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Conception and Development of a Tele-Medical Interface Dedicated to Tele Monitoring of the Renal and Cardiacinsufficiency

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Abstract: *Heart diseases are particularly common in patients with kidney disease. Renal failure patients are more likely to die of heart failure than reaching the stage of dialysis. The kidney is one of the most sensitive to hypoxia bodies. Hypoxemia can be downloaded monitored by photoplethysmography (PPG), which is based on molecular absorption spectrophotometry in the infrared. Photoplethysmography is more advantageous than biochemical methods such as dosage uremic or creatinimec given its non-invasiveness and character embedded system enabling remote continuous monitoring of chronic renal failure. Given the correlation of the heart and kidney failure we thought the achievement of a technical platform capable of simultaneously monitoring of cardiac function and renal function through the respective records of myocardial electrical activity by electrocardiography (ECG) and pulsed oxygen saturation of hemoglobin by infrared spectrophotometry.*
To do this we designed and implemented a technical platform comprising:
-An electro cardiographic amplifier dedicated to the tele monitoring of cardiac function.
-A photoplethysmograph infrared dedicated to the tele monitoring of renal function through an estimate of the pulsed concentration of ox hemoglobin (HbO2) reveals a possible hypoxemia harmful to chronic renal failure and particularly those hemodialysis
Keywords: *Photoplethysmography, Electrocardiography, Spectrophotometry, Microcontroller, Telemonitoring & TCP/IP.*

I. Introduction

Renal failure is a severe illness causing a gradual and irreversible deterioration of the kidneys' ability to filter blood and excrete certain molecules (creatinine, urea ...) [1]. Furthermore renal failure induced short-or long-term heart failure [2][3].

The cardio-renal failure is a serious health problem which results, among other things, shortness of breath and fatigue disproportionate to the product effort [4]. Among the methods used for the supervision of the renal function and / or cardiac we can cite the biochemical exploration by spectrophotometric determination of a number of chemical species such as urea, creatinine, glucose, cholesterol, triglycerides, ketoacidsetc …
Taking into account that the kidney is very sensitive to hypoxia [5] the idea came to us that monitoring it indirectly led to the monitoring of renal function with the cardiac complications which can also be directly monitored by electrocardiography (ECG).

The objective of our work is to realize a simple technique tray, inexpensive and easy to handle dedicated to the tele monitoringof cardio-renal function by continuous evaluation of the pulsed concentration of oxyhemoglobin HbO2 in blood, simultaneous recording of the electrocardiogram and the establishment of their interactivity through the implementation of an algorithm for calculating their cross correlation function and spectral density inter average power.

II. Relation Between The Cardiac And Renal Failure

July 8, 2009 at the Heart Failure Congress 09 of the European Society of Cardiology, the "dangerous liaisons" between cardiac and renal function were grouped under different angles, since the disturbing prevalence numbers to the therapeutic perspectives. [6]

Whether renal failure - comorbidity - usually related to renal artery disease (diabetes, hypertension, atherosclerosis ...) or vasomotor nephropathy secondary to the decrease in cardiac output (cardio-renal syndrome) renal failure seriously compromises the prognosis of heart failure. Renal and cardiac functions are interrelated so it is difficult to know which of the egg or the hen maintains or aggravates fluid overload. So, equally difficult to optimize the management of heart failure whose renal function deteriorates.

The purpose of our research is the study and implementation of a technical platform dedicated to oximeterphotoplethysmography in frared coupled with an electrocardiographic recording for tele monitoring of renal failure and cardiovascular monitoring. The technical platform is built around a microcontroller whose function is to serve as an interface between the patient and a local station for storing and transferring data through medical tele networks.

III. Principle Of Absorption Spectrophotometry

Spectrophotometry measures the absorption of the light through the substances with certain wavelengths [7]. The state of hemoglobin and its absorption characteristics of the light are modified by the fixing of the oxygen, leading to different absorption spectra, and thus to distinguish the oxyhemoglobin [8].The wave length of the infrared absorption by oxyhemoglobin is within the range (850-1000 nm).

Under the effect of infrared radiation, the peripheral electrons of oxyhemoglobin molecules are brought to their most stable state (fundamental state) to a higher energy state (excited state).This state is unstable, it deactivates to the fundamental state either by emitting quantum of electromagnetic energy, either by releasing the excess energy in the environment as heat (non-radiative transition). The passage of the electron in the fundamental state to the excited state is absorbing electromagnetic energy: This is the phenomenon of light absorption by molecules subjected to light radiation. This phenomenon of absorption allows the characterization and determination of oxyhemoglobin [9], [10].

