

Biosignal Processing, Medical Imaging and fMRI (BSPMI) Software Package Based on MATLAB GUI for Education and Research

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Abstract—Laboratory experiments and practical applications of biomedical courses are very important for engineering students by improving their skills in solving and fixing practical problems. The software package developed in this work has educational effect and introduced economical solution without using various and expensive biomedical experimental equipment or needing wide spaces. In this paper a developed Biosignal Processing and Medical Imaging (BSPMI) Software Package based on Graphical User Interface (GUI) using MATLAB is proposed which can be used for students and researchers in medical and biomedical engineering instruments labs.

This package consists of two main modules; the first one deals with the processing of different biosignals, especially Electrocardiograph (ECG), Electroencephalograph (EEG) and Electromyography (EMG) signals while the second introduces different image modalities such as X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and functional Magnetic Resonance Imaging (fMRI). In summary, BSPMI Software Package is designed and implemented as part of biomedical instrumentation course, so it can be easily used by students/researchers using only standalone application or executable file (exe file) without installing MATLAB program.

Keywords – biosignals, engineering education, medical imaging, MATLAB GUI, software package.

1. INTRODUCTION

Laboratories are the main help for researchers and undergraduate students together with courses by improving their skills in solving and fixing practical problems, especially engineering laboratories. These laboratories introduce experiments in developing students' skills leading to develop universities which are the based in developing countries.

The software package design that used in this work is based on using a graphical user Interface (GUI) in MATLAB. A graphical user interface (GUI) is a type of interface to a program. A good GUI can make programs easier to use and allows users to interact with electronic devices and biomedical instruments easily. Gharaibeh's study in introducing dif-

ferent image registration techniques and Alziarjawey's study in using the ECG signal for heart rate monitoring and PQRST detection can be given as examples of using Matlab GUI in medical field [1],[2].

The basic concepts related to biomedical signals and medical images come from human physiology and anatomy as well as biomedical measurements and analysis. The following are introduced in the first two sections of this research are introduced a short introduction related to:

- Biomedical signals and processing.
- Medical imaging and processing.

In section 4 & 5, results and conclusion are presented respectively.

2. BIOMEDICAL SIGNALS AND PROCESSING

Biomedical signal is the term used for any signal senses from a biological tissue or medical source. Electrocardiograph (ECG),

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Electroencephalograph (EEG) and Electromyography (EMG) signals are presented in the design of software package as the most important biosignal and that most used in biomedical instruments laboratory. Physiological principles of biomedical signals and some important digital signal processing techniques are presented subsequently.

2.1. Physiological Principles of Biomedical Signals

Physiological processes are complex and most of them are accompanied by signals that reflect their nature, activities, carries information relative to one or more biological systems and provide the information to a Physician. There are different types of biomedical signals: Electrocardiograph (ECG), Electroneurograph (ENG), Electroencephalograph (EEG), Electromyography (EMG) and Electrogastrograph (EGG) signals. ECG, EEG and EMG have introduced in this package which are the most commonly known, recognized, and used biomedical signals.

2.1.1. Electromyography (ECG) signal:

ECG signal is the measurement of the electrical activity related to the periodically varying potential during the cardiac pumping cycle when the heart pumps blood to the whole body. In the meantime, the current resulting from action potential will spread from heart to the whole body unequally. It explains why we can catch the signal from different parts of the body by a set of surface electrodes placed on the arms and legs or thorax [3].

Generally speaking, the ECG provides a useful tool for monitoring a patient, basically when the purpose consists in detecting irregular heart rhythms or preventing myocardial infarctions. A typical ECG beat mainly has 5 different waves (P, Q, R, S and T) [4], as shown in Fig. 1. ECG Signal Characteristics: Voltage between 10 pV to 5 mV and normal peak reading 1 mV, while bandwidth = 1 kHz max [5].

