

Sensors, Medical Images and Signal Processing: Exploring Multi-Dimensional Medical Imaging Data

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Summary

Objectives: To summarize current excellent research in the field of medical sensor, signal and imaging informatics.

Method: Synopsis of the articles selected for the IMIA (International Medical Informatics Association) Yearbook 2009.

Results: Current research in the field of sensors, signal, and imaging informatics is characterized by theoretically sound techniques and evaluations with focus in imaging informatics.

Conclusions: The best paper selection of articles on sensors, signal, and imaging informatics shows examples of excellent research on methods concerning theoretically sound original development in this field. Imaging and particularly multi-dimensional imaging has had in 2008 by far the largest number of publications compared to signals and sensors.

Keywords

Medical informatics, International Medical Informatics Association, yearbook, image processing, signal processing, medical sensors

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Current developments in sensors, signals and imaging in the medical domain show a clear concentration of original research articles onto the medical imaging field. Original articles with subjects in the domains of sensors [1,2] or signals [3] have become scarcer over the past years, although a significant number of articles on signals such as brain computer interfaces [4] or on sensors, for example for the elderly and the chronically ill [5] continues being published. This is most likely due to the relatively small amount of brand new techniques and rather of gradual improvements in the fields by improving the many existing techniques and tools. On the other hand, there are enormous changes in the imaging field with new modalities (dual energy Computed Tomography, ...), new contrast agents, and new combinations of modalities such as positron emission tomography (PET)/computed tomography (CT) appearing at an ever-increasing speed.

Within the imaging field, a clear separation can also be seen compared to past descriptions in this Yearbook [6] as the tendency of articles is clearly towards multi-dimensional tomographic imaging [7,8]. 4-dimensional imaging such as fMRI (functional Magnetic Resonance Imaging) or dynamic PET has also been well represented in the articles reviewed [9,10]. These multi-dimensional data still require a significant amount of research simply for visualising them properly for clinicians (tools such as OsiriX¹ exist for this) but also for supplying new tools to aid diagnosis. The large amount of data

contained in tomographic series is often hard to analyze manually and can quickly lead to an information overload and a potential miss of important structures. It can thus be expected that this tendency towards multi-dimensional and multi-modal data will likely continue over the coming years. Moreover, recent advances in medical informatics enabled access to most of the radiological exams for all clinicians through the electronic health record (EHR) and the picture archival and communication system (PACS). This change of the medical workflow calls upon computer expert systems able to bring the right information to the right people at the right time and help with diagnosis.

The best paper selection of articles for the section on 'sensor, signal, and imaging informatics' in the IMIA Yearbook 2009 reflects these trends and follows the tradition of previous yearbooks ([11-13]) in presenting examples of excellent research on methods used for computerized signal and image analysis. The content of MedLine/Pubmed containing all articles from 2008 was analyzed with a focus on seven journals treating subjects concerning sensors, signals, and images (see Table 1) using the keywords listed in Table 2. An iterative review process involving international experts allowed selecting six papers based on the presented innovativeness, impact of the topic, practical impact, and theoretical robustness of the techniques. Table 3 presents the selected papers. A brief content summary of the selected best papers can be found in the appendix of this report.

The number of papers returned with keywords associated with imaging is by far superior to the ones associated with signal

¹ <http://www.osirix-viewer.org/>

and sensors (see Table 2), which highlights the current trend towards research on the use of medical images to support diagnosis.

The best paper selection for the Yearbook section ‘signal, sensor, and imaging informatics’ can by no means reflect the broadness of the field. The final six articles selected represent well the current challenges of the domain of sensors, signals and imaging informatics with a strong weight on multi-dimensional imaging.

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Table 1 Target journals used for the best paper selection in MedLine/ Pubmed

Radiology
IEEE Transactions on Medical Imaging
IEEE Transactions on Information Technology in Biomedicine
IEEE Computer Graphics and Applications
IEEE Transactions on Bio-medical Engineering
Medical Image Analysis
Computerized Medical Imaging and Graphics

Table 2 Keywords used to query Pubmed while restricting results to the journals listed in Table 1

Keyword	Number of results	Selected for pool	Selected for review	Best paper
CAD	35	12	2	1
signal*	211	14	2	1
EEG*	26	4	0	0
diagnostic imaging	655	44	10	4
sensor*	44	9	3	0
TOTAL	971	83	17	6

Table 3 Best paper selection of articles for the IMIA Yearbook of Medical Informatics 2009 in the section ‘Signal, sensor and imaging informatics’. The articles are listed in alphabetical order of the first author’s surname.

Section
Sensor, Signal and Imaging Informatics
<ul style="list-style-type: none"> Dam EB, Fletcher PT, Pizer SM. Automatic shape model building based on principal geodesic analysis bootstrapping. <i>Med Image Anal</i> 2008 Apr;12(2):136-51. Dejnabadi H, Jolles BM, Aminian K. A new approach for quantitative analysis of inter-joint coordination during gait. <i>IEEE Trans Biomed Eng</i> 2008 Feb;55(2 Pt 1):755-64. Duchesne S, Caroli A, Geroldi C, Barillot C, Frisoni GB, Collins DL. MRI-based automated computer classification of probable AD versus normal controls. <i>IEEE Trans Med Imaging</i> 2008 Apr;27(4):509-20. Lohscheller J, Eysholdt U, Toy H, Dollinger M. Phonovibrography: mapping high-speed movies of vocal fold vibrations into 2-D diagrams for visualizing and analyzing the underlying laryngeal dynamics. <i>IEEE Trans Med Imaging</i>. 2008 Mar;27(3):300-9. Meyer FG, Shen X. Classification of fMRI time series in a low-dimensional subspace with a spatial prior. <i>IEEE Trans Med Imaging</i> 2008 Jan;27(1):87-98. Verhaeghe J, Van de Ville D, Khalidov I, D’Asseler Y, Lemahieu I, Unser M. Dynamic PET reconstruction using wavelet regularization with adapted basis functions. <i>IEEE Trans Med Imaging</i> 2008;27(7):943-59.

