or ultrasound) or in our case localized plethysmography with Doppler Effect.

The objective of this work is the realization of a technical platform consecrated to the exploration of the arterial parietal rheology, by the implementation of TEDP (Terminal Equipment for Data Processing) relating to physiological signal, in this case the USG, image of parietal rheological properties, then a micro controlled CODEC (coder decoder) responsible for sending this signal to a local computer post for archiving and visualizing them by means of an appropriate algorithm developed in Visual Basic environment.

II. Materials and Methods

A. Doppler Principle (1803 - 1853)

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The medical application of Doppler Effect discovered in 1843 by Johann Christian Doppler. It was only realized in the 1960s, with the use of ultrasonic waves [1].

Doppler Effect is based on the emission of ultrasounds which are mechanical vibrations comparable to the audible sounds but of higher frequency [1, 2] emitted by a source encounters a fixed target; the frequency reflected by this target is identical to the emitted frequency. When the target moves, the reflected frequency is different from the transmitted frequency, this difference (ΔF) between the transmission frequency (Fe) and the reception frequency (Fr) is called Doppler frequency, ΔF is expressed in hertz (Hz) [1] Figure 1.

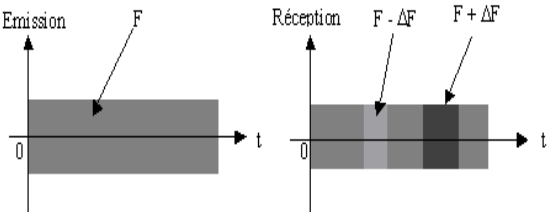


Figure 1. Schematic of a continuous Doppler

General case [8]:

$$Fr = Fe * \frac{c+u}{c-v} > Fe \qquad (1)$$

With:

- Fe: emission frequency of the probe.
- Fr: reception frequency of the probe.
- v: the traveling speed of the ultrasonic source.
- u: the displacement speed of the target (the vascular wall in our case).
- c: mean velocity of ultrasound in the medium (C = 330m/s in air) [7].

In our case the probe is fixed, so $v = 0$.

Carotid wall movements were measured using an ultrasound system with a 1.8-MHz [15]; the displacement speed of the arterial wall can be calculated from the following equation:

$$\Delta F = Fr - Fe = \left(Fe * \frac{c+u}{c-v}\right) - Fe$$

$$= Fe\left[\left(\frac{c+u}{c-v}\right) - 1\right] = Fe[\left(\frac{c+u}{c}\right) - 1] \qquad (2)$$

We use the continuous Doppler Effect for a characterization test of the viscoelastic properties of the vascular wall by recording the speed of displacement transmitted to the surface of the skin, in a localized way (Localized ultrasonic rheography). This examination therefore makes it possible to determine: The presence, the direction and the displacement speed of the vascular wall explored.

B. Technical principle (electromechanical transduction)

Ultrasound is based on the capability of a transducer to convert voltage into an acoustic signal, and to convert acoustic echoes received by the transducer back into a readable voltage [3, 4]. For this process of conversion between acoustic and voltage signals, most ultrasound transducers use piezoelectric elements [5, 13 and 14].

A piezoelectric materials or piezoelectrics are the materials that can produce electric energy upon application of mecanical stress, and vice versa, that induce a mechanical deformation when an electrical voltage is applied across it. The figure 2 [6, 13] shows a piezoelectric transducer and how it is used to transmit and receive ultrasonic waves

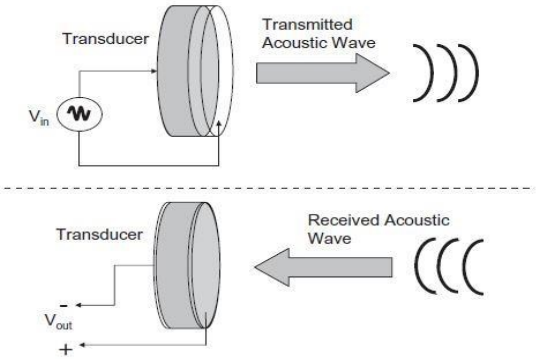


Figure 2. Ultrasonic transducers Top: Applying an electrical voltage to produce an acoustic waves. Bottom: Applying acoustic waves to generate an electrical voltage. Taken from [13,21]

C. The measurement system

In this section we present the practical realization of the various electronic components that we have realized. Figure 3