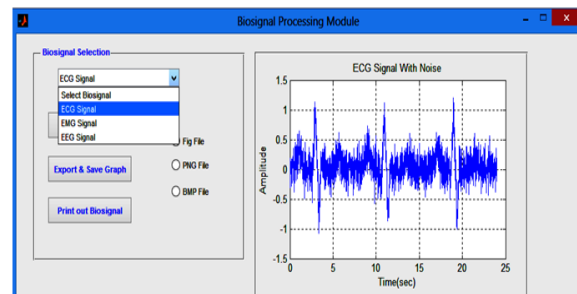


Figure 1. ECG signal.

2.1.2. Electroencephalograph (EEG) signal:

The EEG is a physiological signal related to the brain's electrical activity. Its variation depends on numerous parameters and situations such as whether the patient is healthy pathological, awake, asleep, calm and so on. This signal (Fig. 2) is recorded using electrodes placed on the scalp above the region of the brain under investigation [6]. In clinic, EEG is used as a diagnostic tool, especially for epilepsy and for death recognition.

A considerable amount of the EEG energy signal is located in low frequencies (i.e., between 0 and 30 Hz). This energy is mainly due to five rhythms, namely, δ , θ , α , β and γ . EEG Signal Characteristics: Voltage between 2 pV to 200 pV while bandwidth = 100 Hz max [5].

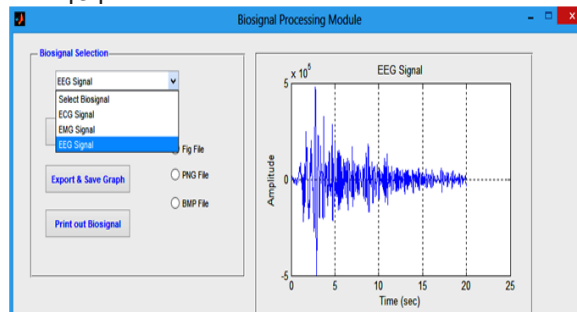


Figure 2. EEG signal.

2.1.3. Electrocardiograph (EMG) signal:

EMG signals are the change of electrical action potential when the fibers of voluntary or involuntary muscle are activated (Fig. 3). This signal can be used to detect any specific abnormalities related to the electrical activity of a muscle [7]. EMG can be recorded from the surface of the body by electrodes placed near to the muscle group under examination or by needle electrodes implanted into that

muscle. EMG Signal Characteristics: Voltage between 20 pV to 500 pV while bandwidth = 2 kHz max [5].

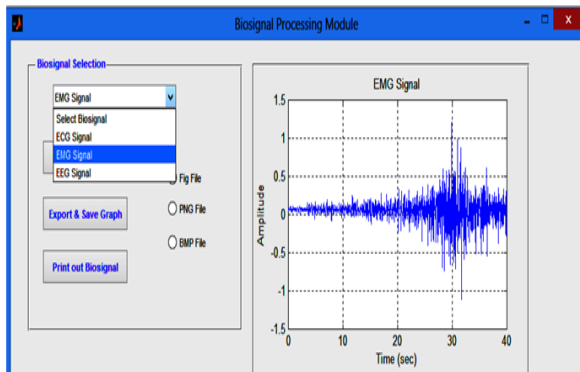


Figure 3. EMG signal.

2.2. Biomedical Signal Processing Techniques

Digital Signal Processing (DSP) techniques can be used in order to remove noise, also it involves: adjusting signal characteristics, spectral estimation, multiplying two signals to perform modulation or correlation, filtering and averaging. Software package in this work has designed to deal with the most digital signal processing techniques used with biomedical signals to remove noises from biological signals, extract some characteristic parameter and process them. Based on reference [8], there is a clear comparison between different DSP techniques; while in this paper Adaptive Filters, Digital Filters (FIR and IIR filters) and Wavelet Analyses have applied on ECG, EMG and EEG signals and displayed using GUI MATLAB in the BSPMI software package.

2.2.1. Adaptive Filter:

Unlike classical spectral analysis methods, FIR and IIR filters and non-adaptive filters; adaptive filters can respond to changes that might happen through the path of the signal, so have the ability of modifying their properties according to selected properties of analyzed signal. Adaptive filter has a number of applications in biomedical signal processing [9, 10]. For example, it can be used to eliminate a narrowband noise 60 Hz line source that distorts a broadband signal, or inversely it can be used to eliminate broadband noise from a narrowband signal. Fig.4 shows an example of the application of Adaptive Filter on ECG signal.