Appendix: Content Summaries of Selected Best Papers for the IMIA Yearbook 2009, Section Signal, Sensor and Imaging Informatics*

Dejnabadi H, Jolles BM, Aminian K

A new approach for quantitative analysis of inter-joint coordination during gait
IEEE Trans Biomed Eng 2008;55(2):755-64

Quantitative analysis of the coordination in human gait can provide innovative tools for assessing recovery after a surgical intervention. This can help with the evaluation of the balance of the elderly and even improve performance in sports [14]. Dejnabadi et al. propose a parametric model for the relationships among the lower limb joint motions. Gait patterns in signals of five sensor modules (consisting of two accelerometers and one gyroscope each) are learned using harmonic analysis, principal component analysis, and artificial neural networks. The trained model, fed by only two control parameters (cadence and stride length) predicts the corresponding gait waveform. Based on the differences between predicted and actual gait patterns, a coordination score is computed at various walking speeds.

Verhaeghe J, Van de Ville D, Khalidov I, D'Asseler Y, Lemahieu I, Unser M

Dynamic PET reconstruction using wavelet regularization with adapted basis functions
IEEE Trans Med Imaging 2008;27(7):943-59

Dynamic positron emission tomography (PET) enables real-time monitoring of the three-dimensional distribution of a contrast agent within the human body, providing spatio-temporal assessment of the functionality of the observed organ [15,16]. Tomographic reconstructions from the initial data acquisition system is challenging due to the low temporal resolution. In the paper of Verhaeghe et al. the spatio-temporal reconstruction is carried out in the wavelet domain and

allows for controlling the trade-off between regularity and precision. A tailored separable wavelet basis consisting of distinct mother wavelet functions for the spatial and temporal domain yields sparse representations of the image that favour a high reconstructed signal to noise ratio (SNR).

Duchesne S, Caroli A, Geroldi C, Barillot C, Frisoni GB, Collins DL

MRI-based automated computer classification of probable AD versus normal controls
IEEE Trans Med Imaging 2008;27(4):509-20

At an advanced stage, neurodegenerative diseases such as Alzheimer's dementia (AD) alter visual appearance of brain tissue in magnetic resonance imaging (MRI) [17]. This provides the opportunity for computerized quantification and automatic detection of abnormal tissue to assist neuroradiologists in the diagnosis workup [18]. In the paper of Duchesne et al. automatic categorization of MRI data from patients with and without AD is carried out linked with the clinical conditions (images with varying acquisition parameters and using a leave-one-patient-out cross-validation). Image features are derived from a comparative methodology that computes the determinant of the Jacobian matrix applied on a deformation field between selected volumes of interest chosen from the image to be classified and a reference image. A 92% accuracy is achieved using a support vector machine classifier on 150 patients (75 AD and 75 normal controls).

Lohscheller J, Eysholdt U, Toy H, Dollinger M
Phonovibrography: mapping high-speed movies of vocal fold vibrations into 2-D diagrams for visualizing and analyzing the underlying laryngeal dynamics

IEEE Trans Med Imaging 2008;27(3):300-9

Lohscheller et al. propose a comprehensive framework for quantifying vocal fold vibrations. Cameras with high frame rates capture images of the laryngeal using a standardized protocol. The segmented edges of vibrating vocal folds are mapped to a 2D image on which the time is represented on the abscissa and the deformation of the vocal folds on the ordinate. The obtained diagram is denoted Phonovibrogram (PVG) by the authors.

Based on a normalised PVG, a unique representation of the PVG geometry is described in terms of a set of six angles denoting closing and opening of the vocal folds at given locations and a derived symmetry measure. Normal versus dysphonic subjects showed very distinct values of the symmetry parameter.

Meyer FG, Shen X

Classification of fMRI time series in a low-dimensional subspace with a spatial prior
IEEE Trans Med Imaging 2008;27(1):87-98

Functional MRI (fMRI) enables the tracking of hemodynamic responses related to a neuronal activity during a mental action. Most of the models used to reconstruct spatio-temporal (4D) datasets consider temporal and spatial dimensions separately and assume that the fMRI signal can be represented as a linear combination of the stimulus time-series and the physiological processes, which is not the case in reality [19]. In the paper of Meyer et al. the fMRI signal is nonlinearly projected onto a low-dimensional subspace composed of a Gaussian mixture model of the distributions of wavelet packet coefficients. The resulting subspace allows better separation between activated versus non-activated voxels (volume elements). A spatial prior using Markov random fields is introduced based on the assumption that activated regions are connected. A validation with realistic and synthetic data shows increased performance compared to linear methods.

Dam EB, Fletcher PT, Pizer SM

Automatic shape model building based on principal geodesic analysis bootstrapping
Med Image Anal 2008;12(2):136-51

Shape modelling has received a growing attention in medical image analysis [20] over the past few decades. Dam et al. propose an iterative method for model building from a collection of training shapes. Starting from a generic shape model, the bootstrap method based on principal geodesic analysis converges to a mean model and its major modes of variation, enabling a gradual capture of the shape variations among training samples. Validation on artificial data as well as manually segmented prostates and cartilage sheets of the knee show rapid convergence to the target shapes.

* The complete papers can be accessed in the Yearbook's full electronic version, provided that permission has been granted by the copyright holder(s).