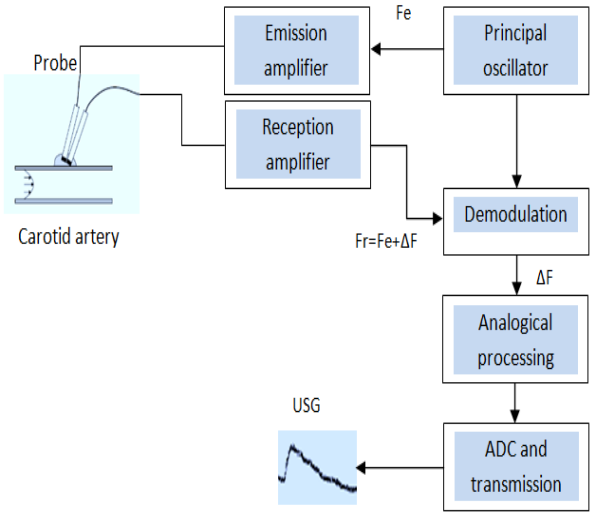


Figure 3. Block diagram of the realized system, composed of: the ultrasound probe, the principal oscillator, analog processing and transmission system.

The probe consists of two piezoelectric transducers, the first one for ultrasonic emission and the other for ultrasonic reception. With an alternating voltage excitation (generated by principal oscillator) applied to the emission transducer at its defined resonance frequency (1.8 MHZ), the piezoelectric material will oscillate with a frequency response identical to that frequency [13]. Once a piezoelectric element has been excited and is oscillating, the mechanical waves are transmitted from this element into the vascular wall [13, 16].

The signal collected by the reception probe, of frequency Fr = Fe + ΔF, is processed by the demodulator in order to extract the Doppler signal, with frequency ΔF.

1) Analogical processing (amplification and filtering)

The pulse waveform utilized to create mechanical vibrations in the ultrasound probe composed of a sinusoidal wave with a fundamental frequency of 1.8 MHZ generated by Transistor Pierce Oscillator [20] the oscillator designed with 2N3919 transistor [20] powered by 12V (figure 4), which allows to provide a 1.8 MHZ frequency sinusoidal signal, the latter will be transformed into a mechanical wave (US ultrasound) through an ultrasonic transmitter (E) of piezoelectric type. Transistor Q2 (BC547) is used as a power amplifier, figure 4. The maintenance of the oscillations imposes the open-loop transmittance of this oscillator is written:

$$T(j\omega 0) = -S * R3 \frac{1}{1 - LC1\omega 0^2 + j\omega 0 R3(C1 + C2) * \left(1 - L\frac{C1 * C2}{C1 + C2} * \omega 0^2\right)} = 1 \quad (3)$$

With the transconductance: s> 0.56 mA/V [20]

The imaginary part must be null:

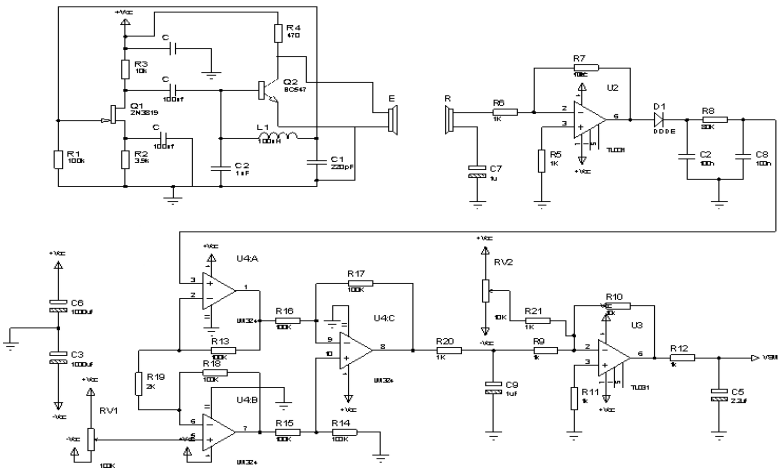
$$L\frac{C1*C2}{C1+C2}\omega 0^2 = 1 \quad (4)$$

Whence:

$$f0 = \frac{1}{2\pi} * \sqrt{\frac{C1+C2}{LC1C2}} \approx 1.8\ MHZ \quad (5)$$

Figure 4. Electronic circuit for parietal USG signal shaping

The echo signal received at the receiver (R) can be seen as a



frequency modulated carrier wave ΔF (Doppler frequency) and in amplitude ΔA by the echoes arising from the movements of the arterial wall transmitted locally to the skin.