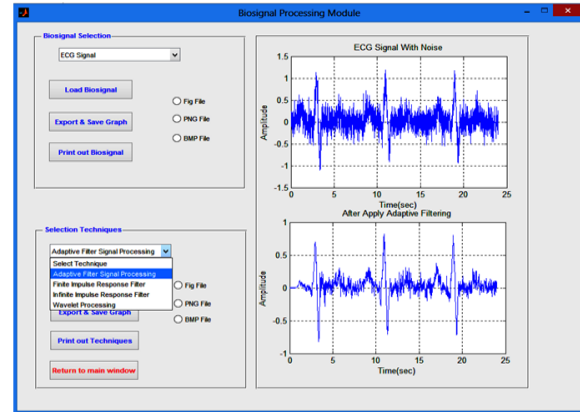


Figure 4. The application of Adaptive Filter on ECG signal.

2.2.2. Digital Filters:

The aim of using filters is to reshape the spectrum in order to provide some improvement in SNR, so they are closely related to spectral analysis. Digital filters can be divided into two groups according to the way that they achieve the reshape of the spectrum, finite impulse response (FIR) filters and infinite impulse response (IIR) filters, and based on their approach. IIR filters are more efficient in terms of computer time and memory than FIR filters; while the FIR filter is stable, have linear phase shift characteristics and initial transient responses of limited length [11, 12]. Fig.5 shows an example of the application of IIR filter on EEG signal.

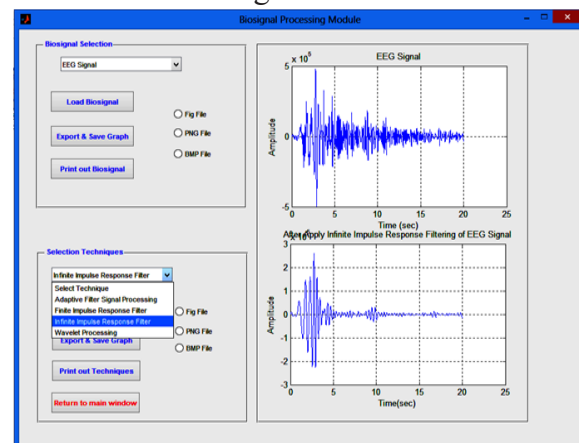


Figure 5. The application of IIR Filter on EEG signal.

2.2.3. Wavelet Analysis:

The wavelet transform is divided into segments of scale rather than sections of time, and it is applied to a set of orthogonal basis functions obtained by contractions, dilations and shifts of a prototype wavelet. The

main difference between wavelet transforms and Fourier transform-based methods is that the Fourier transform-based methods use windows of constant width while the wavelet uses windows that are frequency dependent. So, the wavelet transform is used as another method to describe the properties of a nonstationary biosignal waveform [13, 14]. Fig.6 shows an example of the application of Wavelet Analysis on ECG signal.

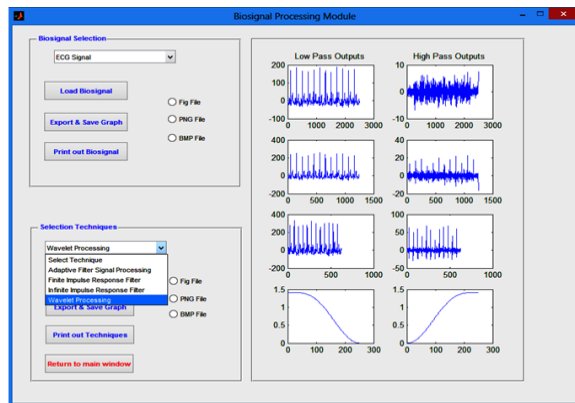


Figure 6. The application of Wavelet Analysis on ECG signal.

