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Synopsis

Image and Signal Processing

This section of the Yearbook includes six articles, two on signal processing and four on image processing. Biomedical signals, whether in one, two or three dimensions, go through a series of steps on the difficult route from the recording of the signal to the provision of one or a few data items of diagnostic importance. Together, these six articles cover important aspects of that route, including methods for data compression, extraction of meaningful features, and classification or diagnosis based on those features. Three of the articles on image processing also deal with the problem of registration: the alignment of two-or-three dimensional data acquired by different imaging modalities or from different subjects.

The two articles on signal processing have in common that they represent innovative applications of well-established signal analysis techniques. Madhukar and Murthy [1] address one of the first steps on the route from the recording of the signals to the diagnostic interpretation: compression of ECG data from long-term recordings. In the article by Akay et al. [2] the purpose of the signal processing is to extract a single feature from the heart sounds that can be used to diagnose coronary artery disease.

The article by Madhukar and Murthy [1] is a *tour de force* in the application of signal analysis techniques. As the result of their efforts, they obtain a data compression of a factor of about 30 in ambulatory monitoring of ECG signals. Madhukar and Murthy first apply a cosine transform to an approximately 1s segment of ECG. Next, they model the cosine coefficients as the impulse response of a auto regressive moving average filter. Finally, they represent the polynomials in the filter by their roots to reduce quantization errors. Together, these steps provide a compression ratio of about 15. A further data compression by approximately a factor of 2 is obtained by observing that the QRS complex usually is relatively stable from one heart beat to the next. This makes it possible to use differential pulse code modulation to store only the changes of the filter from one heart beat to the next.

Data compression by a factor of 30 is worthwhile, in particular since it seems to be at least a factor of 2 better than what previously has been obtained. But nothing comes for free. The algorithmic complexity is considerable, and real-time data compression requires about 5 million floating point operations per second. Decompression is about 100 times less demanding in terms of computational effort. It will be interesting to see if the future technological development will favor the computationally intensive data compression developed by Madhukar and Murthy, or if it will favor the storage of largely uncompressed data on future inexpensive data storage media.

During diastole the turbulent blood flow through a partially occluded coronary artery produces sounds in the 300 - 800 Hz range. Akay et al. [2] compare four different signal analysis methods: FFT, autoregressive modelling, moving average, and the eigenvector method. For each of these methods Akay et al. select a single parameter that is supposed to characterize the increased power in the 300 - 800 Hz part of the spectrum. For the FFT method the parameter is the ratio of the power below 500 Hz and the total power. For the other three methods it is the amplitude of the pole in the models that falls closest to 400 Hz. If a detection threshold is chosen for the single parameter, then the sensitivity and specificity of the method can be computed from 80 cases, where the degree of coronary occlusion had been determined during catheterization. The complete Receiver Operating Curve can be constructed by selecting a range of thresholds. Inspection of the Receiver Operating Curves for the four methods reveals that the eigenvector method seems to perform slightly better than the other methods. This leaves the reader wondering whether different choices of model order, frequency limits, etc. in the different methods could have changed this result, but this is hardly the interesting message in this article.

For readers interested in the diagnosis of coronary artery disease the interesting message is that with an appropriate choice of a detection threshold,

the eigenvector method can provide a sensitivity of 79% and a specificity of 91%. This compares favorably with other non-invasive methods. Readers interested in the relation between signal analysis and medical decision support will find it interesting that the signal analysis in this application has produced a single number, which has a direct diagnostic value in itself.

The four articles on image processing are related to two different subjects: registration of information to bring them into a common frame of reference, and classification of tissue types from multi-modal images. Minoshima et al. [3] estimate the position of the intercommissural line from anatomical landmarks and use it as a reference frame for the localization of functional signals. Barillot et al. [4] bring multi-modal images into register with respect to an anatomical atlas. Kosugi et al. [5] report on inter-subject alignment of PET images for studies of functional activation. Finally, Özkan et al. [6] compare maximum likelihood classification to artificial neural networks (ANN) for classification of registered brain images. In functional activation studies involving several subjects it is necessary to use a common frame of reference.

Minoshima et al. [3] use the intercommissural (AC-PC) line as the frame of reference for recorded signals. They describe how the AC-PC line can be estimated from four landmarks (invariant features) that reside on the line. These invariant features can be detected through application of edge detection on PET images. Once the invariant features have been detected, a linear interpolation is used for estimation of the AC-PC line. This method has been tested on a limited number of subjects, and as part of these tests a comparison to a semi-automatic and a manual method has been made. The accuracy of the auto-

matic method is comparable to semi-automatic and manual methods. The availability of a method that allow automatic detection of basic landmarks from a single modal image is encouraging as such features can provide a reference for processing of images from other modalities.

An alternative approach to alignment of images from several subjects is described by Barillot et al. [4]. They bring multi-modal images from several subjects into register through use of the atlas provided by Talairach and Tournoux [7]. The registration of images is carried out through non-linear warping of individual images. In their article, a number of different descriptors are outlined that might be useful for classification of major cerebral structures. The article provides an overview of different descriptors rather than an in-depth analysis of the robustness of single descriptors. Finally, the article points out that good 3-D visualization techniques are required for interactive manipulation and assessment of volumetric data. Initial results with the bio-medical package ANALYZE are also reported.

For the reader interested in registration of multi-modal images the interesting message is that processing may be simplified considerably if an anatomical atlas is used as the reference for computations. In addition it is pointed out that 3-D visualization today has reached a state which enables use of the technique for interactive manipulation and inspection of both 2-D and 3-D information. An additional message is that well-known statistical classification methods applied to multi-modal images allow identification of major cerebral structures.

In the article by Kosugi et al. [5] it is described how ANNs can be used for inter-subject registration of PET images to facilitate studies of functional activation. The image transfor-

mation between different subjects is highly non-linear, and traditional linear warping models consequently produce poorly registered images. It is demonstrated how ANNs may be used for automatic estimation of the transformation between different subjects. It is further shown how the method may exploit manually provided anatomical landmarks to improve convergence speed and accuracy. Rather impressive results are reported for transformations involving 2-D images. It is, in addition, indicated that the technique may also be used for 3-D images. The interesting message with respect to registration is that the automatic method can be used for registration of images even when no landmarks are used. While earlier work has mainly been based on semi-automatic methods, it is demonstrated here that reasonable results can be obtained when classification of unique features and their use for the estimation of the transformation between images is combined in a single technique. It is evident that ANNs are suited for such applications.

Özkan et al. [6] compare the classification of MR and X-ray images, that are brought into register, by maximum likelihood classification (MLC) and by artificial neural networks. Many different techniques for classification have been reported in the literature with MLC as one of the frequently used techniques. An impressive demonstration of how the ANN has a performance comparable to or better than the MLC method for small training sets (i.e., in the order of 300 pixels) is provided. It is further demonstrated that even for large training sets the ANN has a performance that is comparable to the MLC technique. Given the limited size of the data required for training ANNs, it seems possible to perform on-line training during clinical use of the system.

In the article it is noted that con-

struction of fully automatic classification systems is still unrealistic, for two reasons: (1) The variations between subjects is too large to allow automatic handling, and (2) It is difficult for clinicians to accept results from automatic systems. A natural compromise is, consequently, computer-assisted diagnosis where the physicians use the computer systems as an integral part of their work. In such an approach it is also possible for the physician to interactively train the system. It is noteworthy that the reported work has been carried out as a collaboration between industries, scientists, and physicians. This indicates that the technology has reached a state of maturity where the theoretical methods have successfully been transferred to end-users and producers, a highly commendable achievement.

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