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Advances in biomedical signal and image processing – A systematic review

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ABSTRACT

Biomedical signal and image processing establish a dynamic area of specialization in both academic as well as research aspects of biomedical engineering. The concepts of signal and image processing have been widely used for extracting the physiological information in implementing many clinical procedures for sophisticated medical practices and applications. In this paper, the relationship between electrophysiological signals, i.e., electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG) and functional image processing and their derived interactions have been discussed. Examples have been investigated in various case studies such as neurosciences, functional imaging, and cardiovascular system, by using different algorithms and methods. The interaction between the extracted information obtained from multiple signals and modalities seems to be very promising. The advanced algorithms and methods in the area of information retrieval based on time-frequency representation have been investigated. Finally, some examples of algorithms have been discussed in which the electrophysiological signals and functional images have been properly extracted and have a significant impact on various biomedical applications.

1. Introduction

Biological and medical information processing is a dynamic field of natural science [1]. The biomedical signals have been used by the architects for designing the bioelectrical and biomechanical systems. The physicians and human service experts introduced the diagnosing procedures of medical issues. The biomedical signals handled by these experts have been broadly focussed on both diagnosis as well as interpretation of information on the health status of an individual. The existing signal processing tools or programs are more suitable for engineers working in biomedical applications, according to their position they can utilize the tools or programs easily [2]. The most important biomedical signals are classified into two types such as action potential and event-related potential. Electromyogram (EMG), electroneurogram (ENG), electrocardiogram (ECG) and electroencephalogram (EEG) are existing action potential. The event-related potentials (ERPs) are electrogastrogram (EGG), phonocardiogram (PCG), carotid pulse (CP), signals from catheter-tip sensors, speech signal, vibromyogram (VMG), vibroarthrogram (VAG), oto-acoustic emission signal [3]. The various image modalities are widely used in the biomedical field, i.e., functional magnetic resonance imaging (fMRI), computed tomography (CT), ultrasound imaging and positron emission tomography (PET) [1]. The fMRI data produces high spatial resolution functional data and comparatively low temporal resolution, which have been generally used to study the working of the healthy and diseased brain, under different task conditions and under rest [4]. Recent literatures have demonstrated that the EEG and fMRI modalities have focused to analyse and develop the methods to quantify pain in sickle cell disease patients [5]. Furthermore, these modalities can identify the epileptic seizures by recording resting state [6], and also be practiced for detecting differences in brain activity [7]. Meanwhile, the computed tomography (CT) associated with anatomy, which provides the spatial and temporal resolution [8]. The multi-detector CT is a non-invasive imaging method that is a recent technological advancement tool for visualisation of cardiac anatomy with high resolution [9].

In ultrasound (US) imaging techniques, 2D techniques have been used for assessing the plaque morphology, since insufficient image contrast and variation in 2D ultrasound examination may affect the accurate assessment of morphological plaque change. Hence 3D techniques were developed for improving the visualization and quantification of complex anatomy and pathology [10]. Nowadays, the ultrasound images are widely used in vivo nerve movement by speckle tracking using frame by frame cross correlation investigation [11] and utilized in fetal measurements [12]. The nerve detection and segmentation approach was carried out by Hadjerci et al. [13] using ultrasound images. The ultrasound-guided regional anesthesia (UGRA) technique has been used for nerve identification. This technique uses four approaches namely, despeckling filter, feature extraction, feature selection, and classification/segmentation. The processing techniques

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associated with images from modalities such as fMRI, CT and US have been extensively reviewed in the existing literatures, particularly in analysing the atrial fibrillation and ventricular tachycardia [14]. Moreover, these processing techniques can also be used in the detection of breast cancer [15,16] and malignant rhabdoid tumor of the liver [17].

Image processing techniques include several methods namely enhancement, segmentation, detection of the region of interest, pre-filtering method, thresholding technique and morphological operations. Segmentation is a process that is used for eliminating the complex procedures in images. The information from texture, shape, contours, etc., is used in the classical image segmentation [10]. Edge detection is a technique used to find boundaries of objects inside an image. An edge is defined as sudden discontinuities in an image. A sudden change in brightness level within an image can be termed as an edge. Different first derivative and second derivative edge detectors are Sobel, Prewitt, canny Robinson and Laplacian. Image enhancement techniques used to restore the original image either in space domain or frequency domain. The space domain approaches are point processing and mask processing.

The various types of biomedical signals and images can be measured by particular sensors. The processing of biomedical system explained with several steps such as (i) Acquire the relevant biomedical information using sensors, (ii) Pre-processing can be done after acquisition, (iii) The filtering and feature extraction techniques is used to convey the condition of biomedical system and (iv) The last step seems to be classification and diagnostics, where the status of result is decided by the normal and abnormal samples [1].

The aim of this systematic review is to give attention towards biomedical signal and imaging fusion procedures because of their importance in the medical field. Therefore, the paper is systematized as; Section 2 particularizes the methodology of the literature. Section 2.1 describes the basic transforms that are often used in the fields of cardiology and neurosciences. Section 2.2 explains the common algorithms of signal and image fusion techniques. Section 3 discusses the overview of transforms used and some examples associated with fusion techniques. Section 4 concludes the present study.