3. MEDICAL IMAGING AND PROCESSING

X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and functional Magnetic Resonance Imaging (fMRI) have presented in the design of software package as the most important components of clinical and research laboratories. In clinics, these components are used for diagnosis and then treatment planning or surgical guidance [15]. While in research laboratories, these components are used for distinguishing between normal and abnormal images or monitoring the treatment effects. Physical principles of medical imaging and different digital image processing and filtering techniques are presented subsequently.

3.1. Physical Principles of Medical Imaging

Medical imaging is the technique and process of presenting a visible image showing the internal structures of the body hidden by the skin and bones for clinical analysis, diagnosis and medical intervention. Medical imaging modalities grouped mainly into two according to radiation type into ionising radia-

tion (X-ray, CT, Nuclear Medicine, Fluoroscopy, Mammography, Angiography ... etc.) and non-ionising radiation (Ultrasound, MRI, fMRI). Physical principles for X-ray, CT, MRI and fMRI have presented shortly in the following sections.

3.1.1. X-ray:

X-rays are electromagnetic waves (like light) that pass through the body to generate an image with high resolution showing bones clearly but are poor in the imaging of soft tissues such as the brain or muscle [16]. X-ray energy approximately 1 to several hundred kiloelectronvolts (keV); while in medical x-ray imaging, the x-ray energy typically lies between 5 and 150 keV according to the part of the body and amount of x-ray absorbance. It is harmful if it is used frequently, for a long time or with high dose.

3.1.2. Computed Tomography (CT):

Conventional radiography suffers from the collapsing of 3D structures into 2D images, so CT has developed to overcome these problems although it has a lower spatial resolution. CT has produced an excellent anatomical image by reconstructing the slices that obtained from a large number of measurements of X-ray transmission through the patient into maps of the x-ray linear attenuation coefficient [17]. In order to have an image with better low contrast resolution, CT has designed to give this feature using high radiation dose approximately more 10 times than that of conventional X-ray which enables detection of small changes (about micro) in tissue type.

3.1.3. Magnetic Resonance Imaging (MRI):

MRI uses a magnetic field and radio waves to obtain specific and 3-D images with more details. So the doctor can see the entire parts of the patient's body like bones, joints, blood and specially the tissues in the brain without using X-ray or pigment injection for obtaining a good contrast [17]. MRI is less harmful effect than X-ray or CT because it is non-ionising radiation.

3.1.4. Functional Magnetic Resonance Imaging (fMRI):

fMRI uses MRI to calculate the levels of oxygen in the blood. MRI views the anatomical or structural image with high resolution and produces the differences between tissue types with respect to space, while fMRI views the functional image with low resolution and produces the differences between tissue types with respect to time. So, MRI produces the anatomical of organs, soft tissues, bone and all other internal body structures which allow physicians to evaluate them and detect the presence of certain diseases, while the fMRI views the metabolic function for measuring brain activity because it measures the hemodynamic response function (hrf) or metabolic demands (oxygen consumption) of active neurons in the brain or spinal cord and doesn't measure neuronal activity directly [8, 18].

3.2. Digital Image Processing and Filtering Techniques

Medical imaging is important for a clinician in making a diagnosis based on how it looks, i.e. changes in shape, for example enlargement or shrinkage of a particular structure, changes in image intensity within that structure compared to normal tissue and/or the appearance of features such as lesions which are normally not seen. There are some quantitative criteria related to the parameters which are important to a clinician for diagnosis, the most important three of them are the spatial resolution, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) [18]. So, when images with low quality and difficultly to detect and extract information must get under a process as image enhancement, which contains an aggregation of techniques that look for improving the visual aspect of an image.

Image Enhancement (IE) and denoising algorithms for executing the requirements of digital medical image enhancement have introduced in the design of software package that used in this work to improve features and gain better characteristics of medical images for a right diagnosis [19]. There are different types of filters that used with IE as shown in Fig. 7; most of them have designed in this package, while the most important and influential filters have introduced shortly in the next paragraphs.