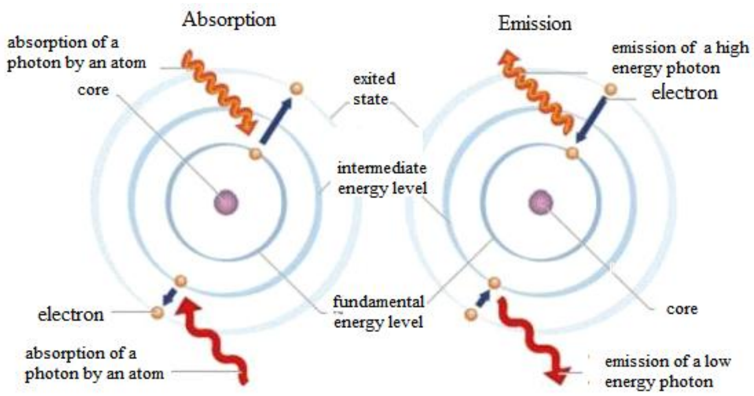


Fig.1 Absorption and emission of photons [11]

IV. Physical Rules Absorption

The concept of Photoplethysmography is based on the law of Beer-Lambert. The unknown concentration of a solute in a solvent may be determined by the absorption of light [8]. Beer (1729) and Lambert (1760) proposed to observe the attenuation of light's beam in order to predict the concentration of a compound [12].

The Lambert-Beer law joins absorption at a wavelength λ, and concentration of molecules that absorb c. If the intensity of incident radiation at the wavelength λ is I_λ^0 , then the intensity after crossing through the cell will I_λ.

I_λ and I_λ^0 are joined by the relation [13]:

$$I_\lambda = I_\lambda^0 e^{-\varepsilon_\lambda \ell c}$$

The absorbance is given by the relation:

$$A=\lg\left(I_\lambda^0 / I_\lambda \right) = \varepsilon_\lambda \ell c$$

With:

A_λ: absorptance of the medium to the wavelength λ.

λ : wavelength expressed in nm.

ε_λ: specific coefficient of molar absorptance (or molar coefficient of extinction in L· mole-1· cm-1)

ℓ: optical way of the cell in cm.

c : molar concentration in mole · L–1 of the absorbing molecules.

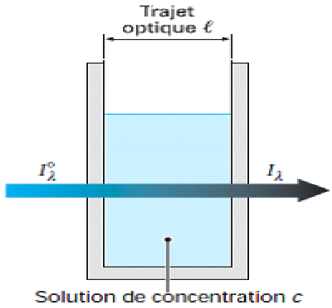


Fig.2 Diagram of a cell of absorption

Figure 2 representsthediagram ofa cellandexpressthe variables used. AbsorbanceAλistherefore proportional totheconcentrationcof the moleculesof the species thatabsorbsthis wavelength[13].

V. Method And Material

V.1. Collectionof Electrocardiographic Signal

ThisiscollectedonderivationDI using a classical instrumentationamplifier [14] in the circumstancesthe Analogdevice (AD620) as is shown inFigure3.

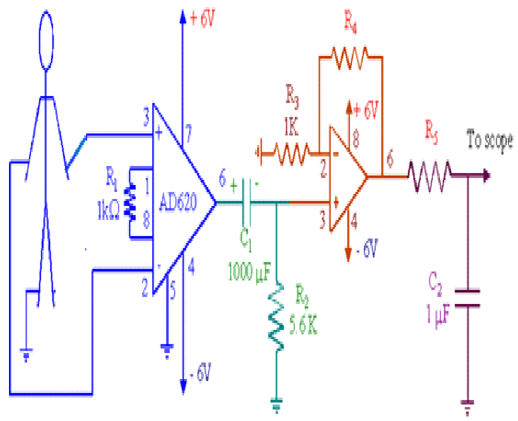
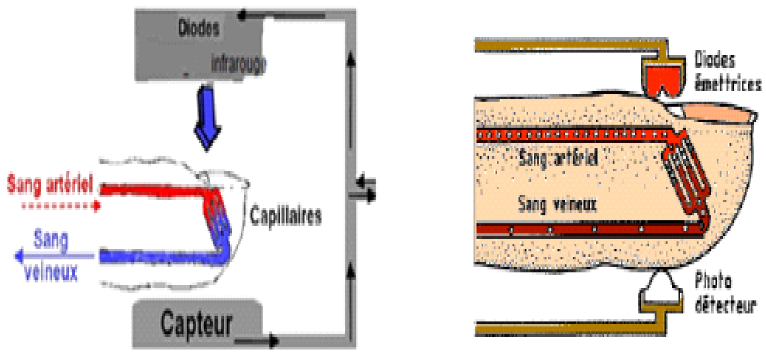


