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An Intelligent Medical Platform for PCG Signal Preprocessing For Patients with Mechanical Double-Winged Prostheses Valve

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Abstract— **In this work, we present the implementation of a platform for the pre-processing of a PCG signal from a double-winged mechanical heart valve. This platform is essential for the treatment of a patient undergoing a valve replacement operation. This application facilitates the intervention in case of emergency as well as the follow-up of the patient's health condition. Indeed, this approach will help cardiologists and scientific researchers to design a simple, secure, and intelligent digital tool, allowing them to have an additional source of information in the field of digital processing of cardiac signals. Finally, we tested and validated this platform with a cardiac signal from a patient with a blocked valve.**

Keywords— **Medical platform, Phonocardiogram (PCG) signal, Mechanical heart valves, Hilbert-Huang Transform (HHT).**

Index Terms— **CF: Cinefluoroscopy, IQR: Interquartile range, MHV: Mechanical heart valve, PCG: Phonocardiogram, ECG: Electrocardiogram, RBF: Radial Baseline Function, VP: Positive Predictive Value, LSC: Localization of Cardiac Signals, PT: Normal Prothrombin Rate, INR: International Normalized Ratio, HHT: Hilbert-Huang transform, EMD: Empirical mode decomposition, IMFs: Intrinsic mode functions, TEE: Transesophageal Echocardiography**

I. Introduction

The Phonocardiogram (PCG) is used for diagnostic purposes to assess the health status of the heart and to detect cardiovascular diseases. This research aims to develop a method for pre- processing PCG recordings collected from different databases, and recorded in different ways. In the literature there are several online platforms such as Physio Net[1], the surname of "Research Resource for Complex Physiologic Signs", was created in 1999, under the auspices of the National Institutes of Health. In cooperation with the annual Computing in Cardiology conference, [2] PhysioNet also organizes an annual challenge series, focusing research on unsolved problems in clinical and basic sciences. It has several advantages such as its importance in the diagnosis of cardiac diseases as well as the treatment of various signals [3]. Like any technology, this platform also has its drawbacks. With so many different physiological signals, it may be difficult to find the specific information of a particular signal. In our paper, we are interested in the preprocessing and analysis of PCG signals for double- finned mechanical valves in the state of normal operation in the case of malfunction, if one of these fins is blocked as in the case of a thrombosis.

Thrombosis of the prosthetic heart valve after valve replacement is a rare complication in the order of 0.1 to 0.6% per patient per year [4], but may be very serious. To process a complex PCG signal hidden by heart sounds [5], we need to go through the preprocessing phase to remove noise and other artifacts [6]. Given the specificity of the signal processed, we have developed a new platform, easy to handle and well secured contains a multitude of data such as the type of prosthesis, stethoscope that controls the necessary PCG signals, from which we build our research work and it has an added value in the field of PCG signal processing for waves emitted by double-winged mechanical valve prosthesis [7]. It gives the users a precise idea of the different types of these signals and facilitates their learning and processing. In the literature, researchers use several methods for PCG signal processing. Moreover, such as Fourier analysis, but this method is not suitable for processing PCG signals because these signals are classified as non-stationary signals [8]. Therefore, the use of Fourier transform is inadequate because it does not provide time-localized frequency content information. Thus, the application of Fourier transform is not suitable for processing non-stationary signals such as PCG signals. About the wavelets that have been treated [9] with a threshold of transform coefficient allowing to clear the useful signal from the noise [10]. Although this method has shown its interest for PCG denoising, the authors [11] use the Shannon energy [12], this type of processing in the presence of breaths and murmurs in the cardiac signals, is that they introduce in the extracted envelope, maxima that correspond to the breaths and murmurs is not adequate for a LSC method where the goal of locating only the normal noises that represent the first and second cardiac sound [8]. Shannon energy performs well for clinical signals with 90% sensitivity and 91% PPV; at higher noise levels (SNR=5dB), the results are acceptable, but at SNR=0dB (80% sensitivity and 84% PPV) [8], the results are poor. The Radial Basis Function (RBF) neural network technique used to extract cardiac sound envelopes has been shown to be effective for low-level noisy signals [13]. at high noise levels the performance of the RBF method degrades, because the RBF method works directly on heart sounds without a feature extraction step [13].