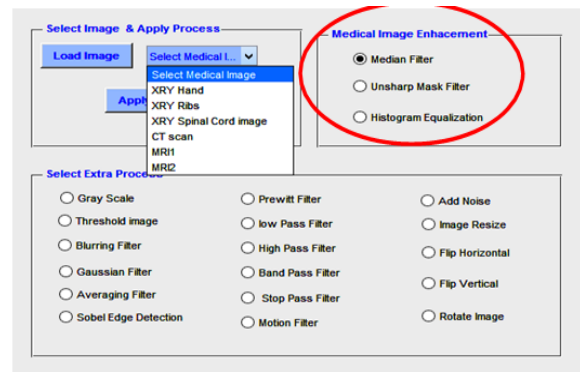


Figure 7. Image Enhancement (IE) filters.

3.2.1. Median Filter:

It is a common filter used for noise reduction with less blurring and enhances image certain details such as edges and eliminate unwanted elements of noise. Median filtering is a popular technique of the medical image enhancement that usually contains salt and pepper noise due to the presence of minute gray scale variations in the image; by removing impulse noise without effectively reducing the image sharpness [20, 21].

3.2.2. UnSharp Mask Filter (USM):

It is an uncomplicated process for edges sharpening improvement. The classical unsharp masking filter can be used after a median filter to reduce the remained noise and sharpen the edges. First obtaining is a blurred original image after applying USM filter on it. So, the low-pass filter must be applied firstly, then pixel subtracted from the original image and so it is obtained the high pass component.

Then, the output image is obtained by adding the high-pass components to the original image, because it could contain also pixels with negative values; i.e. in order to normalize [22].

3.2.3. Contrast Limited Adaptive Histogram Equalization (CLAHE):

It is a technique that is used to generalize the ordinary histogram equalization and adaptive histogram equalization for improving the local contrast of images. CLAHE works like ordinary Histogram Equalization (HE) and does not operate on the whole image, but it works on 'tiles' which is small areas in an

image. The adjacent tiles are combined using bilinear interpolation to eliminate artificially induced boundaries, while the contrast can be limited to avoid amplifying any unwanted information like noise in images [23].

4. RESULTS

Biosignal Processing, Medical Imaging and fMRI (BSPMI) Software Package designed in this work is based on MATLAB GUI and has the following main features:

- Presented the most important biosignal and that mostly used in biomedical instruments' laboratory, which are: Electrocardiograph (ECG), Electroencephalograph (EEG) and Electromyography (EMG) signals.
- Applied some biomedical signal processing techniques to each one of the above biosignals (ECG, EMG and EEG), which are: Adaptive Filters, Digital Filters (FIR and IIR filters) and Wavelet Analyses have applied to signals and displayed using GUI MATLAB in the BSPMI software package.
- Presented the most important medical imaging modalities used in clinical and research laboratories, which are X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and functional Magnetic Resonance Imaging (fMRI).
- Applied some digital image processing and filtering techniques to X-ray, CT and MRI, which are: Image Enhancement (IE) and denoising algorithms by using the Median filter for removing noise on images followed by an UnSharp Mask filter (USM) for sharpening, then Contrast Limited Adaptive Histogram Equalization (CLAHE) is applied to obtain good quality.
- Showing fMRI brain images just by choosing a number of slices in the pop-up menu; i.e. without going to the codes each time and changing a number of slices inside them.
- Export and save any graph as (.fig, .png or .bmp types).
- Save data as (.txt, .mat or .xlsx types).

This package consists of two main modules using the MATLAB Graphical User Interface (GUI); the first one deals with the

processing of different biosignals, especially Electrocardiograph (ECG), Electroencephalograph (EEG) and Electromyography (EMG) signals while the second one introduces different image modalities such as X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and functional Magnetic Resonance Imaging (fMRI). Fig. 8 shows the main window with two push buttons for the first and second module.



Figure 8. *The main window.*

In the first module, Biosignals Processing Module, ECG, EEG and EMG signals are loaded and plotted in the BSPMI package as shown previously in Fig. 1, Fig. 2 and Fig. 3 respectively. Fig. 4, Fig. 5 and Fig. 6 in the first module showing how the biomedical signal processing techniques: Adaptive Filters, Digital Filters (FIR and IIR filters) and Wavelet Analyses are applied to ECG, EMG and EEG signals.