The demodulation is the primary step of the analog processing, and amplifies the initial Doppler signals (ΔF) that are received at mini amplitude in the ambit of some mV. A second amplification stage is necessary to clearly visualize the signal, using the integrated circuit LM324, RV1 is used for compensation of the offset voltage to the input voltage. A final stage of amplification, with U3 (type TL031) of the gain:

$$AU3 = (1 + R10/R9) = (1 + 10k\Omega/1k\Omega) = 11 \quad (6)$$ was used.

Furthermore, for eliminate all the parasitic signals, it was decided to filter the signal, with a simple low pass R-C bridge, whose cut-off frequency:

$$FC = \frac{1}{2\pi RC} = \frac{1}{2\pi R12C5} = \frac{1}{2\pi * 2.2 * 10^3 10^{-6}} = 72{,}5Hz. \quad (7)$$

The potentiometer RV2 is used for output voltage compensation against the DC component.
The output signal of this circuitry is to 4V level.

2) Acquisition card

The acquisition chain can be represented according to the block diagram of figure 5. Following the analogical processing stage, the anti- aliasing filter is done to minimize the band width of the signal predated to sampling and converting by the ADC.

The acquisition cart utilized to digitization and transmission of the received ultrasound signals using a PIC16F876A microcontroller [6, 10]. Figure 6 appears an electronic circuit of the PIC16F876A evolution board with its input connector. The PIC16F876A microcontroller [10] containing a 10-bit analog to digital converter (ADC) and an USART (Universal Serial Asynchronous Receiver Transmitter) module, for the local communication asynchronous function. After sampling, the numeric signal is transmitted across serial communication

port RS232 to a CP (computer post) for post-processing and signal analysis. In fact, the acquisition card is utilized to administrate all multiplexing procedures, sampling, analog-to-digital conversion and data transmission.