Fig.3 Electrocardiograph

V.2. Collection of Photoplethysmography signal

This one usesthemolecular absorption spectrophotometryforinfraredrecordingpulsedoxyhemoglobin[7] bythelast**HbO_2**contributionofinfraredemitting diodeand aphototransistoras shown infigure4. Therecordingpulseoxyhemoglobinreflects theefficiencyof pulmonaryexchanger[15] that is tosayofthe alveolar-capillary action andconsequentlya possiblehypoxemia.

The principle is toemitmonochromatic lightthroughelectroluminescentdiodein the infrared andto assess theabsorptionofthe latter bymeans of areceivingphotocell(phototransistor).



Figu.4 Schematic diagram of the collection of the PPG signal.

Figure 5 showsthe electrical diagram ofPhotoplethysmographyimplemented.

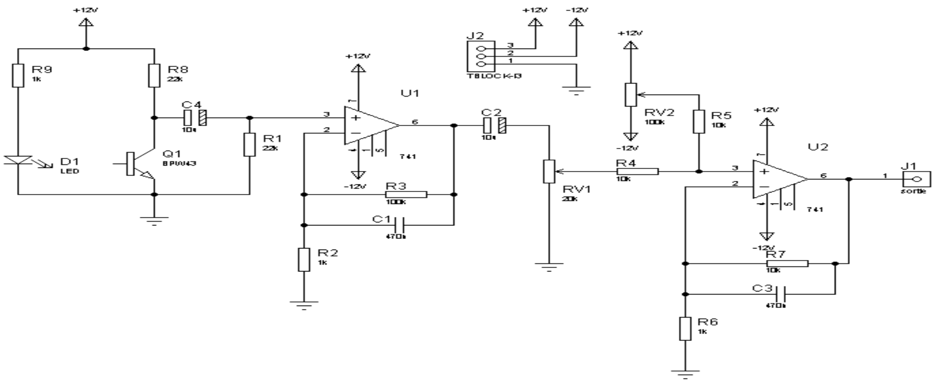


Fig. 5 Diagram of Photoplethysmography

V.3. Implementation of the interface for local data transfer

Itcomprises:

- A source ofinformation(patientin our case).
- Theelectrocardiographicsensor.
- Thephotoplethysmographicsensor.
- Theshapingcircuitsperform the functionsof amplification,filtering andcalibration.
- The acquisition carddatafortheman-machine interface.
- Software supportwith the acquisition, display, processing andtransmissionofdata in accordance withRS232communication protocol.

The acquisition cardisshown in Figure6.

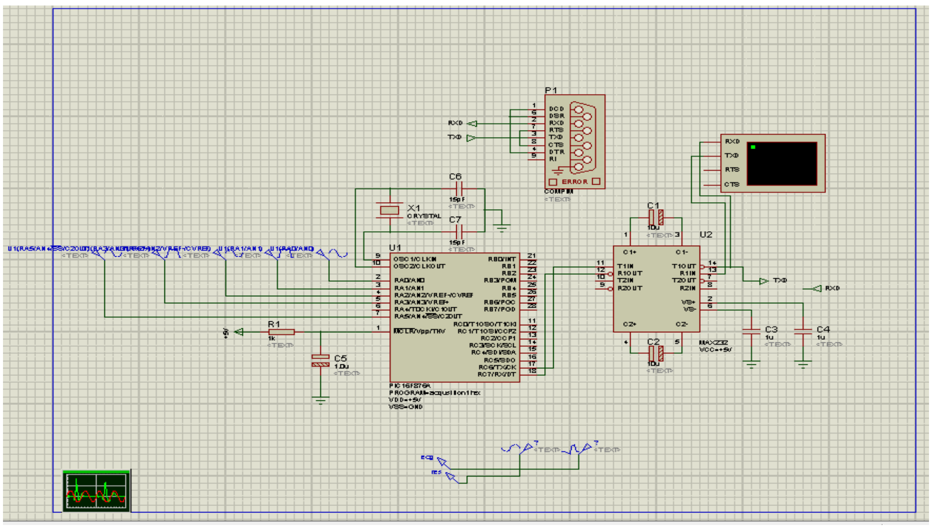


Fig.6Hardware implementation of the man-machine controlled by 16F876A micro interface

The following figure showsthecompleted acquisitioncard.