II. Development of a medical platform

In order to solve the problem of the researchers of the information around the health cases in detail for the patients with mechanical heart valves, we are in need of a secure management system that automates the registration of the medical records of this type of patients. At this level we propose a reliable solution that takes into account all the

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requirements of the protection of personal data of the patient, such as name, personal address, and their identity number..., This is done by assigning a special code to each patient that will allow to meet the future needs of users in compliance with the rules of secure computer networks. The following Fig. represents the general architecture of our application [Fig. 1]. For the realization of our application, we define a development environment that facilitates the user's access to different interfaces to consult, update and save patient information [Fig. 2]

Our application is in the form of a Platform we named it (Radhia PCG signal) consisting of a security system, a system that manages a large volume of data regardless of the type of file holder, a scalable web development site that meets the needs of users, and confidential access to information (patient data). Our platform is based on the main actors: Admin, patient, cardiologist, and scientific researchers. The admin accesses the platform with his password, if the password is not identified he receives an error message, if the identification is valid, he can manage the platform. [Fig. 3-4] The admin has the right to modify the information stored, add or delete a patient, and even the whole list. The admin also has the right to authorize access to the information finder to only read and print the information registered in the patient list, it also gives access to the cardiologist identified by the system to only add a patient to the patient list or read the data of a patient already registered. [Fig. 5] The cardiologist does not have the right to delete any patient stored nor to modify the data of a patient registered by another cardiologist, in case of need he sends a report by mail to the administrator [Fig. 6]. Our application can be managed by several cardiologists from all countries and nationalities all over the world, each one can consult his own space to log in, the cardiologist asks the permission of the admin and has to fill in the Email and Password fields then he has to click on the Login button. If he is authenticated, the specific interface for each user will be displayed. Otherwise, an error message will be displayed, this interface includes the index page of this web application after logging in to the platform. This page displayed as an administrator may have limited action. [Fig. 7] Adding a patient with a mechanical valve is registered fill in the boxes of their identity: name, first name, sex, date of birth, phone number, email, nickname, password, and name of cardiologist who treats him. Then store their medical record before and after valve replacement in the form of tables grouped by date in descending order for each consultation: Ultrasound, TEE, CBC, PT, INR, ECG, PCG, materials used, and prosthesis data. Among the identity information only the nicknames, gender, and age will be displayed health information displayed in an anonymous encrypted form. [Fig. 8] In our article we are only interested in the cases of treatment of a PCG signal of a double-winged mechanical valve prosthesis, we use the PCG table in the patent list. [Fig. 9] For more information on the implanted prosthesis the admin fills in the fields (Reference, Type of prosthesis, model, valve position, date of replacement, report ...), then he must click on the validate button to validate the registration, and this window will display for researchers if needed [Fig. 10].

Cardiologists use different devices to examine the patient from where the possibility of obtaining different and not precise results of research for that we added give material as for example the type and the reference of stethoscope to use during the recording of a signal PCG [Fig.11].

III. Pre-processing of a PCG signal for patients with mechanical heart valves

A. *Choice of pre-treatment method*

The heart's mechanical activity can be appraised by auscultation recordings, one for each cardiac valve, as there are invisible murmurs when a single area is examined. This paper presents an effective approach for cardiac murmur detection based on acoustic representations derived from Empirical Mode Decomposition (EMD) and Hilbert- Huang Transform (HHT) of PCG. HHT is an effective tool used in many signals processing applications, including the analysis of PCG signals. Here are some reasons why HHT is essential in PCG analysis:

