Sensors, Medical Images and Signal Processing:
Comprehensive Multi-modal Diagnosis Aid Frameworks

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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 2010.

Results: Current research in the field of sensor, 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. Research published in 2009 was characterized by the emergence of mature computerized diagnosis aid frameworks with assessment of input and output quality. The purpose of these systems is clearly to bring new image and signal interpretation tools to clinicians.

Keywords

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

Introduction

The content of MedLine/PubMed containing articles from 2009 was queried while searching for excellent research in the fields of sensors, signals and imaging. Three major research topics appeared clearly from the query results:

- development of multi-modal, case-based reliable computerized diagnosis aid tools with assessment of confidence scores;
- video and multidimensional image visualization and analysis;
- sensors and mobile systems for ubiquitous monitoring the patient's vital signs.

The three research trends are discussed in the following sections and the associated five most representative high quality papers listed in Table 1 are summarized in the appendix.

Reliable Case-Based Computerized Diagnosis Aid Tools

During the passed year, developments in sensors, signals and imaging in the medical domain were clearly driven by the need for computerized diagnosis aid tools (CAD) for the interpretation of the growing amount of digital information in modern hospitals. Up to now, major limitations in performance of CAD systems in the medical domain were partly due the fact that these were based on one single modality or source

of information, meaning that either if the quality of input information or sensitivity/specificity measures are below a given threshold, the CAD becomes unusable. This instability of CAD performance discredits tools in the eyes of the clinicians as they still have to screen the entirety of the examination under investigation. This inconvenience motivated the interest to develop CAD systems based on several sources of information (i.e. case-based) [1-4] and that are able to provide a level of confidence for their output [5]. Some of these multi-modal diagnosis aid frameworks also address the problem of input quality assessment in [1] for signals and in [2] for images.

Video and Multidimensional Imaging

As already observed in 2009 [6], the growing interest for the analysis of multi-dimensional imaging data was confirmed in 2010 with several publications in video analysis [7,8] and 4D imaging (3D+time) [9]. These novel types of information media require more than ever efficient ways for visualising and analyzing large amounts of data. A remarkable example is the transformation of several minutes of wireless capsule endoscopic videos into a 2D image in [7] that allows having an overview of the whole exam at a glance.

Ubiquitous Patient Monitoring

Care of developing increasingly portable tiny sensors with an aim of ubiquitous patient monitoring was a clearly observed trend in 2010. The recent developments of wireless communication devices such as mobile phones that include powerful central processing units (CPU) enable ubiquitous monitoring of the vital signs to possibly detect as early as possible anomalies in the patients' health. Publications on this topic were found with various application domains such as psycho-physiological state monitoring during a work ability rehabilitation program in [4]; real-time detection of apnoeas on a personal digital assistant (PDA) in [10]; development of an in-ear micro-optic reflective sensor for monitoring heart activity in [11]; and quantification of low-oxygen-saturation in arterial and venous circulation in [12].

Conclusions and Outlook

The best paper selection for the Yearbook section 'Sensor, signal 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 14 for a detailed review was even harder. The final five articles selected represent well the current research trends of the domain of sensors, signals and imaging informatics with a strong weight on comprehensive multi-modal diagnostic aid frameworks. Up-to-date information about current and future issues of the IMIA Yearbook is available at http://www.schattauer.de/de/magazine/uebersicht/zeitschriften-a-z/imia-yearbook/objectives-contents-formats.html.

Table 1 Best paper selection of articles for the IMIA Yearbook of Medical Informatics 2010 in the section 'Sensor, signal, and imaging informatics'. The articles are listed in alphabetical order of the first author's surname.

Section

Sensor, Signal and Imaging Informatics

- Clifford GD, Long WJ, Moody GB, Szolovits P. Robust parameter extraction for decision support using multimodal intensive care data. Philos Transact A Math Phys Eng Sci 2009;367 (1887):411-29.
- Deguchi D, Mori K, Feuerstein M, Kitasaka T, Maurer CR Jr, Suenaga Y, Takabatake H, Mori M, Natori H. Selective image similarity measure for bronchoscope tracking based on image registration. Med Image Anal 2009;13(4):621-33.
- Niemeijer M, Abramoff MD, van Ginneken B. Information fusion for diabetic retinopathy CAD in digital color fundus photographs. IEEE Trans Med Imaging 2009;28(5):775-85.
- Schoevers J, Scheffer C, Dippenaar R. Low-oxygen-saturation quantification in human arterial and venous circulation. IEEE Trans Biomed Eng 2009; 56(3):846-54.
- Szczypiński PM, Sriram RD, Sriram PV, Reddy DN. A model of deformable rings for interpretation of wireless capsule endoscopic video. Med Image Anal 2009;13(2):312-24.

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8. Deguchi D, Mori K, Feuerstein M, Kitasaka T, Maurer CR Jr, Suenaga Yet al. Selective image similarity measure for bronchoscope tracking based on image registration. Med Image Anal 2009; 13(4):621-33.
9. Zhao F, Zhang H, Wahle A, Thomas MT, Stolpen AH, Scholz TD, et al. Congenital aortic disease: 4D magnetic resonance segmentation and quantitative analysis. Med Image Anal 2009;13(3):483-93.
10. Burgos A, Goñi A, Illarramendi A, Bermúdez J. Real-Time Detection of Apneas on a PDA. IEEE Trans Inf Technol Biomed 2009.
11. Vogel S, Hülsbusch M, Hennig T, Blazek V, Leonhardt S. In-ear vital signs monitoring using a novel microoptic reflective sensor. IEEE Trans Inf Technol Biomed 2009;13(6):882-9.
12. Schoevers J, Scheffer C, Dippenaar R. Low-oxygen-saturation quantification in human arterial and venous circulation. IEEE Trans Biomed Eng 2009;56(3):846-54.
13. Usher D, Dumsky M, Himaga M, Williamson T, Nussey S, Boyce J. Automated detection of diabetic retinopathy in digital retinal images: A tool for diabetic retinopathy screening. Diabet Med 2004;21:84–90.
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Appendix: Content Summaries of Selected Best Papers for the IMIA Yearbook 2010, Section Sensor, Signal and Imaging Informatics*