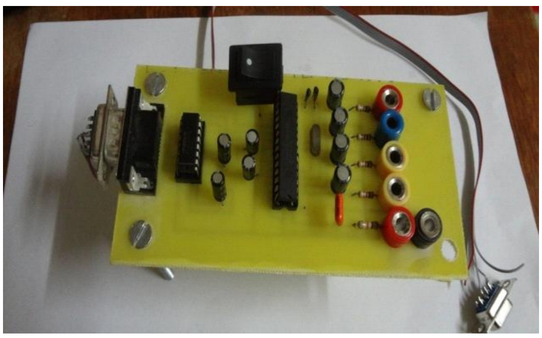


Fig.7 Map of universal asynchronous serial interface built around the 16F876A microcontroller.

V.4. Communications Protocols

V.4.1. Local Protocol Communication (RS232)

The parameters RS232 [8] which we used to program in assembly language microcontroller 16F876A of Microchip under Mplab environment are:

Transmission speed 57600 bauds

8 bits of data

A bit of parity

A bit of stop

The configuration of the registers system of the microcontroller concerning analogical conversion and transmission speed are:

Put at 1 and 0 of bits 6 and 7 respectively of register ADCON0 to choose a frequency of conversion equal to fosc/32= 625 Khz, is one duration of conversion of a bit equal to Tad= 1,6 µs.

Setting with 1 of bit BRGH of register TXSTA to choose the mode High speed.

Loading of register SPBRG with the decimal value 20 to select a flow of 57600 Bauds.

V.4.2.Distant Protocol Communication

The distant transmission of the electrocardiographic and photoplethysmographic signals is done according to protocol TCP/IP

TheTCPprotocol unit[18] is calledasegment. Thesesegmentsare exchangedto establish the connection, transfer data,makeacknowledgments, change the size ofthe window andfinallyto closea connection.Informationflow controlcanbe carried in thereverse datastream.

Eachsegmentis composed oftwoparts: aheader followedbythe data representedin Figure 8.

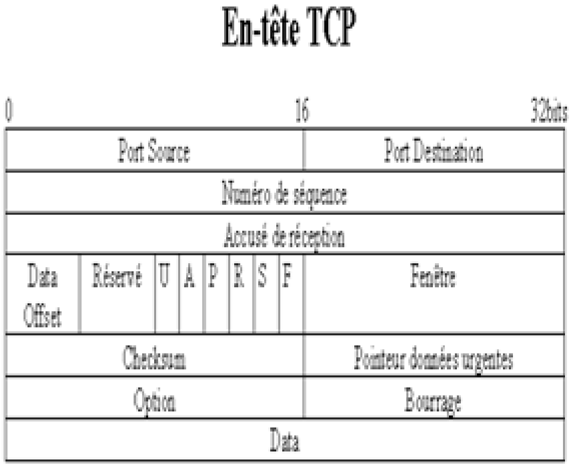


Fig.8Segment’s format

The figure 9 shows the fields and the general structure of the IP header.

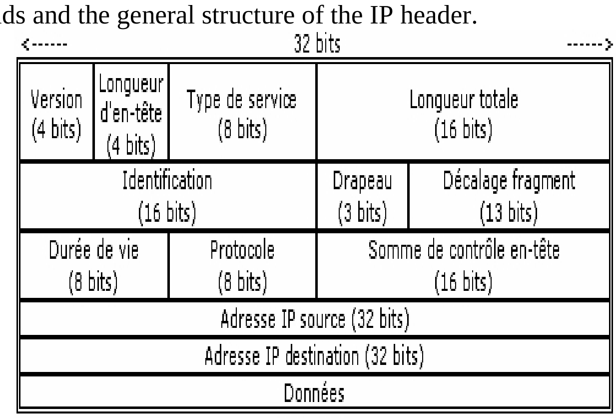


Fig.9 IP header

VI. Man-Machine Interface (Hmi) Spectrophotometric Dedicated To The Tele Monitoring Of Cardio-Renal Function

VI.1. Synoptic Diagram
The synoptic diagram of the interface man machine (IHM) is represented in figure 10:

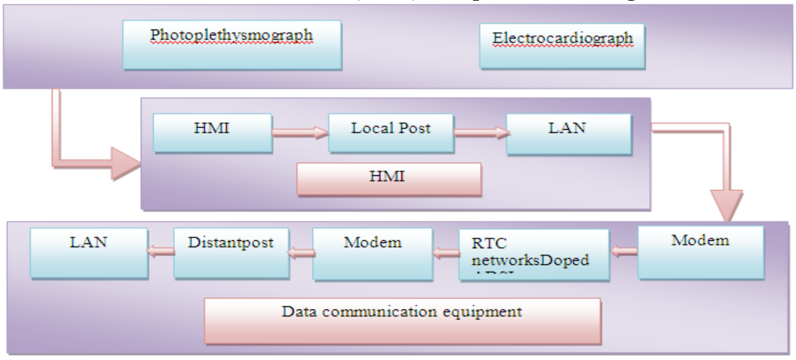


Fig.10Synoptic diagram of the IHM

The HMI(Human Machine Interface) includes:

PPGandECG, HMI(acquisition card), the network data communication. The firstmodule consists ofan analog electronicresponsible of the shape setting of our studysignals. Theman-machine interfaceis responsible for transferringthe analog valuesto a computerterminal(localstation). Itessentially consists ofa microcontrollerwith anADCto convertanalog to digitalA / Ddata from thephotosensorandtheECGamplifier, and amodulusUSART(UniversalSynchronousAsynchronous Receiverransmitter) [19] to transferdata on thelocal level accordingtoRS232Protocolcomputer terminal.The microcontrollerwasprogrammed in assemblylanguage inMPLAB. Thelocal stationisresponsible for hostingsoftwareinVisual Basicenvironmentwhich aimsto displayPPGsignals andECG, performing theirspatio-spectro-temporal analysis,especiallycalculates theircrosscorrelationfunction, archivethe resultsand transferthroughtelemedicalnetworksdedicated totelemonitoringrenal.

Thedatacommunication network(DCEDataComunicationEquipment)consists ofan ADSLmodemresponsible for adaptingthe bandwidth of thephysiologicalsignaltransmission channelis generallythe RTC networkdoped with ADSLconductingliaison with theBack Bone internetby theTCP/ IPprotocol.The doping of theline byADSLprocessmaximizes thetransmission rates.

Exampleof implementing atele monitoringstationcardiorenalduring ahemodialysis session11.

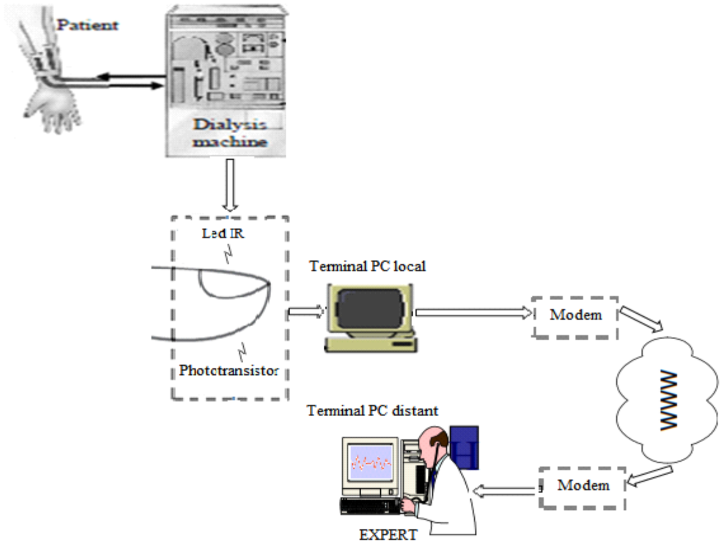


Fig.11 Block diagram of a tele-medical interface man-machine dedicated to telemonitoring of renal failure [20]

VII. Results

VII.1. Correlative Analysis

VII.1.1. Plot Of The AutocorrelationFunctions:

Thecalculating algorithm of theautocorrelationdiscrete functionshas been implementedin accordance withthefollowingrelation definition[21], [22]:

$$C_{f,f}(\tau)=\frac{1}{N}\sum_{k=\tau}^{N} f(k).f(k-\tau), avec : N=2^{q}\ldots(1)$$

$$et \qquad \tau=0,..,N$$

Thefigure 12representsthe autocorrelation functionofan electrocardiographicsignal[23].