HHT is a powerful tool for analyzing non-stationary and nonlinear signals. PCG signals are non- stationary signals, which means their statistical properties vary with time. Therefore, traditional signal processing methods such as Fourier transform cannot provide accurate information about these signals. HHT can decompose the PCG signal into a set of Intrinsic Mode Functions (IMFs) that have a well-defined instantaneous frequency, making it easier to analyze these signals. HHT provides time-frequency representation of the PCG signal. This means that it can show how the frequency content of the signal changes over time. This information is crucial in identifying different heart sounds and murmurs present in the PCG signal. HHT can provide accurate and reliable information about the amplitude and frequency of different components of the PCG signal, making it easier to identify pathological conditions such as heart murmurs, stenosis, and regurgitation. HHT can extract hidden information from the PCG signal. In many cases, the PCG signal contains information that is not immediately visible to the human ear. HHT can extract this information and provide valuable insights into the patient's condition. In summary, HHT is an essential tool in PCG analysis because it can provide accurate and reliable information about the non-stationary and nonlinear characteristics of the PCG signal, making it easier to identify pathological conditions and extract hidden information.

B. *Application design for PCG processing with HHT*

An application design for PCG processing with HHT can be broken down into several stages: Data collection: The first step is to collect PCG data from the patient using a microphone and an amplifier. This data is then stored in a database or a file for further processing. Preprocessing: The PCG signal needs to be preprocessed before it can be analyzed with the HHT algorithm. This includes filtering out any noise or interference, and removing any baseline drifts or artifacts. Hilbert-Huang transform: The HHT algorithm is applied to the preprocessed PCG signal to extract the intrinsic mode functions (IMFs) and the instantaneous frequencies associated with each IMP. Feature extraction: The IMFs and instantaneous frequencies are used to extract relevant features from the PCG signal, such as the timing and intensity of heart murmurs. Analysis: The extracted features are analyzed using various signal processing techniques, such as pattern recognition or statistical analysis, to identify any abnormalities in the heart sound. Visualization: The results of the analysis can be visualized in various forms, such as graphs or charts, to help clinicians interpret the findings. Reporting: Finally, a report is generated summarizing the analysis results and any detected abnormalities, which can be used to inform diagnosis and treatment decisions. The application design should also include user-friendly interfaces for data input and output, as well as various configuration settings for signal processing parameters and analysis algorithms. Additionally, the application should be designed to ensure data security and patient privacy.

C. Results and Interpretations

As a new method of signal analysis, Hilbert-Huang Transform (HHT) has become one of the research hotspots in modern signal processing field. The main innovations of HHT are the creation of the empirical mode decomposition (EMD) method and the introduction of the concept of intrinsic mode function (IMF). The signal is decomposed as IMFs through EMD, and then we can get the instant frequency through Hilbert Transform (HT). Nowadays, the theory of HHT has been effectively applied to many practical fields. However, there are lots of research to be done for the improvement and development of HHT.

Transformation of Hilbert-Huang (HHT) can also be applied to analyze cardiac phonocardiogram (PCG) signals, which are sound recordings of the sounds produced by the heart during its cycle of contraction and relaxation. By using HHT to decompose PCG signals into intrinsic mode functions (IMFs), researchers can identify patterns that may be associated with certain cardiac conditions or abnormalities, such as murmurs, clicks, bells or murmurs. This can help diagnose heart disorders, such as valvular heart disease, coronary artery disease, and cardiomyopathies.

