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Synopsis

Intelligent Signal and Image Processing

Signals and images are multidimensional information that are recorded in routine clinical practice. Due to their multidimensionality (from 2-D to 4-D) they can convey large amounts of information which, however, are usually masked under noise, or are abstracted from other information floating around. Another element is the increase in the number of signals that can be simultaneously acquired in routine clinical practice. Today, due to hardware advances, it is possible to record multi-channel data which contain more information; however this information is becoming difficult to extract and interpret. Hence the need for efficient and intelligent information processing techniques, and the need for defining evaluation protocols on the information processing techniques in use.

During the last decade, we have witnessed a considerable increase in research on biomedical signals and images. The reasons are the increase in image and signal acquisition modalities, the increased use of networks, and the increased awareness that advanced signal and image processing can reveal clinically important information usually not evident in the framework of a routine investigation. Moreover, processing techniques are shifting from linear ones to non-linear techniques, and to intelligent techniques based heavily on learning systems such as Neural Networks and fuzzy logic. There is an increase in integrated environments of information processing with numerous modules ranging from digital filters to non-linear transformations and dedicated classifiers. With the wide use of non-linear methods, classification has become an increasingly important area, and visualization is expected to follow. In fact, image preconditioning and rendering for fast and reliable visual-ization of 3-D and 4-D image sequences is expected to be a focus of research in the years to come, and is expected to open up virtual reality in medicine.

The seven papers to be reviewed here can be subdivided in the following categories:

1. Papers dealing with signal acquisition and analysis [1-4]. These papers can be further subdivided into two groups: a) those dealing with instrumentation and recording techniques of biomedical signals coupled with information processing for parameter extraction [1-3] and b) one paper dealing with assessment of multi-channel ECG interpretation looking into the effects of electrode position in diagnosis quality [4].
2. Papers dealing with image processing and management [5-7]. In particular there are two papers that use image processing techniques for visualization and rendering of image data [5,6] and there is one paper dealing with image processing using Neural Network based techniques in combination with expert rules [7].

More specifically the analysis of each paper is as follows:

Amplitude Demodulation of the ECG for Respiration Monitoring and Compensation during MR Examination

We start the synopsis with the paper by Felblinger and Boesch [1]. This paper presents a new method for respiratory monitoring during MR-sequences using the ECG, and more specifically the changes in the R-wave amplitude. Using digital demodulation, the method produces an estimate of the respiration curve, which in turn can be used for patient monitoring, triggering or respiration compensation of MRI sequences. An extremely important characteristic of this technique is that the estimate of the respiratory signal using digital demodulation showed no drift, even during apnea, making it superior compared to the respiratory signal produced by analog demodulation techniques. The cardio-respiratory signal can be correlated with the diaphragm position (correlation is very strong > 0.9), and since only digital processing of ECGs (which can be acquired by modern MRI systems) is required, this method presents a superior alternate for triggering or respiration compensation of MR sequences, which in turn can result in higher quality MR images of the heart.

Total and partial coherence analysis of spontaneous and evoked EEG

The second paper by Liberati et al. [2], deals with the processing of multichannel EEG signals by means of coherence measures. AR modelling is used for the estimation of the spectral matrix, and subsequently partial and total coherence between selected channels is performed. The use of a multivariable autoregressive approach gives reliable results even for short time windows (0.1-0.15 sec) thus addressing the stationarity constraint. This technique is of great importance when stimulus-related potentials are investigated which impose stationarity constraints to the signals.

The novelty introduced in this paper is the estimation of the partial coherence, and its linkage to the determination of cortical interactions resulting from combined visual and somatosensory stimulation. Partial coherence is achieved when the comp-uted conditioned spectra are substituted for the conventional spectra.

It is shown in this paper that comparison of partial and total coherence allows the non-invasive detection of cortical and possibly sub-cortical interactions of the central nervous system under multiple stimulation, or stimulation-free conditions.

Automated Fetal Breathing Movement Detection

The third paper by Yamakoshi et al. [3] is a new method for an automated fetal breathing movement detection from ultrasound based fetal diaphragm movement recording. In the processing part, a modified autocorrelation technique is used which is able to detect sinusoidal displacements due to the fetal breathing induced diaphragm movement. In particular, the autocorrelation coefficients are calculated for time lags 0.75 sec, 1 sec and 1.25 sec. Subsequently, the maximum value of the three autocorrelation coefficients is taken at each time instant, and a threshold is imposed. At all time instants which have maximum autocorrelation coefficient values above this threshold, fetal breathing movement is detected. The determination of the above-mentioned threshold is done by trial and error, and by calculating the true-positive and true-negative values using different threshold values. Nontheless, this is an interesting method since, although simple, it gives good results.

Effect of Electrode Positioning on ECG Computer Interpretation

In the paper by Schijvenaars et al. [4] the variability in automated ECG interpretation due to electrode position was assessed in healthy individuals and patients with myocardial infarction or left ventricular hypertrophy.

