Design and construction of a photoplethysmographic device

Mohammed Benabdellah1, M. Nasr Kaid Ali1, Bruno Salgues2
1Tlemcen University, 22, Rue Abi Ayed Abdelkrim Fg Pasteur, Tlemcen 13000, Algeria
2Institute Mines Telecom, France
Abstract

The aim of this article is to study and develop an interface (human-machine) for monitoring the cardiovascular-respiratory function, through the evaluation of the characteristics indexes of response to vascular expansion. This interface will be a technical device capable of taking simultaneously and in real time three representative physiological signals respectively: the electrical cardiac activity (electrocardiogram ECG), the mechanical ventilatory activity (the pneumotachogram PTG), and the respiratory activity of the pulmonary exchanger (photoplethysmogram PPG) and then, send these signals to a local computer post.

The configuration of this interface comprises:

• Sensors with their formatting circuits responsible for collecting different signals of the patient.
• Capture card built around a microcontroller; that is responsible for digitizing the signals and transfers them to a local computer terminal.
• A graphical interface developed in Visual Basic environment dedicated for driving the capture of signals, the temporal and spatial processing and archiving of data.

The temporal and spatial analysis of these three signals allows evaluating perfusion index (PI), the plethysmographic variability index (PVI), the Pre-ejection period (PEP) and the left ventricular ejection time (LVET).

Keywords: ECG - PPG - PTG - PEP - LVET - PI - PVI - microcontroller - RS232 - Visual Basic – vascular Filling.
**Introduction**

- Hemodynamic monitoring in the intensive care unit (ICU) is a key element of the most severely ill patients aimed at accessing to the monitoring and evaluation of circulatory function [1].
- In recent years, cardiopulmonary interactions have been the subject of several studies and publications because of their potential interest in the development of hemodynamic monitoring tools to guide fluid resuscitation in patients on mechanical ventilation [7, 8, 9].
- In 1987, Partridge showed for the first time that the respiratory variations of the plethysmography peak of the wave could detect hypovolemia in patients on mechanical ventilation [10].
- Later, in the early 2000s, the concept of 'useful filling' appeared. Indeed, several studies can demonstrate a reduction in morbidity and mortality in the units of resuscitation and anesthesia in connection either with an effective plasma volume for an improvement in cardiac output or with an altitude restriction filling [11].
- The emergence of dynamic indexes response to volume expansion and the rediscovery of plethysmographycurve lead to the development of parameters derived from its respiratory variability.
- Among these indexes, the most used is deriving from the pulse plethysmography, perfusion index (PI) and plethysmographic variability index(PVI).
- PVI is the first and only commercially available measurement that automatically and continuously calculates the respiratory variations in the photoplethysmosographic waveform[23].
As part of this article, we develop a technical device capable of collecting three signals representative of cardiovascular respiratory function; namely the electrocardiogram (ECG), the photopleysmogram (PPG) and pneumotachgram (PTG).

The spatial and temporal analysis allows to extracting information from the PPG curve to evaluate the dynamic indices: perfusion index (PI), the pleth variability indexes (PVI), the pre ejection period (PEP), the left ventricular ejection time (LVET) and the ratio of PEP / LVET.
Material and Methods

- The technological media that allows us the implementation of the technical platform are:
  - 1. The ISIS environment for the arrangement of electronic circuits.
  - 2. The MPLAB environment for assembly programming of microcontroller 16F876A.
  - 3. The Visual Basic environment for the interface of digital processing of signals.
Pleth variability index (PVI)

- PI is calculated as the pulsatile infrared signal (AC or variable component), indexed against the non-pulsatile infrared signal (DC or constant component) “Figure 1” and expressing this number as a percentage (equation 1) [23].

\[
PI = \frac{\text{AC}}{\text{DC}} \times 100 \%
\]

- Figure 1. Graphic representation of raw infrared signal processed internally by the pulse oximeters, where AC represents the variable absorption of infrared light due to pulsating arterial inflow and DC represents the constant absorption of infrared light due to skin and other tissues.
The PVI is a measure of the dynamic changes in perfusion index (PI) that occur during one or more complete respiratory cycles “Figure 2”.