Additionally, the use of HHT can help predict the risk of heart disease by analyzing the characteristics of heart rate variability in PCG signals. Overall, the use of HHT in analyzing PCG signals can improve the diagnosis and prevention of heart disease. The HHT (Hilbert-Huang Transform) is a mathematical method used for analyzing non-linear and non-stationary time series data. The HHT transform involves two main steps: Empirical Mode Decomposition (EMD) and Hilbert spectral analysis. EMD decomposes a signal into a set of intrinsic mode functions (IMFs) which are derived from the data itself using a sifting process. The IMFs are individual components that describe the different frequency modes present in the signal. Each IMF represents a narrow

frequency band and has a well-defined instantaneous frequency. The Hilbert spectral analysis involves applying the Hilbert transform to each IMF to obtain the instantaneous frequency and amplitude. The instantaneous frequency is a measure of the frequency variation of the signal as a function of time, while the amplitude represents the magnitude of the signal. The HHT transform is useful in analyzing complex time series data, such as in the fields of meteorology, seismology, and biomedical signal processing. It has applications in areas such as signal denoising, feature extraction, and pattern recognition. [Fig. 12-13-14] The frequency versus time plot is a sparse plot with a vertical color bar indicating the instantaneous energy at each point in the IMF. The plot represents the instantaneous frequency spectrum of each component decomposed from the original mixed signal. Three IMFs appear in the plot with a distinct change in frequency at 1 second. [Fig. 15] The spectrogram shows three distinct components of signal.

IV. CONCLUSION

This paper presents the design and implementation of a platform for analyzing phonocardiogram (PCG) signals using the empirical mode decomposition (EMD) and Hilbert-Huang transform (HHT) techniques. The platform comprises of two main components: a front-end application for signal acquisition and processing, and a back-end analysis module for performing EMD and HHT on the acquired PCG signals. The front-end application to capture PCG signal from a double winged mechanical heart valve from a patient's chest, and preprocesses the signals using bandpass filtering and denoising techniques. The preprocessed signals are then passed on to the back-end analysis module, which performs EMD and HHT to extract the underlying components and identify characteristic features of the PCG signal. The paper concludes that the developed platform can effectively analyze PCG signals using EMD and HHT techniques, and can provide valuable insights into the diagnosis of cardiovascular diseases. The platform can also be used for other applications, such as fetal heart monitoring and remote patient monitoring.

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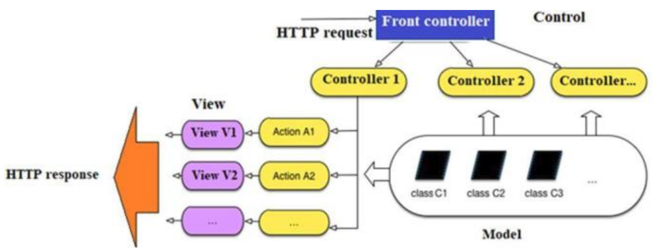

