Sensors, Medical Images and Signal Processing:

Exploring Multi-Dimensional Medical Data

A Depeursinge[1], H. Müller[1,2], Managing Editors for the IMIA Yearbook Section on Sensor, Signal, and Imaging Informatics
[1]Medical Informatics Service, University Hospitals and University of Geneva, Switzerland
[2]University of Applied Sciences Western Switzerland (HES SO), Sierre, Switzerland

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

Geissbuhler A, Kulikowski C, editors. IMIA Yearbook of Medical Informatics 2009. Methods Inf Med 2009;

Introduction

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 OsiriX[1] 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 to 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.

Trends Analysis

The best paper selection of articles for the section '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 and sensors (see Table 2), which highlights the current trend towards the use of medical images to support diagnosis.

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: Keyword 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

1 http://www.osirix-viewer.org/

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 'Sensor, Signal, and Imaging Informatics'. The articles are listed in alphabetical order of the first author's surname.

Dejnabadi H, Jolles BM, Aminian K, A new approach for quantitative analysis of inter-joint coordination during gait, IEEE Trans Biomed Eng, 55(2):755-64, 2008.
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;27(7):943-59, 2008.
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;27(4):509-20, 2008.
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; 27(3):300-9, 2008.
Meyer FG, Shen X, Classification of fMRI time series in a low-dimensional subspace with a spatial prior, IEEE Trans Med Imaging; 27(1):87-98, 2008.
Dam EB, Fletcher PT, Pizer SM, Automatic shape model building based on principal geodesic analysis bootstrapping, Med Image Anal;12(2):136-51, 2008.

Conclusions and Outlook

The best paper selection for the Yearbook section 'signal, sensor, and imaging informatics' can by no means reflect the broadness of the field. An extremely large number of papers were reviewed and even the initial selection of over 100 target articles was hard to make. Reducing this selection to only 17 for a detailed review was even harder. 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. Up-to-date information about current and future issues of the IMIA Yearbook is available at http://www.schattauer.de/index.php?id=1384.

Acknowledgements

We greatly acknowledge the support of Martina Hutter and of the reviewers in the selection process of the IMIA Yearbook.

References

1. Dejnabadi H, Jolles BM, Aminian K, A new approach for quantitative analysis of inter-joint coordination during gait, IEEE Trans Biomed Eng, 55(2):755-64, 2008.
2. Woo HS, Kim WS, Ahn W, Lee DY, Yi SY, Haptic interface of the KAIST-Ewha colonoscopy simulator, IEEE Trans Inf Technol Biomed;12(6):746-53, 2008.
3. Gutiérrez D, Nehorai A, Array response kernels for EEG and MEG in multilayer ellipsoidal geometry, IEEE Trans Biomed Eng;55(3):1103-11, 2008.
4. Friman O, Volosyak I, Graser A. Multiple channel detection of steady-state visual evoked potentials for brain-computer interfaces. IEEE Transactions on Biomedical Engineering, 2007;54(4):742-50.
5. Zheng JW, Zhang ZB, Wu TH, Zhang Y. A wearable mobihealth care system supporting real-time diagnosis and alarm. Med Biol Eng Comput 2007;45(9):877-85.
6. Müller H, Sensors, Signals, and Images in Medical Informatics: Progress and Evaluation, IMIA Yearbook of Medical Informatics 2008, supplement of Methods of Information in Medicine, volume 3(1), page 64, 2008.
7. 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;27(4):509-20, 2008.
8. 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; 27(3):300-9, 2008.
9. 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;27(7):943-59, 2008.
10. Meyer FG, Shen X, Classification of fMRI time series in a low-dimensional subspace with a spatial prior, IEEE Trans Med Imaging; 27(1):87-98, 2008.
11. Geissbuhler A, Haux R, Kulikowski CA, IMIA Yearbook of Medical Informatics 2008, supplement of Methods of Information in Medicine, volume 3(1), 2008
12. Geissbuhler A, Haux R, Kulikowski CA, Yearbook of Medical Informatics 2007, Methods of Information in Medicine volume 46 supplement 1, 2007.
13. Kulikowski C, Haux R, IMIA Yearbook of Medical Informatics 2006, supplement of Methods of Information in Medicine, volume 45 supplement 1, 2006.
14. Chau T, A review of analytical techniques for gait data. Part 1: Fuzzy, statistical and fractal methods, Gait Posture. 2001 Feb;13(1):49-66.
15. Choi Y, Huang SC, Hawkins RA, Kuhle WG, Dahlbom M, Hoh CK, Czernin J, Phelps ME, Schelbert HR, A simplified method for quantification of myocardial blood flow using nitrogen-13-ammonia and dynamic PET, J Nucl Med. 1993 Mar;34(3):488-97.
16. Smith GS, Kramer E, Hermann C, Ma Y, Dhawan V, Chaly T, Eidelberg D, Serotonin Modulation of Cerebral Glucose Metabolism in Depressed Older Adults, Biol Psychiatry. 2009 Apr 14.
17. Ashburner J, Csernansky JG, Davatzikos C, Fox NC, Frisoni GB, Thompson PM, Computer-assisted imaging to assess brain structure in healthy and diseased brains, Lancet Neurol. 2003 Feb;2(2):79-88.
18. Freeborough PA, Fox NC, MR image texture analysis applied to the diagnosis and tracking of Alzheimer's disease, IEEE Trans Med Imaging. 1998 Jun;17(3):475-9.
19. Logothetis NK, Pauls J, Augath M, Trinath T, Oeltermann A, Neurophysiological investigation of the basis of the fMRI signal, Nature. 2001 Jul 12;412(6843):150-7.
20. McInerney T, Terzopoulos D, Deformable models in medical image analysis: a survey, Med Image Anal. 1996 Jun;1(2):91-108.

Correspondence to:
Prof. Dr. Henning Müller, HES SO Valais, TechnoArk 3, 3960 Sierre, Switzerland,

Appendix: Content Summaries of Selected Best Papers for the IMIA Yearbook 2007, Section Bioinformatics*

Dejnabadi H, Jolles BM, Aminian K,
A new approach for quantitative analysis of inter-joint coordination during gait,
IEEE Trans Biomed Eng, 55(2):755-64, 2008.

Quantitative analysis of the coordination in human gait can provide innovative tools for assessing recovery after a surgical intervention. This can help with 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;27(7):943-59, 2008.

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 favours 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;27(4):509-20, 2008.

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 tissues 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; 27(3):300-9, 2008.

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; 27(1):87-98, 2008.

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;12(2):136-51, 2008.

Shape modelling has received a growing attention in medical image analysis [20] over the past more than ten years. 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.