In the second module, Medical Image Processing Module (Fig.9), X-ray spinal cord image has displayed as an example. Then average filter and histogram have applied to it. While, lower part of this window shows fMRI brain images that will be displayed slice by slice, in this figure slice number 6 has taken as an example.

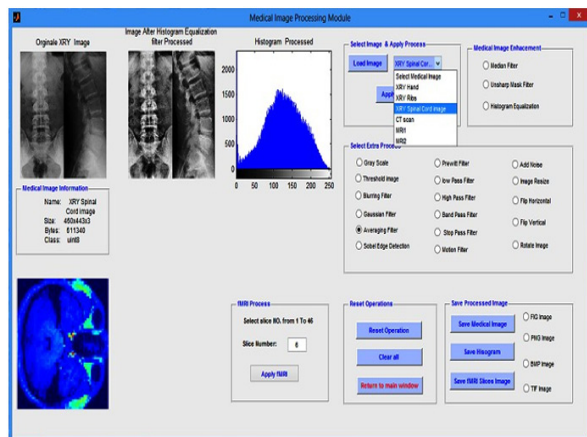


Figure 9. *Medical Image Processing Module.*

Mainly the upper part of the second module has introduced how X-ray, CT and MRI images are loaded and displayed in the BSPMI package as shown in Fig. 10, Fig. 11 and Fig. 12 respectively. Fig. 10 has taken for X-ray hand image and displayed as .JPG with the following features: Size= 304x233x3 (height x width x no. of samples), Bytes= 212496 and Class= uint8 (8-bit). Fig. 11 has taken for CT Lungs image and displayed as .JPG with the following features: Size= 388x512x3, Bytes= 595968 and Class= uint8. Fig. 12 has taken for MRI image and displayed as .JPG with the following features: Size= 476x359x3, Bytes= 512652 and Class=uint8.

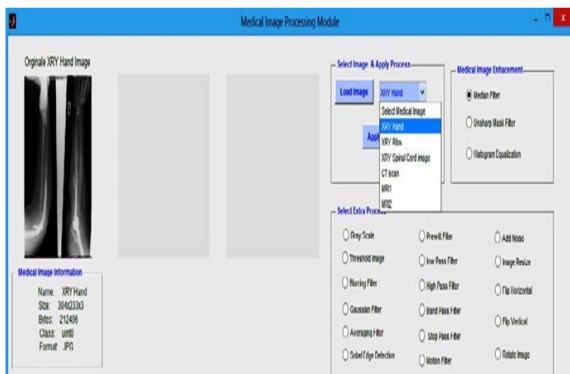


Figure 10. X-ray image.

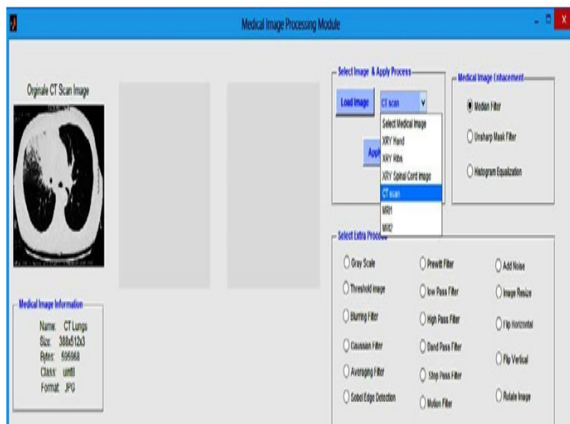


Figure 11. CT image.



Figure 12. MRI image.

Fig. 13 Shows fMRI brain images that will be displayed slice by slice. When any number shown in the pop-up menu has chosen, a new fMRI slice will appear without needing on going to the program codes each time and changing a number of slices inside them, in this figure slice number 35 has taken as an example.



Figure 13. fMRI image.

In the second module the Image Enhancement (IE) using: Median filter, UnSharp Mask filter (USM) and CLAHE are applied to X-ray, CT and MRI images. Fig. 14, Fig. 15 and Fig. 16 showing how the Image Enhancement (IE) using: Median filter, UnSharp Mask filter (USM) and CLAHE are applied to X-ray image respectively.

