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Development of a Human Machine Interface of Information and Communication in telemedicine HMI-ICTM: Application to Physiological Digital Signal Processing in Telemedicine

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Abstract: *We propose in this paper to present the development a man machine telemedical interface of information and communication telemedical HMI-ICTM. This allows respectively:*
-To measure on the patient multidimensional signals representing its pathophysiological state.
-To Control substitution medical systems of physiological defective organs.
-To support the transfer of data through computer medical networks.
The first configuration of this interface consists of:
-A Terminal Equipment Medical Data Processing dedicated to three physiological signals: The first representative of myocardial electrical activity (electrocardiogram ECG), the second representative of the mechanical ventilatory function (the pneumotachogram PTG), and the third representative of the exchanger and the pulmonary flow function (photoplethysmogram PPG).

The Hardware interface built around a microcontroller (CODEC), responsible for digitizing the signals from the DTE (Data Terminal equipment) and transfers them to a local computer-terminal. The Software interface developed in Visual Basic environment responsible for controlling the acquisition, processing spatial, temporal and spectral, archiving and transferring of the medical data through medical networks in the TCP / IP.

The simultaneous recording of these three signals allows a better management of cardio respiratory failure. This management is on a diagnostic bares, the processing and the monitoring through digital processing, and multiparametric spatial, temporal, spectral and correlation of these signals.
Keywords: *ECG, PTG, PPG, Telemedicine, EDRA, EDRF, PDRA, PDRF, Autocorrelation, Intercorrelation, FFT, DSP.*

I. INTRODUCTION

The global structure of a chain HMI - ICTM is represented by Figure 1:

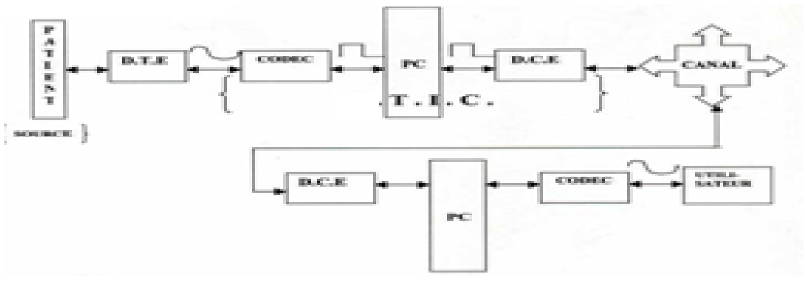

Fig. 1 Structure of the platform Tele-medical

It includes:

- The source's patient and destination of medical information.
- The DTE (Data Terminal Equipment) responsible to collect information from the patient.
- The CODEC (coder decoder) Microcontroller charged to transit information from the DTE to the local computer terminals.
- The PC (Computer terminals) local or distant responsible for presenting medical information to medical practitioners usable, store this information and host the various applications and software platforms of digital processing and the transfer multimedia medical information using a program environment.
- The DCE (Data Communication Equipment) charged to adapt information's signal to the transmission channel, to transfer medical data to remote terminals by telemedical networks and maximize the flows using the broadband techniques (ADSL modem).

Depending on the nature of medical information man-machine, the DTE are[1]:

- Linear which sensors transform physiological data to electrical data.
- Two-dimensional involving different electromagnetic radiation (radiofrequency, Ultrasonic, Infrared, Visible, Ultra Violet, X and γ) and their interaction with biological samples for the reconstitution of medical image.
- Three dimensional including an endoscopic camera for viewing a video image from inside or outside of body human which are dedicated both of diagnostic phase of medical practice and therapeutic phase (Laparoscopic surgery minimally invasive).

The CODEC allow the generation of signals controlled locally or distant of medical systems (extracorporeal circulation of hemodialysis or surgery open heart, artificial ventilator, Hearing or heart appliances, insulin pumps, surgery robot ...) and are dedicated to the therapeutic phase of medical practice.