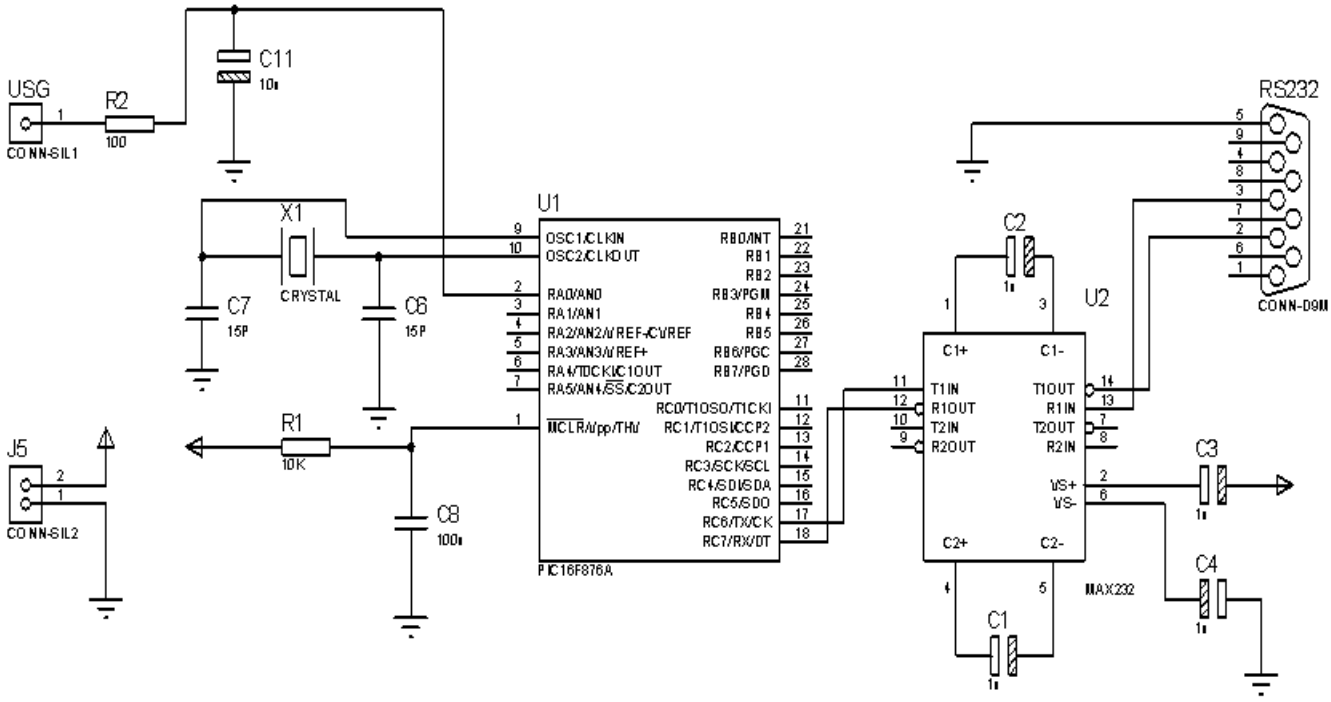


Figure 5. Structure of an acquisi

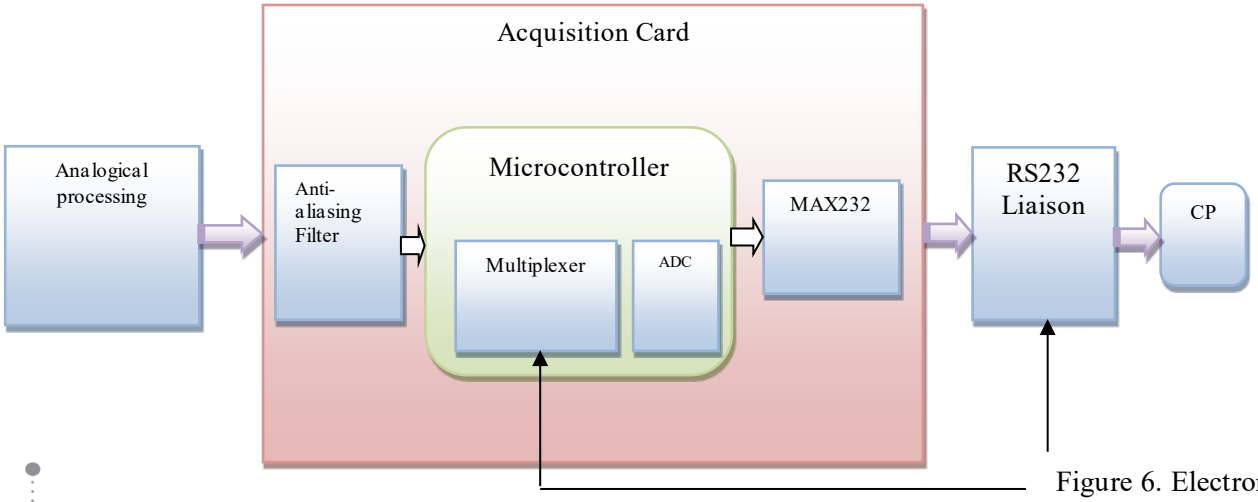


Figure 6. Electronic scheme of a

https://doi.org/10.20428/jst.v28i2.2177

The figure 7 exposes a real photograph of our system design.

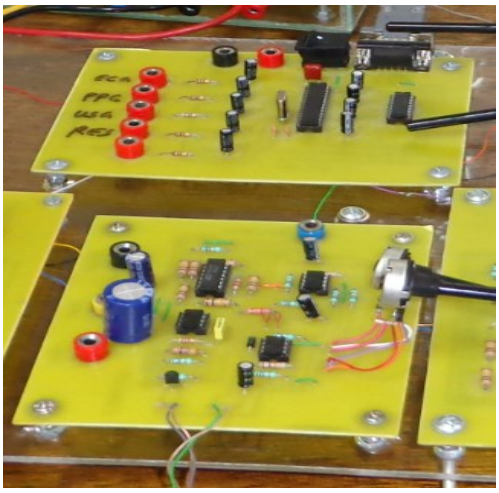


Figure 7. A real photograph of experimental prototype by utilizing PIC16F876A

3) Graphical interface

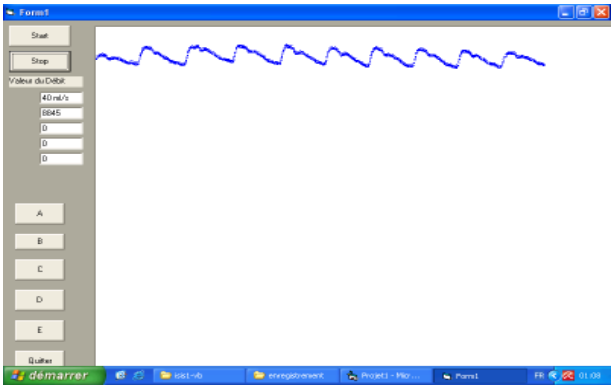
The program implementation of the data acquisition and display has been applier by Visual Basic (VB) environment using the Mscomm component of VB, who is allowed the asynchronous serial reception and display of the data, figure 8.