Fig. 1 THE MVC ARCHITECTURE

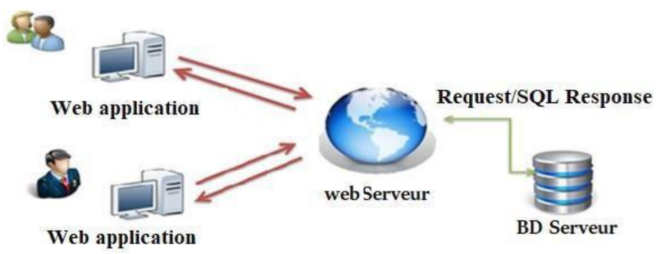

Fig. 2 APPLICATION ARCHITECTURE

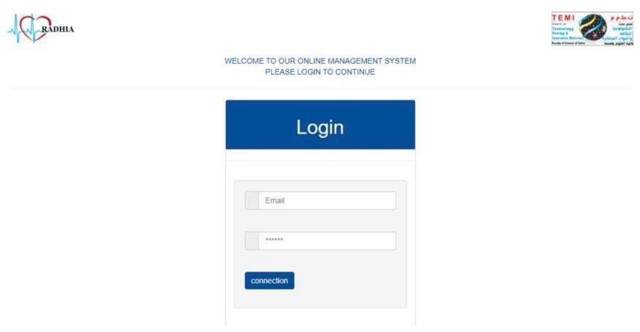

Fig. 3 AUTHENTICATION INTERFACE

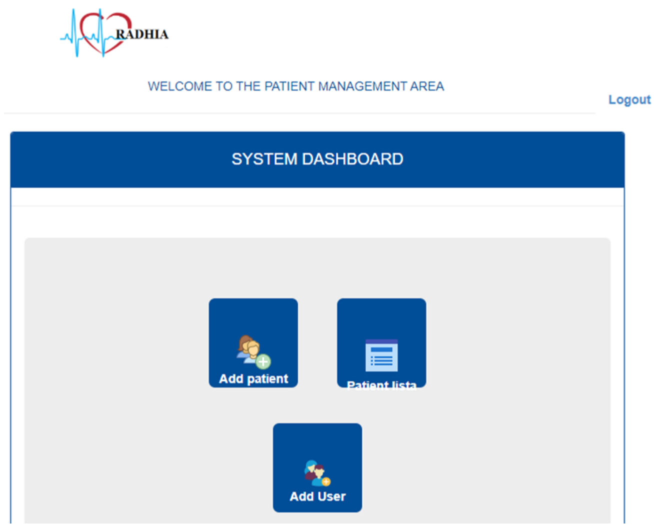

Fig. 4 ADMIN HOME PAGE

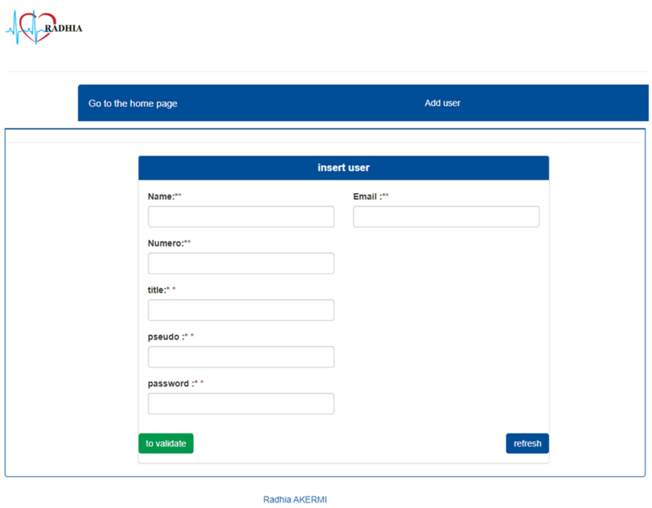

Fig. 5 ADD USER

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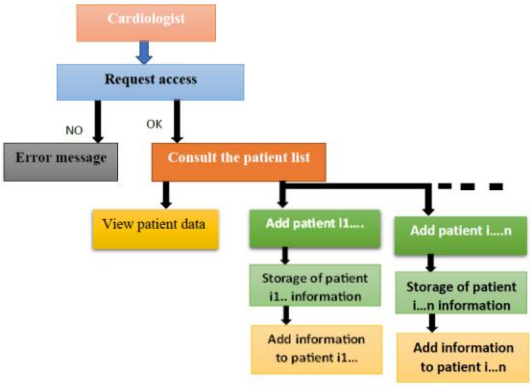