II. GENERAL PROBLEM OF IHM-ICTM

The device we propose is designed to answer of several problems:

Medical and surgical practice (diagnosis, treatment, monitoring) involves the use of a variety of technical platforms. The current power of information and communication techniques permit to think to a progressive integration of the multitude of technical platforms as a Human Interface Device (HID)versatile, adaptive and scalable charged to transform a terminal computer in a real station of practice surgical medical local or distant which lead to concept of PC - Hospital.

- The simultaneous collection of multiple signals representing different physiological functions will establish their inter-correlations through the implementation of appropriate algorithms. This permit to get a result in better diagnosis and give therapeutic indications.
- The integration almost unlimited of additional exam in this system will prevent the displacement of the patient from service to other.

III. PROBLEMATICOFTHE FIRSTCONFIGURATIONIHM-ICTM

The cardio respiratory system components:

The heart pump responsible of blood circulation in the vascular system, the ventilatory pump responsible of the mobilization's thoracic cage and the pulmonary exchanger responsible of the diffusion capillary alveolar gas. The failure of one or more of these elements results hypoxemia requiring artificial ventilator.

The simultaneous exploration of these elements using the IHM-ICTM permit to inadequate if the patient need artificial ventilation and weaning thereof avoiding to the patient failure.

This same configuration will provide to the practitioner of intensive care a monitoring device specific to each patient.

IV. HARDWAREIMPLEMENTATIONOF THEHMI-ICTM

It was constructing around the microcontroller 16F876Acomport an ADC module 10bits and an USART module.

The RS232 parameters used are:

- Transmission rate 57600Bauds
- 8 data bits
- One parity bit
- One stop bit

V. DIGITAL PHYSIOLOGICAL SIGNAL PROCESSING IN TELEMEDICINE

The digital processing we develop for these three signals can make information to the practician a diagnostic to guide his therapeutic.

Cardiac and respiratory activities are linked since one assures oxygen to the blood and the other assures the transport of the oxygen to various organs and tissues in the body.

We were interested in this work:

1- To calculate and plot the autocorrelation and inter-correlation functions, to calculate and plot the densities spectral and inter-spectral of average power of signals. For this, we developed an algorithm to calculate the correlation functions and spectral densities based on the FFT [2].

2- To extract of the respiratory signal from the ECG signal by demodulation of amplitude and frequency and the establishment of correlations.

3- To extract of the respiratory signal from the PPG-signal by demodulation of amplitude and frequency and the establishment of correlations.

The algorithms that perform these calculations were implemented in Visual Basic environment.

1. Spatial Analysis

This allows simple selection of the different waves on different signals (ECG, PPG and PTG) to show their amplitudes. We also implemented a numerical integration to calculate tidal volume from the inspiratory flow.

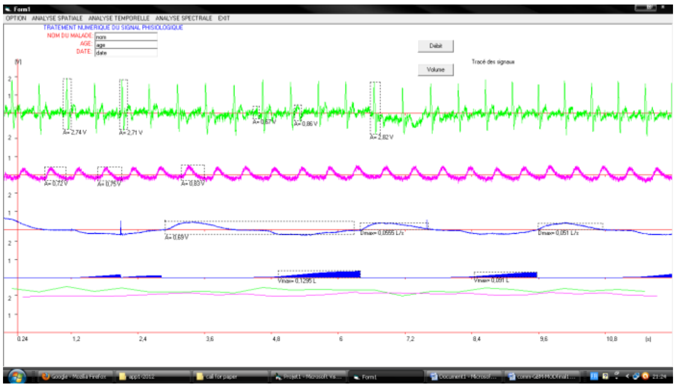

Fig.2 viewing magnitudes (1.ECG, 2.PPG, 3.PTG, 4.Tidal Volume VT)

We can select different waves from the ECG of a healthy man aged 56 years old. For this ECG signal, we have selected: the QRS wave which has the magnitude of: 2.17V, for the P wave: 0.67V and the T wave: 0.86V.

We have selected the wave of the PPG signal and it has the magnitude of: 0.75V.

Also, we have selected for the respiratory signal, the maximum flow and the maximum volume of one inspiration which are respectively: 0.051l/s and 0.12l.