In this context a new algorithm built on the PI to calculate by an automated manner the PVI defined by equation 2[23].

\[ \text{PVI} = \left( \frac{\text{PI}_{max} - \text{PI}_{min}}{\text{PI}_{max}} \right) \times 100 \% \]  

Figure 2. Graphical representation of photoplethysmography signal, where the PVI is an automatic measurement of dynamic changes in the perfusion index (PI) that occur during the respiratory cycle[24].
This tool has been used and been under study in the two recent studies of Cannesson team in 2008 [12, 13]. The first demonstrated the validity of PVI as an index can predict a value of $\Delta PP_{LET}$ (Pulse plethysmography variation) greater or less than 13% with a sensitivity of 93% and a specificity of 97%. The threshold value established was 11.5%. The second highlighted that PVI can predict noninvasively in the operating room the response to vascular filling with a threshold value set at 14% for a sensitivity of 81% and a specificity of 100%.

All these studies highlight the feasibility of this non-invasive technique and thus its interests and its application to patients non-equipped with an arterial catheter.
The response to vascular filling using systolic intervals

- The determination of systolic time intervals was used for tracking ischemic heart disease, of valvular disease, hypertrophic cardiomyopathy, and hypertensive disease and of certain pharmacological effects on the myocardium [14-16]. The most used time intervals systolic were: The pre ejection period PEP, the left ventricular ejection time (LVET) and PEP / LVET ratio [14].

- The pre ejection period (PEP).

- The PEP is defined by the time interval between ventricular depolarization [27] (beginning of the QRS on ECG) from the start of left ventricular ejection (opening of the aortic valve) [14, 27] “Figure 3”. This length of time depends on the preloading, post loading and contractility [18]. The normal value for adults is 106 ± 7 ms [19].
Figure 3. Schematization of measuring pre-ejection time by an ECG recording and photoplethysmography signal, where the PEP is the time interval between the beginning of the QRS on ECG and the beginning of ventricular ejection. [26]
The left ventricular ejection time (LVET).

- The LVET is defined by the systolic time interval, during which the left ventricle ejects blood into the aorta (opening-closure of the aortic valve) [18, 27] “Figure 4”. This duration of time depends mainly on the VES (systolic ejection volume) [20], the normal value for adults is 292 ± 18 milliseconds [19]. This value inversely correlated to heart rate, according to the fact that the VES decreases when the heart rate increases [20].

- Figure 4. Graphical representation of photoplethysmography signal, wherein the LVET is the time interval during which the left ventricle ejects blood into the aorta (opening-closure of the aortic valve).
The ratio PEP / LVET.

The ratio PEP / LVET is a reliable index of cardiac contractile function [18]. Indeed, the appearance of a cardiac dysfunction increases the value of the PEP and decreases the duration of LVET [18]. Thus, the PEP / LVET ratio increases in the case of a decrease in contractility. The normal value for adults is $0.37 \pm 0.03$ [19]. Diverse studies have found a correlation between this ratio and the different indexes assessing the left ventricular performance [15, 17, 21, 22].
- Electronics associated with the PPG sensor.
- It consists of the parts exposed in the block diagram of the “Figure 9”
- The sensor part includes the infrared light source and the photon detector.
- Signal conditioning.
- The formatting circuit.

Figure 9. General block diagram of a photoplethysmography.
“Figure 10” shows the electrical circuit realized of a photoplethysmograph (PPG).

Figure 10. Electrical circuit of photoplethysmography.
After the formatting, we bring the three signals ECG, PPG and PTG at a level compatible for connection to a microcontroller. The acquisition circuit realized around the PIC16F876A microcontroller [4] with an ADC module (Analog to Digital Converter) 10 bit for the digitization and a USART module (Universal Serial Asynchronous Receiver Transmitter) for asynchronous local communication in RS232 protocol, as shown in “Figure 13”. In fact, this component is used to manage all the multiplexing procedures, sampling, analog to digital conversion and transmission of data, whose the sampling period is of 390.6 microseconds, this giving the sampling frequency is equal to 2.56KHZ.
Figure 13. Schematic diagram of the acquisition card.
The communication of this card with the PC is done through an RS232 serial connection (DB9) connected to the microcontroller through its pins 2 and 3 (RX, TX) via a MAX232 circuit whose role is the adaptation of TTL / CMOS signals. As shown in “Figure 14” the transmission being of asynchronous type (no common clock between the transmitter and receiver), additional bits are essential to the functioning: beginning bit of word (Start), end bits of word (stop).