2. Methodology

The basic transforms and algorithms that are often used in the fields of cardiology and neurosciences are explained in this section. It includes the transforms such as Fourier, Fast Fourier transform, wavelet transform, Laplace transform, curvelet transform, wavelet packet decomposition, Hilbert transform, Hadamard transform and warblet transform, shearlet transform, and contourlet transform.

2.1. Overview of transforms used in biomedical signal and image processing

2.1.1. Transforms based techniques for ECG signal analysis

Gutiérrez-Gnecchi et al. [18] propounded a method to classify the arrhythmia that is implemented on a digital signal processing platform (DSP). The wavelet transform based on quadratic wavelets algorithm is used for identifying ECG waves and fiducial marker array. The arrhythmia classification was done by the probabilistic neural network. The classification includes 5 step process, Cardiac frequency calculation, RR interval measurement, P wave measurement, PR interval measurement and QRS complex measurement. The wavelet transform is represented in a mathematical notation (Eq. (1)). The transform includes four scale values corresponds to a bandwidth: 62–125 Hz, 18–60 Hz, 8–26 Hz and 4–13 Hz. The first three scales were used for detection of R peaks. Local maximum and minimum values were used to detect Q and S waves with the limit of 30%. The P and T waves were detected by the fourth scale. The probabilistic neural network distributes the probability of arrhythmia. The authors [19,20] used the wavelet transform to detect the QRS complex wave from the acquired ECG signal.

$$W_f(u,\, s) = f^{*}\varphi_{u,s}^{*} = = \int_{-\infty}^{+\infty} f(t) \frac{1}{\sqrt{s}} \varphi^{*}(t{-}u/s) \tag{1}$$

where s is the scale factor and $\varphi_{u,s}^{*}$ is the mother wavelet.

To estimate the realistic geometry from body surface potentials a spline Laplacian (SL) ECG algorithm was proposed by He et al. [21]. The estimation algorithm is linked with the parameters of spline Laplace. Taking the inverse of the general matrix produces the formulation of spline Laplace. Among the parameters, one is needed to estimate the realistic geometry surface from body surface potentials. This algorithm is furthermore scrutinized in computer simulations to authorize this approach in spherical volume conductor, where the feasibility of mapping cardiac electrical sources, heart torso-model was tested. The conductivity of the torso volume conductor is mentioned as 1.0. To simulate the noise contaminated body surface potentials Gaussian white noise (GWN) associated with the different noise levels were used. It has been reported that the conventional five-point local Laplacian estimator performs the SL and give local based Laplacian ECG estimation [22]. He et al. [23] proposed a system that strongly reports, that the SL algorithm efficiently implements the realistic geometry spline in EEG based studies.

Jero et al. [24] applied curvelet transform for hiding information of patients' ECG signals. To apply this method, the ECG signal is decomposed into frequency sub-bands. The patient information is secured by quantization approach. The transform is based on scales, where four scales were represented in this study. The co-efficient of this four scale computation is expressed in Eq. (2).

$$C^D(j,\, l,\, k) = \sum_{n1,n2 \in P_j} \hat{f}\,[n1{,}n2 - n1\tan\theta]\,\widetilde{U}_j[n1{,}n2]\,e^{i2\pi\left(\frac{k_1 n_1}{L_{1j}} + \frac{k_2 n_2}{L_{2j}}\right)} \tag{2}$$

Using zero threshold value the ECG steganography based on curvelet transforms was evaluated. The curvelet transform is also used to decompose the image into frequency sub-bands to the number of scales [25].

One optimal combination method for detecting the R peaks in ECG consists of Hilbert transform with the adaptive thresholding method. The noise presented in the signal was removed by the discrete wavelet transform in both time and frequency domain. The authors denoted the Hilbert transform of the signal in (Eq. (3)) [26].

$$z(t) = H[y(t)] = \frac{1}{\pi} \int_{-\infty}^{\infty} y(\tau) \frac{1}{t-\tau} d\tau \tag{3}$$

where $y(\tau)$ is the time function.

Hilbert transform is nothing but a linear filter, there is no change in spectral component amplitudes but changes occur in phase values. The maximum amplitude was identified to detect the R peaks by the adaptive thresholding method.

Conjugate symmetric- complex Hadamard transform (CS-CHT) was used for detecting the atrial fibrillation (AF) in ECG features [27]. The complex Hadamard transform matrices were expressed in Eqs. (4)–(6).

$$H_s = \begin{matrix} H_{s/2} & H_{s/2} \\ H'_{s/2}T_{s/2} & H'_{s/2}T_{s/2} \end{matrix} \tag{4}$$

Where

$$T_s = \begin{matrix} H'_{s/4} & H'_{s/4} \\ H'_{s/4}I'_{s/4} & -\ H'_{s/4}I'_{s/4} \end{matrix} \tag{5}$$

$$I'_{s/2} = \begin{matrix} I_{s/4} & 0 \\ 0 & -\ I_{s/4} \end{matrix} \tag{6}$$

The feature extraction techniques were used with different orderings like natural, Paley, sequency and Cal-sal. The Levenberg-Marquardt neural network classifier was used for approximation and