2. Temporal Analysis

This allows simple selection of view durations of the different waves and their temporal intervals.

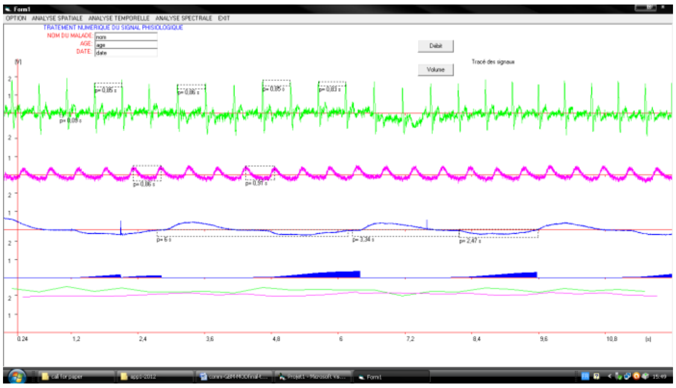

Fig. 3 Time slicing physiological signals ECG-PPG-Respiratory

This allows the duration of the interval RR which is around of 0.86s and the different wave selected: the P wave of 0.09s. The interval PP for the PPG signal is also selected and gives: 0.86s. The value of the respiratory period selected is: 6s. The values of the inspiration and expiration periods are respectively: 2.42s and 3.34s.

2.1. Detections Peaks of different Signals:

We developed an algorithm to detect peaks of the various signals contained the steps bellow:
Averaging, thresholding and windowing of the various signals.

This algorithm is shown on figure 7:

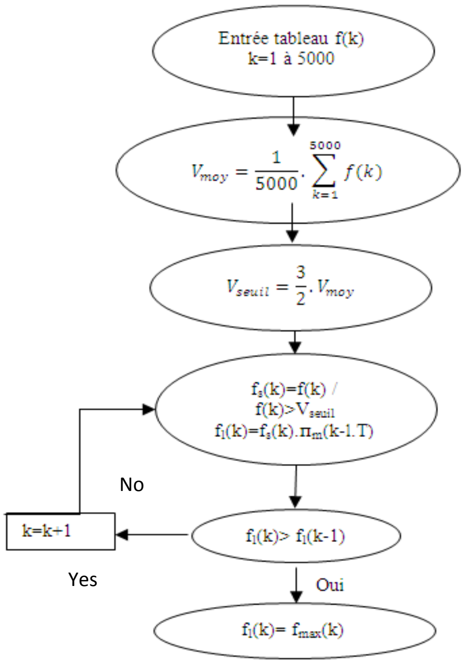

Fig. 4 Algorithm of peak detection.

T is determined by the following value of $f_l(k)$ after detection of the previous peak.

2.2. Plotting signals EDRA and PDRA:

With the peak detection algorithm related to physiological signals developed, we can proceed to the deriving respiration of the signal from ECG signal with magnitude demodulation called EDRA or from the PPG signal called PDRA, the figure 8 shows the EDRA, the PDRA and their superimposition with the respiration signal [2], [3].

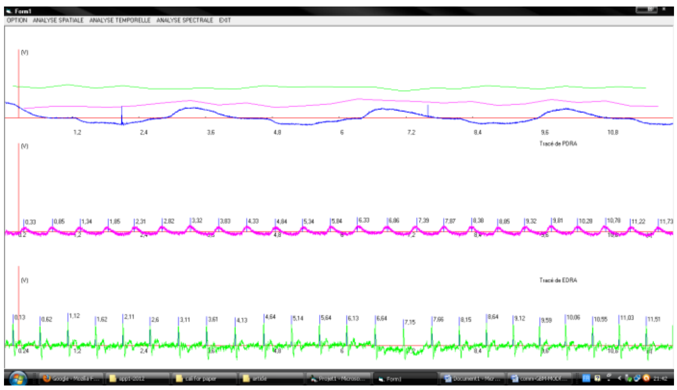

Fig.5 EDRA, PDRA signals and their superposition with the respiration signal.