The experiments used shifts of leads V1-V6, in four patterns. 1) Longitudinal displacement from 5 cm upward to 5 cm downward in steps of 1 cm; 2) Transverse displacement of leads V1-V3, with V1, V2 shifting in opposite directions and exhibiting a displacement (3 cm) double the displacement of lead V3 in steps of 6 mm; 3) Transverse shifts in electrodes V5-V6 with V6 exhibiting a maximum displacement of 3 cm (in steps of 6 mm) and V5 exhibiting half the displacement of V6 and; 4) Rotational dislocation of leads V1-V6 with lead V2 kept constant.

When the above-mentioned experiments were done, the effects on specific measured parameters of the ECG signals for different groups of patients were calculated, and tests on whether the computer program would change the diagnosis were performed. Analogous protocol was followed by an expert cardiologist.

The results concerned changes in the measurement of four parameters (QRS duration, Q duration, Q amplitude and Sokolow index) due to electrode position shifts, and in changes in diagnosis. It was shown that longitudinal and rotational shifts caused large changes in the Sokolow index, while the effects on Q duration were larger (although not significant) than those observed in QRS duration. In the diagnosis, it was shown that for the myocardial infarction category in the case of longitudinal shifts, there were significant changes in diagnosis in 6% of the cases, while for the remaining scenarios significant changes did not result in more than 3.5% of the cases. In the case of left ventricular hypertrophy, significant changes were observed in 3% of the cases, while for the rest of the scenarios of electrode shifts, significant changes were observed in less than 1% of the cases. An expert cardiologist who analysed a subset of 80 cases, agreed with the computer in 38 of 40 cases in which it made no change. In 40 cases with large diagnostic changes, the cardiologist made no change in 18 cases. This fact shows that the cardiologist was less influenced by the effects of electrode shifts than the computer. Thus the effects on classification are significant, meaning that correct chest electrode placement is mandatory for reliable diagnosis.

In the image processing and analysis area, we find three papers [5-7]. Two of these papers deal with processing of images for 3-D visualization enhance-ment [5,6], while the third one deals with intelligent image processing using Self Organising Neural Networks [7].

Segmentation of the Visible Human for High-quality Volume-based Visualization

In particular, the article by Schiemann et al. [5] presents a number of methods for interactive classification and super-sampling visualization for enhancing the realism of 3-D reconstructions of data sets such as the Visible Human. (Note: The Visible Human data sets consist of 3 parametric photographic images which we want to display in 3 dimensions.) In addition the proposed classification of objects is performed based on ellipsoidal regions in RGB space.

The paper presents a detailed description of the problems encountered in the 3-D visualization of color data.

One problem is the huge size of the available data, and methods for handling it are discussed. Also, the registration problems of CT and MRI data with the anatomical data are mentioned.

For volume-based visualization, 3 different approaches are analyzed:
- polygon-based rendering of surfaces (fast, considerable detail is lost for low number of polygons, difficult accurate mapping of surface and realistic cutting)
- volume rendering based 3-D images by summing up all voxel values along the path of each ray (usually very slow, does not create realistic images)
- volume-based surface rendering of surfaces using object membership attributes obtained by segmentation (most preferred, can produce a high degree of detail and realism).

The conditions for computing high-quality images are given and the determination of segmentation-based classification is performed through the definition of RGB ellipsoids. The detailed implementation issues (ranging from binary morphology and connected component labeling) are described but simplified versions are followed for efficient execution. The authors claim that their methods showed an improvement in quality of rendering.

In conclusion, this article is quite specialized in terms of presenting the latest results in rendering 3-D surfaces using segmentation and thresholding in the RGB space. The presented analysis is likely to be interesting to a relatively small part of the audience, yet interesting since it discusses novel 3D imaging methods.

Hybrid Rendering of Multidimensional Image Data

In the paper by Englmeier et al. [6] a new hybrid rendering method that combines the advantages of surface and volume presentation and minimizes the limitations of surface and volume rendering techniques is presented. This method, based on the graphical interfaces offered by X11 and OSF/MOTIF, uses the following:
- A common data representation for both surface and volume rendering techniques.
- A pre-processing module for the construction of a data volume and the calculation of object surfaces.
- A user-friendly open system enabling the support of applications such as virtual reality and stereolithography.

The aim of the paper is to introduce image analysis and synthesis and, specifically, 3-D visualization methods that can be used in a clinical environment. To accomplish this, the methods should be computationally fast, reliable and user friendly.

In particular, as it concerns the internal data representation the generalized voxel method is used. To optimize the 3-D display of hybrid rendering, the computed results of segmentation and surface construction are stored during the entire process time. The quality improvement of 3-D images is supported by the computation of the normal vectors of the surface voxels (needed to be calculated only once) of the segmented objects, which in turn are used for the fast vector interpolation along the voxel surfaces. In order to compute the values of the isotropic voxels, efficient new interpolation methods such as matching interpolation or shape-based interpolation are used to estimate the grey values between the images that result from tomography devices.