Fig. 6 CARDIOLOGIST TASK

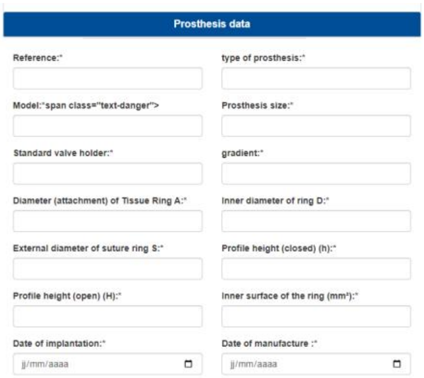


Fig. 10 PROTHESIS DATA

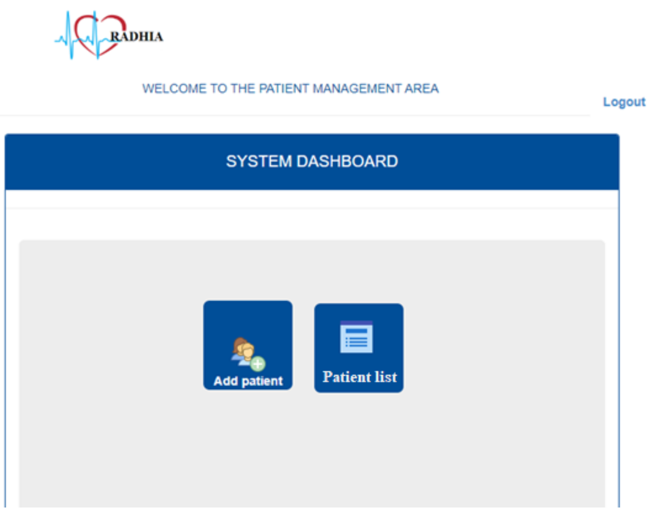


Fig. 7 CARDIOLOGIST HOME PAGE

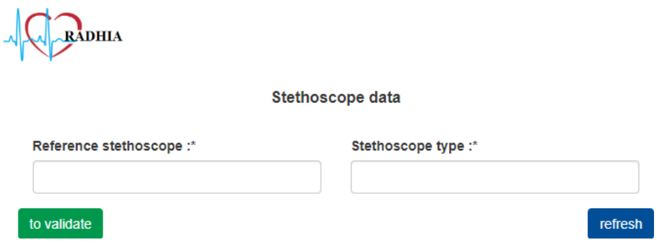


Fig. 11 STETHOSCOPE DATA

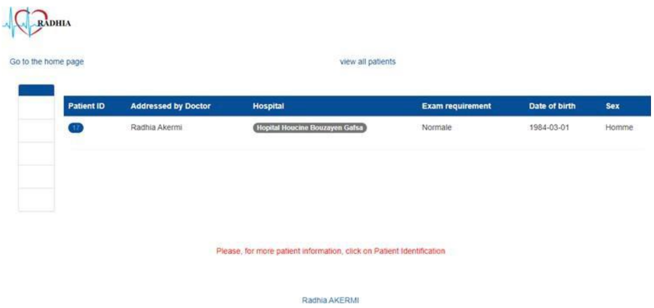


Fig. 8 PATIENT LIST INTERFACE

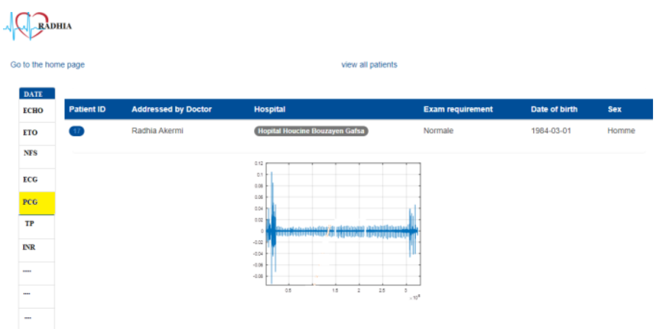


Fig. 9 PATIENT LIST INTERFACE

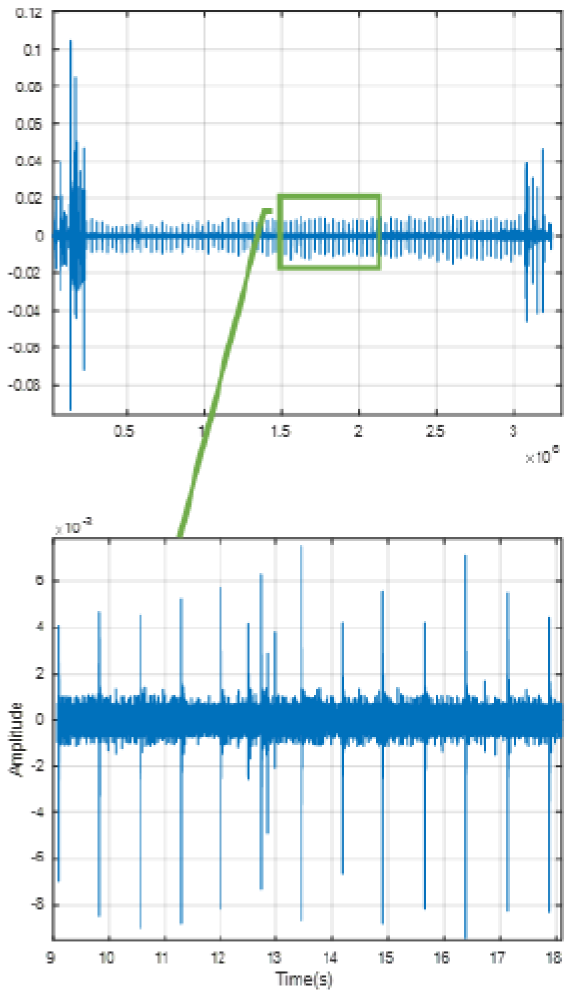


Fig. 12 EVOLUTION OF THE PCG SOUND SIGNAL

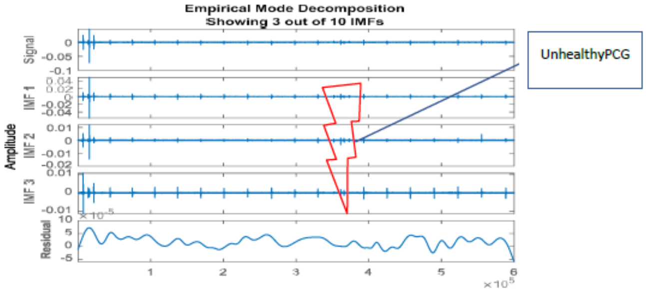