2.3. Plotting Signals EDRF and PDRF:

The same algorithm used above allows the derivate respiration signal from ECG and PPG signal by frequency demodulation called respectively EDRF and PDRF as shown by Figure 6:

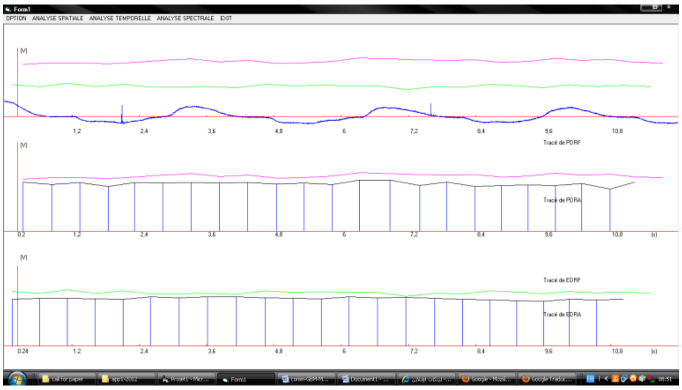

Fig.6 EDRF and PDRF signals and their superimposed with respiration signal.

We try to compare the three signals: respiratory signal, the EDRF and the PDRF signals, we note that the variation of the respiration appears on the PDRF where each peak appears in the same time.

2.4. Plotting Signal HRV and the variability of the PPG signal:

This represents the heart rate variability and constituted a good indicator of cardiac arrhythmias [4]. We propose the plot of Variability of the PPG signal that can inform us of the goog pulmonary alveolus capillary function.

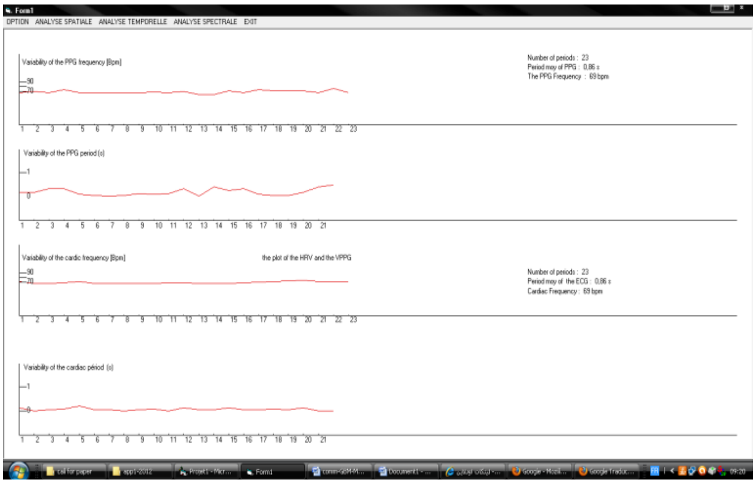

Fig.7 HRV signal and average period.

We note that the ECG and the PPG signals have the same number of beat per minute which is 69BPM and their periods are: 0.86s.

2.5. Correlation Analyses:

2.5.1. Plotting Autocorrelations Functions:

The algorithm for calculating the temporal autocorrelation function has been implemented in accordance with the following definition [6], [7]:

$$K_x(\tau) = \frac{1}{T}\int_T x(t)x(t-\tau)dt. \qquad (1)$$

$$K_x(\tau) = \frac{1}{N}\sum_{k=\tau}^{N} f(k).f(k-\tau), with : N = 2^q \qquad (2)$$

$$and : \tau = 0,..,N.$$

The Fig.8 represents the autocorrelation function of an ECG signal.

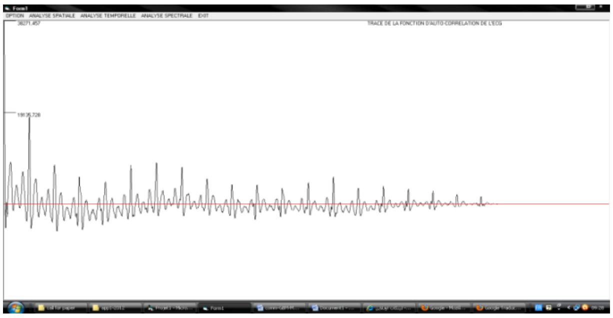

Fig.8 Autocorrelation function of ECG signal.