After the above pre-processing steps are made, the main process starts with the surface construction, which aims in to reduce gaps in the reconstructed surface and to accelerate and simplify existing surface construction algorithms. In this process the authors use the following steps:
- Computation of the surface by definition of surface primitives
- Construction of a look-up table of the applicable polygons
- Selection of the best fitting candidate
- Generation of a list of polygons to describe the object surface.

The hybrid rendering aims at surpassing the disadvantages of existing approaches for image rendering, which is the missing capability to visualize in real time, thus creating problems in applying virtual reality techniques in the field of medical therapy planning. The developed method is based on the internal data representation, and on two different approaches for the color determination within polygons using graphic hardware. The two methods are:
- Specification of normal vectors at the polygons' vertices - Computation of the illumination equation by a graphic engine - Interpolation of the resulting vertex colors using the Gouraud shading algorithm.
- Direct determination of the colors at the polygon vertices without the consideration of optical effects.

For texture mapping techniques to be used, (they use surface structures called texels) both from high-end and low-end graphic workstations the use of efficient algorithms to achieve maximum rendering performance is addressed. The method is applied on 3-D subtraction angiography with impressive results, and it opens new application fields in medicine such as the simultaneous display of multimodal 3-D image data such as CT and MRI and presentation of time-dependent image sequences. In fact, using high-end graphics hardware, 3-D textured volumetric images can be rendered at rates of up to 10 images per second enabling thus the application of new virtual reality techniques.

Automatic Detection of Ground Glass Opacities on Lung HRCT

The last paper in the area of image and signal processing is the work by

Heitmann et al. [7]. In this work the implementation of a method to automatically detect ground glass opacities (GG) on HRCT using a hybrid scheme composed by neural networks (NN) and expert rules is presented. The method is validated using high-resolution CT images obtained on a third generation CT scanner from 20 patients, and 120 individual scans which were reviewed by an experienced chest radiologist. Subsequently, the NN based method output was compared with the diagnosis of the radiologist.

The self-organizing map (SOM) was chosen to act as GG classifier. The reason is that it can be trained in an unsupervised way, and if fed with a set of training vectors with unspecified classes, it can organize its memory in such a manner that it can subsequently recognize similar inputs in the classification process. As training patterns, parts of CT scans were used. The input to the NN can be images or feature vectors defined as sets of textural parameters calculated on a small image neighborhood.

It was shown that when using NN only for detection of GG from HRCT, the classification results showed high sensitivity (> 95%), but poor specificity due to the misclassification of high-contrast areas of low-density lung tissue close to high-density structures. Thus, the next step was to train different SOMs with different inputs, and connect their outputs through expert rules. Thus, a single SOM was trained to detect GG, while two additional SOMs were trained to detect only high-contrast areas. Subsequently, using a simple expert rule combining the outputs of the three SOMs, the false-positive rate fell back strongly.

The environment used for the development of this NN based detector (FLEXKON) operates under MS-WINDOWS and partially under SUN-SOLARIS, and allows the easy set up of defining and connecting processing, learning and classification modules based on NN and fuzzy logic, thus permitting the update of the hybrid detector scheme used. The results of this experiment are quite promising, since 91 out of the 120 slices were correctly classified by the NN based system, while 16 normal cases were misclassified as mild cases due possibly to inadequate window setting. Only 11 cases were significant false classifications due to motion artifacts or diaphragm. Thus, this paper shows the added power in detection and classification problems in medical imaging of hybrid methods containing modules that can be a combination of NN and expert rules that use as input NN outputs.

Conclusion

In conclusion, the first three papers [1-3] show that intelligent instrumentation techniques for the recording of biosignals can reduce the complexity of signal processing algorithms, and at the same time provide clinically reliable and usable results. It is interesting to note that the two papers deal with the issue of respiration, while the other one with multi-channel EEGs. It is also interesting to note that in the papers dealing with respiration the auxiliary use of ultrasound and ECG gated MRIs are pivotal to the success of the proposed methods. Hence the use of integrated information in everyday clinical practice becomes a reality.

The paper by Schijvenaars et al. [4] exposes the problems we face when artifacts (such as electrode shifts) influence diagnosis. The results show that we still need numerous evaluations of automated ECG analysis programs in order to use them reliably in everyday clinical practice. To this end, the collaboration of human experts is a must, but it is not an easy task.

The last three papers [5-7] address issues in image processing. It is evident that future directions in research in biomedical imaging include:

- Efficient data management
- Intelligent pre-processing using modular and hybrid unsupervised techniques
- Conditioning for reliable 3-D visualization and rendering in high or low end graphics workstations for the development of medical virtual reality techniques.

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