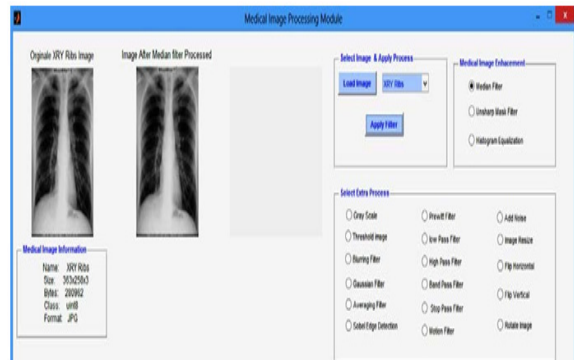


Figure 14. The application of Median Filter on X-ray image.

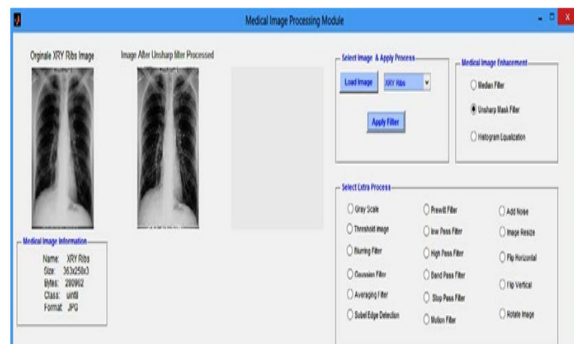


Figure 15. The application of UnSharp Mask filter (USM) on X-ray image.

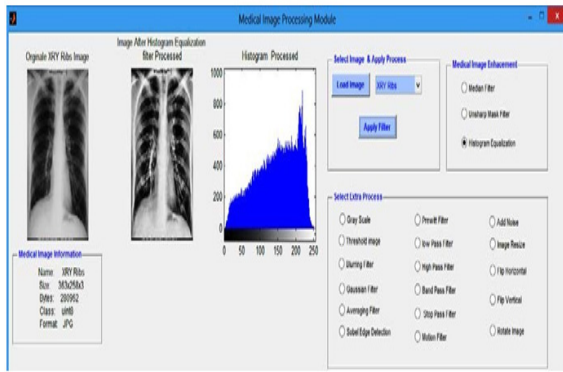


Figure 16. The application of CLAHE on X-ray image.

As explained previously, after using median filter, noise is removed slightly from the original image as shown in Fig. 14. Median filter is followed by an unsharp mask filter which is used for reducing the remaining noise and sharpen the edges as shown in Fig. 15. Also the unsharp mask filter is followed by CLAHE for obtaining better quality, especially in contrast as well as a generalization of ordinary histogram equalization and adaptive histogram equalization, as shown in Fig. 16.

5. CONCLUSION AND FUTURE WORK

Laboratory experiments are the main help for researchers and undergraduate students together with courses especially engineering laboratories. These laboratories introduce experiments in developing students' skills leading to develop universities which are the bases in developing countries. But still the equipment's used in these laboratories are expensive, so the suggested package in this work is a good user-friendly cheap educational interface. This package can open a new line for undergraduate and postgraduate students and researchers on how they can use these biosignals and images in the future for processing and finding the characteristics related to them. Also, it will help them in subsequent analysis of different biomedical signals, techniques and image data; while by designing the fMRI graphical simulator in the second module is aimed to improve the student's learning and understanding of some basic aspects of fMRI. This package can be easily used by students/researchers using only standalone application or executable file (exe file) without installation of MATLAB program.

For future work, some topics are sug-

gested as:

- Using another biosignals as ENG, ERG and EOG.
- Using other DSP techniques as Parametric and Non Parametric Approaches, Time-Frequency Analysis Methods, Principal Component Analysis (PCA) and Independent Component Analysis (ICA).
- Using other image modalities as Mammography, Angiography, Nuclear Medicine Imaging (NMI) and Ultrasound.
- Using another Image Processing Techniques and other Filters types.

Also the package results could be shared to website using ASP .NET, which can give facility for users or students by sharing applications which requires no installation of MATLAB or any special program just a Web browser.

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