The autocorrelation function of a PTG signal is represented by the figure 9.

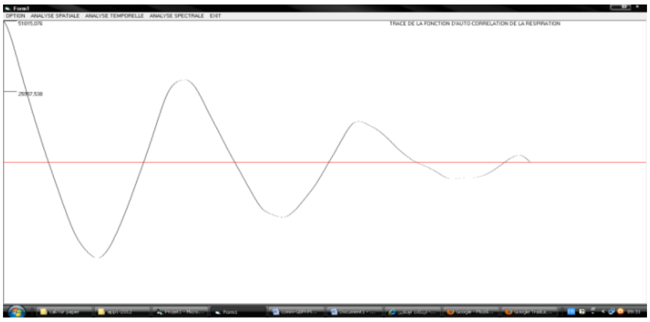

Fig.9 Autocorrelation function of respiration signal.

The autocorrelation function of a photoplethysmographic signal is represented by the figure 10.

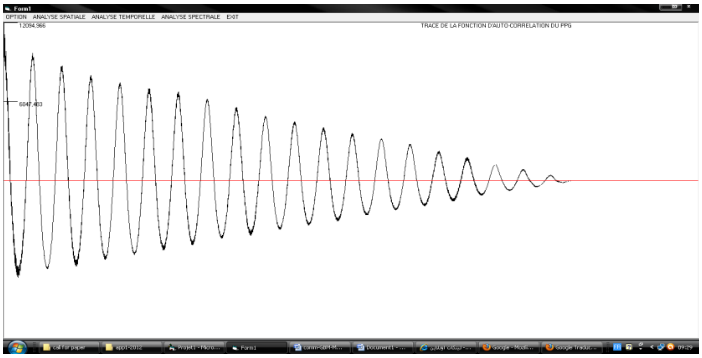

Fig.10 Autocorrelation function of the PPG signal.

The algorithm of the temporal inter-correlation function has been implemented according to the following definition [5], [6]:

$$K_{xy}(\tau) = \frac{1}{T}\int_{T} x(t)y(t-\tau)dt. \quad (3)$$

Figure 11 represent the plot of inter-correlation function PPG –PTG signals.

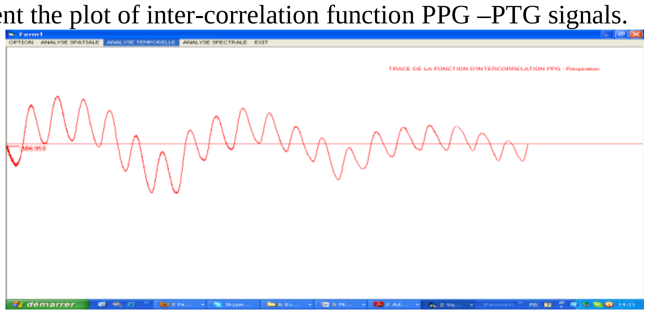

Fig.11 Intercorrelation function of PPG-PTG signals.

VI. Calculation And Plot Of The Medium Power Spectral Density Of The Physiological Signal by FFT

Spectral analysis is a key element of signal processing. It aims is to improve information of a signal by interesting at its variation in the frequency domain.

We developed an algorithm for its calculation which is based on the discrete Fourier transform of N order which is given by [6]:

$$X_N[k]=\sum_{n=0}^{N-1} x(n)e^{-j\frac{2\pi}{N}kn} \qquad (4)$$

$$=\sum_{n=0}^{N-1} x(n).W_N^{kn} \quad and: W_n = e^{-j2\pi/N}$$

N is the length of the input sequence, $0 \le n \le N-1$, and $0 \le k \le N-1$.