Figure 14. Timing diagram for the serial protocol of transmission. [5]
The transmission of characters not can function correctly only if the different variable parameters of this weft it known to both the transmitter and to the receiver. It is then necessary to adjust the following parameters: the transmission speed, the number of bits of the character transmitted, the parity, the number of stop bits.

In our case:
- Transmission speed 57600 baud (bit/s)
- 8 data bits.
- No parity.
- One start bit.
- One Stop bit.

The real image of the system made is shown in the “Figure 15”.
Graphic interface

Figure 16. Flowchart of dialog Hard-Soft.
Results

The “Figure 17” shows the simultaneous recording of three physiological signals from a normal subject, ECG image of the electrical activity of the myocardium, PPG hemodynamic activity of alveolar-capillary exchange and the capacity of the blood flow to power the various tissues and organs in oxygen and PTG representative of pulmonary respiratory capacity respectively. Even these signals are recorded as archived data (*.DAT). Simultaneous recording of these three signals allows for better apprehension of the cardiovascular-respiratory system, the diagnostically, aimed access to surveillance and evaluation of circulatory function.
Figure 17. The simultaneous recording of signals ECG, PPG and PTG in real time.
The processing of resulting spatiotemporal data is meant to estimate the representative indexes in the response to vascular filling.

Spatial analysis

Spatial analysis allows to extracting information from the PPG curve to implement the indices of perfusion (\( PI_{\text{max}} \) and \( PI_{\text{min}} \)) and the pleth variability index (PVI), during the respiratory cycle, “Figure 18”.

Figure 18. Parameterized different: FC, Plmin, Plmax and PVI.
Temporal analysis

Temporal analysis allows to extracting information from the PPG curve to evaluate the preejection period (PEP), left ventricular ejection time (LVET) and the PEP/LVET ratio “Figure 20”.

Figure 20. Parameterized different: FC, PEP, LVET and the ratio PEP/LVET.
Conclusion

- The objectives concerning the implementation of a technical platform dedicated to exploration multi parametric of the cardiovascular-respiratory system, seems reached on the electronic map prototyped. It remains to develop a validation of the system on the medical plan but may not see the day as in the clinical environment in collaboration with the specialists of this system that will better guide the implementation of algorithms suitable for correlative exploration and monitoriessurveillance of the cardiovascular-respiratory system.

- Respiratory variations in the amplitude of the plethysmographic wave given by pulse oximetry allow predicting reliably and completely non-invasive response to vascular filling in patients under mechanical ventilation.

- Numerous studies demonstrate that PVI is able to predict fluid responsiveness following volume infusion in sedated adult patients under positive pressure ventilation. PVI represents the first noninvasive, continuous, widely available, easy-to-use index that can be used to predict fluid responsiveness in these patients.
References

[1] Hélène FERRY "valeur de l'index de variabilité de pléthysmographie comme indice prédictif non invasif de réponse au remplissage vasculaire en réanimation pédiatrique ", thèse pour obtenir le grade de docteur en médecine le 16 octobre 2009.
[27]. Alice Delacroix"évaluation de la réponse au remplissage vasculaire chez le patient âgé en sepsis sévère par un monitorage non invasif : la bioimpéandancemétrie thoracique", thèse pour le diplôme d'état de docteur en médecine, université du droit et de la sante - lille 2 présentée et soutenue publiquement le 10 juillet 2013.
Books
L’E-sante et la télémédecine

Télésanté, espoir du monde rural

And : Health industrialisation
Call for paper
Bruno Salgues, Nasr Kaid Ali, Mohammed Benabdellah

- Tlemcen University, 22, Rue Abi Ayed Abdelkrim Fg Pasteur, Tlemcen 13000, Algeria
- Institute Mines Telecom, France
  - Centre Ingénierie santé, Institut Mines Telecom