Fig. 13 THREE PRINCIPAL IMF EVOLUTION

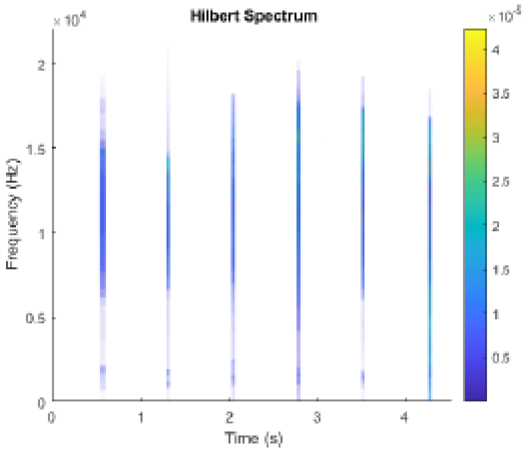


Fig.14 THE HHT OF THE PCG SIGNAL

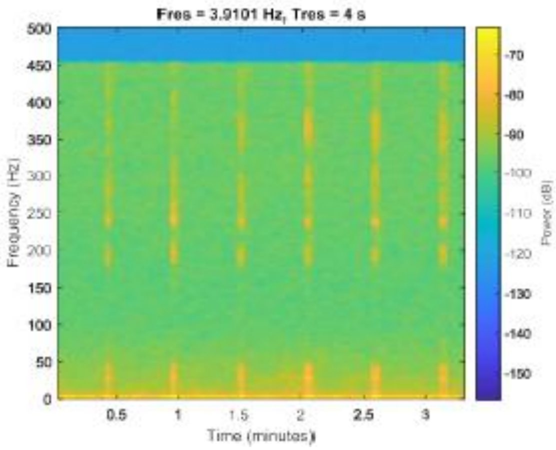
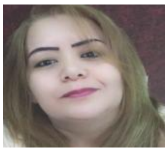


Fig. 15 THE SPECTROGRAM OF THE PCG SIGNAL



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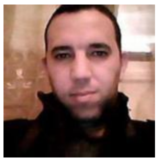
He has participated in several scientific commissions and international research projects.



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