Coupled to the Radix 2 algorithm which consists of decomposing an N-point DFT into a series of successive 2 points [8]; m steps of processing are necessary, where m=log2N.

$$X[k]=\sum_{r=0}^{N-1} x[2r]W_{N/2}^{rk}+W_N^k.\sum_{r=0}^{N-1} x[2r+1]W_{N/2}^{rk} \quad (5)$$

The plot of the spectrum of the ECG signal is represented in Fig.12 where we can observe the different significant stripe.

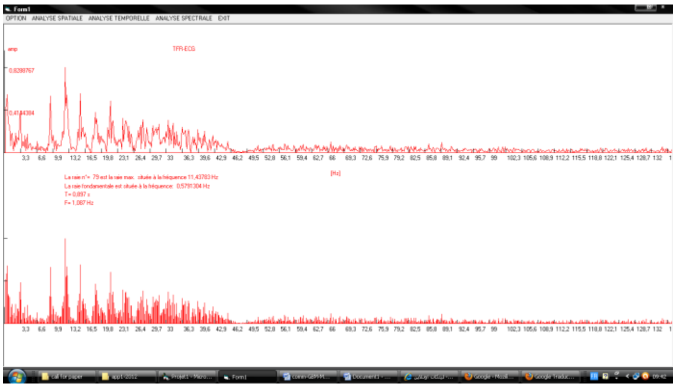

Fig.12 FFT-ECG

We note on this plot that the spectral component of the ECG signal changes from 0 to 200Hz, the frequency of this ECG signal is 1.08Hz; the period is 0.89s which are equal to those calculated in the time domain. Also we note too other frequencies the first for the fundamental frequency at 0.57Hz and the line up frequency at: 11.43Hz. We note that this values change from different ECG signal and the frequencies change for each pathological case where the line up frequency great.

Similarly we can trace the spectrum of photoplethysmographic signal.

Fig.13 PPG-FFT signal

We note on this plot that the spectral component of the PPG signal changes from 0 to 150Hz, the frequency of this PPG signal is 1.08Hz; the period is 0.89s which are equal to those calculated in the time domain. We note two other frequencies, the first for the fundamental frequency at 0.28Hz and the line up frequency at: 3.04Hz. We note that this value change from different PPG signals and the frequencies change for each pathological case where the line up frequency changes.

Similarly we can plot the spectrum of a pneumotagraphic signal.

Fig.14 FFT-PTG signal

We note on this plot that the spectral component of the respiration signal changes from 0 to 100Hz, the frequency of this respiration signal is 0.14Hz; the period is 6.88s which are equal to those calculated in the time domain. We note that the two frequencies which are the fundamental frequency and the line up frequency are at the same frequency: 0.63Hz. We note that this value change from different respiration signals and the frequencies change for each pathological case.

VII. Calculate and Plot of Medium Power Spectral Density by Fourier Transform Of Autocrrelation Function

The average power spectral density can be calculated by the following definition [6], [7]:

$$TF(K_x(\tau)) = TF(\frac{1}{T}\int_T x(t)x(t-\tau)dt). \quad (6)$$

We have shown in the figure.19, the plot of this function for the ECG signal.

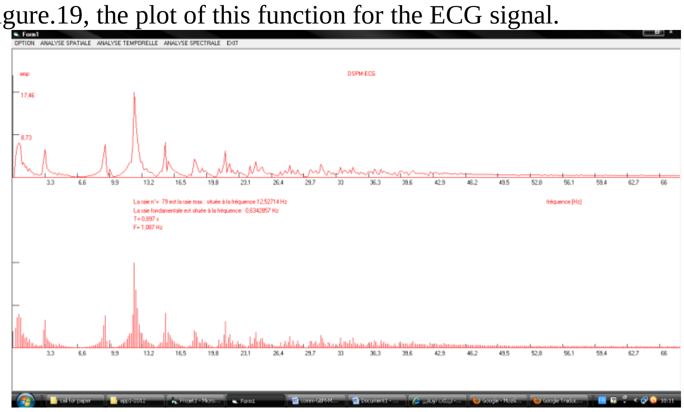

Fig.15 Power Spectral Density of ECG

We note on this plot that the medium power spectral density the ECG signal changes from 0 to 100Hz, the frequency of this ECG signal is 1.08Hz; the period is 0.89s which are equal to those calculated in the time domain. The fundamental frequency is at 0.63Hz and the line up frequency at: 12.52Hz. We note that this values change from different ECG signal and the frequencies change for each pathological case where the line up frequency approaching for the height frequencies.