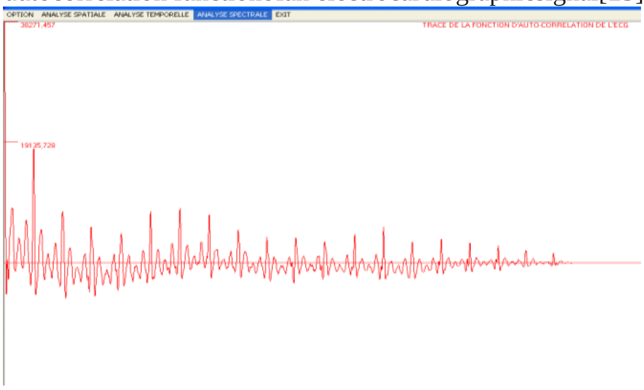


Fig.12 Plot of the autocorrelation function of an ECG signal

The figure 13showstheautocorrelation function of the PPG signal

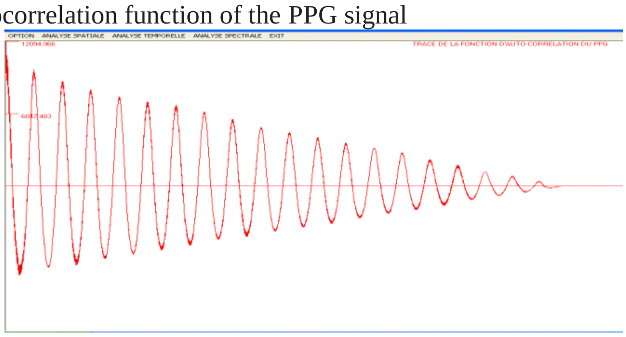


Fig.13 Plot of the autocorrelation function of a PPG signal

VII.1.2. DrawingoftheCross-CorrelationFunctionof ThePPG -ECGSignals

The algorithmofthe discrete cross-correlationfunction of the PPG (f(k)) and ECG (g(k))has been implementedin accordance withthefollowingrelationdefinition[21], [22]:

$$C_{f,g}(\tau)=\frac{1}{N}\sum_{k=\tau}^{N} f(k).g(k-\tau), avec : N=2^{q}\ldots(2)$$

$$et \qquad \tau=0,..,N$$

We haveshown on Figure 14, the plot of thecross-correlation (PPG-ECG) function.

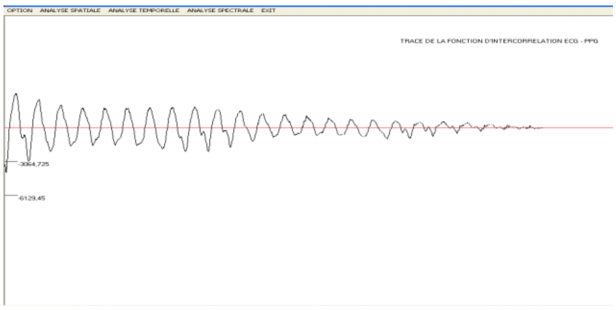


Fig.14 Plot of the cross-correlation function of ECG signals PPG

VII.1.3. Calculationand Drawing of the Average Power Density by Fourier Transform of the Autocorrelation Function

Theaveragepowerspectral densitycan be calculatedby the following equationofdefinition:

$$TF(C_{f,f}(\tau)) = TF(\frac{1}{N}\sum_{k=\tau}^{N} f(k).f(k-\tau))\dots(3)$$

We haveshownin figure.15, the plot of this function for theelectrocardiogram.

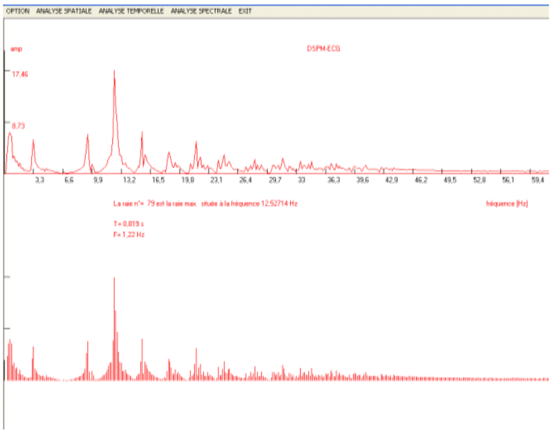


Fig.15 Power Spectral Density of ECG

The plot of thespectral densityof theaverage powerof theplethysmographic is given by figure16.