III. RESULTS AND DISCUSSION

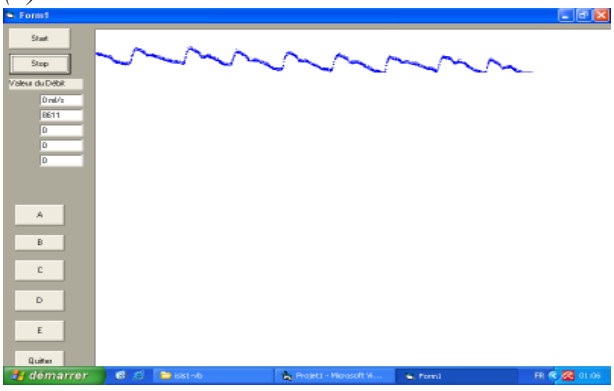
The understanding of parietal rheology of the arteries, taking into account the vascular geometry complexity, requires the development of models and techniques for experimental exploration of the arteries dynamics.

The aim of this practical work is therefore, the development of an ultrasonic method capable of better understanding and visualizing the localized motion profile of the carotid arteries in a non-invasive manner. This technique makes it possible to confirm the local rheological behavior of the artery from Doppler plethysmographic measurements.

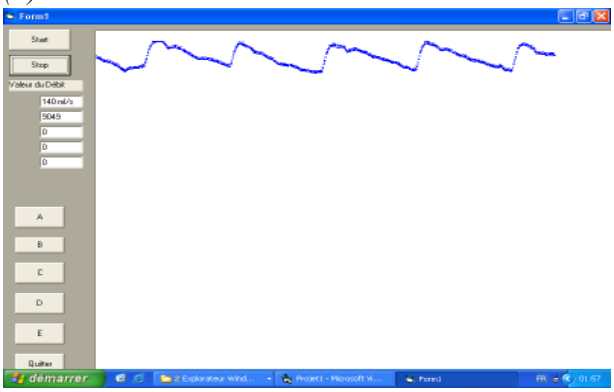
Four examples of the parietal USG measurement made using the human carotid artery is shown in figure 8, for normal subjects, with ages between 20 and 30 years, representative of the displacement speed of local vascular wall in carotid artery.



(A)



(B)



(C)

(D)

Figure 8. Examples of representative parietal ultrasonographic measurements of the carotid artery during the pulse cycle for four persons.

The top of these signals represents the maximum displacement of vascular wall, of the arterial carotid, during the cardiac systole and the lower represents the minimum displacement of the vascular wall, of the arterial carotid, during the cardiac diastole.

This work introduces a new technique for evaluating the parietal rheology in human carotid artery through dynamic movement of carotid artery using ultrasound probe. This non-invasive method allows simultaneous measurement of artery displacement by an angle insensitive, Doppler technique. The use of ultrasound technology in order to extract these data represents a fast, cheap, and widely applicable method that can extract data suitable for superficial blood vessels.

IV. Conclusions

This study is an chance for us to present our works in Biomedical Engineering and which is based on the implementation of a multiparametric exploration device for the cardiovascular system. This work was concretized by a practical realization of an electronic platform allowing first the extraction of the parietal USG signal, followed by analogue and digital processing dedicated to the transmission of data to a local computer via the RS232 serial port and finalized by the software application in integrated development environment (IDE) VB6 enabling the display, archiving and digital processing of parietal ultrasonic signal, image of the parietal rheology of the local vascular wall for the carotid artery.

The goal of this research was to design an electronic prototype that can be used to experimental measure of parietal rheology in human carotid artery using ultrasound, for reconnaissance the possibility of using ultrasonic wave as part of a continual and non-invasive measurement of the arteries parietal rheology.

V. Acknowledgments

This work was financially sponsored by the laboratory Genie Biomedical of Tlemcen University under the scientific programme: “phD projects” the academic year 2018-2019.

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