The medium power spectral density of the photo plethysmographic signal is representing by the figure.16

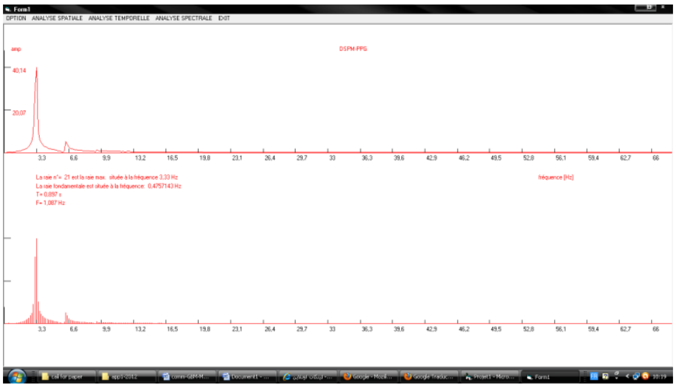

Fig.16 Medium Power Spectral Density of PPG signal

We note on this plot that the medium power spectral density of the PPG signal changes from 0 to 100Hz, the frequency of this PPG signal is 1.08Hz; the period is 0.89s which are equal to those calculated in the time domain. The fundamental frequency is at 0.47Hz and the line up frequency at: 3.33Hz, while that the line up frequency for the same signal calculated before is: 3.04Hz. This value change from different PPG signal and the frequencies change for each pathological case.

The medium power spectral density of the pneumotachogramme signal is given by the figure.17.

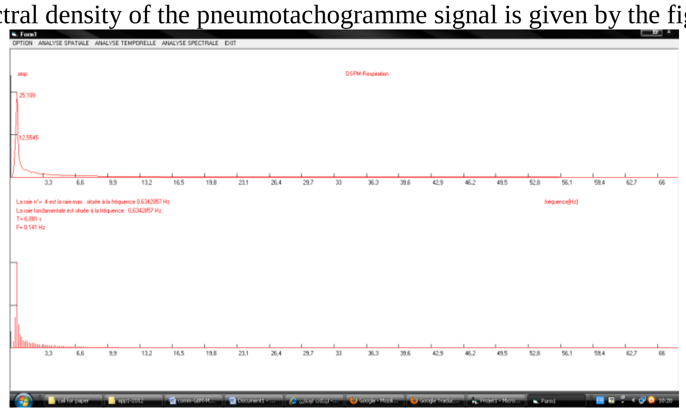

Fig.17 Power Spectral Density of Respiration

We note on this plot that the medium power spectral density of the Respiration signal changes from 0 to 100Hz, the frequency of this signal is 0.14Hz; the period is 6.88s which are equal to those calculated in the time domain.

The fundamental frequency and the line up frequency for the medium power spectral density are at 0.63Hz and are equal to that calculate above by spectral analysis. This value change from different Respiration signal and the frequencies change for each pathological case.

VIII. CONCLUSION

This work consists to:

-Implement an acquisition system controlled by microcomputer. This should be included in a channel of acquisition since the final objective is the realization of a Telemedicine station.

-Implement software of digital processing of physiological signal. In this context, the physiological signals have received the latest developments in digital signal processing by implementing a spatial, temporal and spectral analysis.

The clinical validation of the system must pass through a statistical study performed on a large population of patients who attain various cardiac and respiratory diseases to involve the autocorrelations functions temporal and statistics.

The prospects of this work is how to implement software able to take over the signal processing cardiopulmonary respiration which reflects the function of the heart and respiratory pump through of the three signals representative of the different activities (ECG-PPG-Respiration).

The transfer in real time (point to point) of the various signals through telemedical networks with protocol TCP/IP which is devoted to the implementation of an intelligent house of health (H.I.S).

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