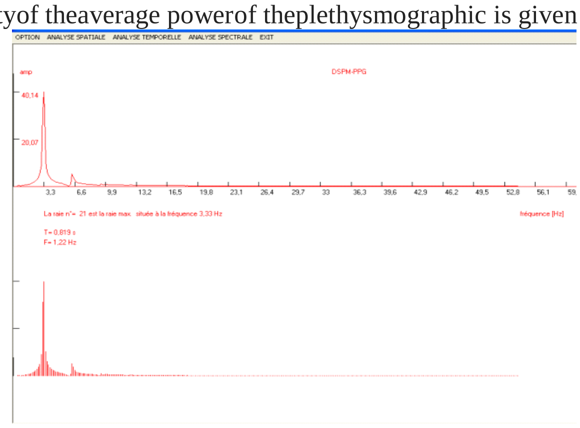


Fig.16 Power spectral density of the PPG

VII.1.1.4. Calculationand Drawing of the Inter Spectral Density of Average Power by Fourier Transform of the Cross-Correlation Function

The inter spectraldensityofaveragepower can be calculatedby applyinga Fourier transformtothe cross-correlationfunctionofthe signalsrespectivelyECG-PPG,

the following equationofdefinition is:

$$TF(C_{f,g}(\tau)) = TF(\frac{1}{N}\sum_{k=\tau}^{N} f(k).g(k-\tau))\dots(4)$$

which are represented in Figure 17.

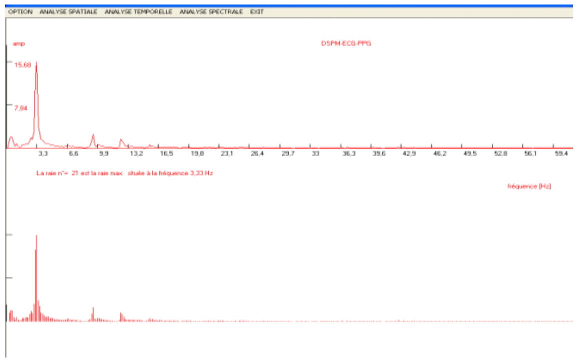


Fig.17 interspectral density of average power ECG-PPG

VIII. Conclusion and Perspectives

This articleisan opportunity for usto present the workthat revolvearound the designdedicated to a telemonitoring ofrenal functiontechnical platformand / or cardiac functionthroughan original methodleveragingPhotoplethysmographyinfrared absorptionfor assessingtheconcentrationofthepulseindicativeof a potentialadverseoxyhemoglobin **HbO_2** hypoxemiainrenovascularheart failure, coupled toa functionalexplorationbycardiacelectrocardiogramfor assessingtheseverityofheart failure.

The development ofa process fortele monitoringofthecardio-renal functionbythephotoplethysmographicmethodcoupled with theelectrocardiographicisappearedto us the mostinterestingcomparedto theclassicalbiochemical assaymethodbecause ofits mobility,non-invasive, reliabilityand easinessof its useby thepatient himselforany else actor of telemedicine.Local controlparametersetahardwaredeviceandsoftwarebased ona microcontroller andtheRS232protocol. The distantcontrol uses theTCP/ IPprotocolinvolvingtheWinsockcomponent inVisual Basicprogrammingenvironment.

Dynamicarchivingresultsfor epidemiological purposes, as well as the implementation of adatabase ofmeasurements ofoxygen saturation inthe bloodand recordingofECGsignalsare part ofour prospects.

A clinicalvalidation of the methodby specialists innephrologyand cardiologyshould beimplemented ona significantrenal impairmentand /or cardiaccorpus. This is also part of our perspectives; we will alsocompare the resultsof this validationwith classicalbiochemical method. Amongour prospectalsoincluded theimplementation ofaphotoplethysmographyinred and infrared simultaneouslyrealizingat the same timethe proportions ofoxyhemoglobinandreduced hemoglobinthat allowthe calculation of thesaturationpulseofoxygen inthe blood (**SpO_2**) objective evidenceofa malfunctionat thealveolar-capillarygas exchangeresponsible forhypoxemiaandits impact onrenal failure.

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