Clifford GD, Long WJ, Moody GB, Szolovits P

Robust parameter extraction for decision support using multimodal intensive care data

Philos Transact A Math Phys Eng Sci 2009;367(1887):411-29

Major challenges of computerized decision support based on multiple data sources within the intensive care unit (ICU) are identified and the related literature is reviewed and discussed. Methods for robust feature extraction and information fusion from several signals recorded from bedside monitors (e.g. electrocardiogram, arterial blood pressure, photoplethysmograph, etc.) are proposed based on signal quality analysis, noise reduction, missing data management and data fusion using the Kalman gain to assess trustability of information sources. Semi-automatic extraction of diseases and procedures from free text in discharge summaries based on corpuses of concepts is proposed to provide labels and annotations to ICU data.

Deguchi D, Mori K, Feuerstein M, Kitasaka T, Maurer CR Jr, Suenaga Y, Takabatake H, Mori M, Natori H

Selective image similarity measure for bronchoscope tracking based on image registration

Med Image Anal 2009;13(4):621-33

Methods for localizing bronchoscopes in the rib cage are proposed based on

image similarity between real and virtual bronchoscopic images. Virtual bronchoscopic images are obtained from chest x-ray computed tomography data. Real bronchoscopic images are divided into overlapping blocks and the image similarity is computed using a selection of blocks showing characteristic structures (e.g. bifurcations). This selection allows removing parts of the images containing bubble patterns that will not be present in virtual bronchoscopic images. The image similarity is computed using a modified mean squared error (MoMSE) with the remaining blocks. The minimum value of MSE is found by optimising six parameters: a translation in x-, y- or z-direction and a rotation around x-, y- or z-axis. The minimum MSE value is used as similarity value between the real and virtual image series. This method was able to track up to 1600 bronchoscopic video frames (about 50 seconds) without using external positioning sensors.

Niemeijer M, Abramoff MD, van Ginneken B

Information fusion for diabetic retinopathy CAD in digital color fundus photographs

IEEE Trans Med Imaging 2009;28(5):775-85

Case-based computer-aided diagnosis (CAD) for diabetic retinopathy in digital fundus photographs is investigated. Each image of one patient is separately analyzed by a dedicated CAD subsystem, and the global output of the CAD is based on the fusion of all subsystems. The CAD subsystem outputs consist of two sets of candidate lesions (i.e. microaneurysms, hemorrhages or exudates, drusen, ...) and an image quality measure. The final system outputs an estimation of the likelihood that the case is abnormal only if the quality of the images is not too low to warrant automatic analysis. Four fusion strategies are compared for merging the outputs of the CAD subsystems to compute the final result:

- the output is calculated from custom measures based on the poste-

rior probabilities delivered by the subsystems (i.e. maximum, sum, average,...),
- likelihood distribution normalization is applied before using the maximum value among probabilities and image quality as output,
- multi-threshold fusion (see [13]): one threshold on image quality measures determines if an image is ungradable and two thresholds based on lesion posterior probabilities sets if an exam is normal or suspicious and a voting is carried out among the subsystems' outputs,
- supervised fusion: a k-nearest neighbour classifier learns from the outputs of each CAD subsystem.

A validation of the system based on a collection of 15,000 patients with several images each shows that the combination of the likelihood distribution normalization and supervised fusion allow excellent performance with an area under the receiver operator characteristic curve above 0.88.

Schoevers J, Scheffer C, Dippenaar R

Low-oxygen-saturation quantification in human arterial and venous circulation

IEEE Trans Biomed Eng 2009;56(3):846-54

An innovative method is proposed for measuring oxygen in arterial and venous circulation under low-oxygen-saturation conditions. An artificial pulse is induced in a photoplethysmograph by means of a peristaltic action that is generated pneumatically on the organ under investigation (i.e. an extended index finger). This allows having a pulsating behaviour in both arterial and venous circulation. As the value for arterial pulse oximetry can be obtained by means of empirical calibration curves (see [14]), the saturation value is then refined with a linear combination of both arterial and venous pulse oximetries relying on a novel principle of arterial-to-venous compliance ratio. The validation on 12 healthy volunteers allowed validating the arterial-to-venous ratio hypothesis,

which is promising for measuring blood oxygen saturation in low-saturation scenarios.

Szczypiński PM, Sriram RD, Sriram PV, Reddy DN

A model of deformable rings for interpretation of wireless capsule endoscopic video

Med Image Anal 2009;13(2):312-24

Computer-aided diagnosis based on a model of deformable rings (MDR) is proposed for the detection of abnormalities in the small intestine using wireless capsule endoscopic (WCE) videos. The MDR allows registering consecutive WCE video frames and computing a motion descriptor as well as a two-dimensional map of the internal surface of the digestive system. The MDR consists of a circular mesh of interconnected nodes. To preserve the arrangement of the nodes through video frames, the model incorporates an estimation of the tissue tension. The 2D map of the intestinal surface is built as follows. Each image frame is sampled along the outer ring to form the rows of the 2D map, where rows are put together according to their chronological order. The MDR is optimised and validated on an artificially created video where velocity and deformation properties are known. Features from MDR motion descriptors allowed an efficient discrimination of three motility patterns (motionless, smooth motion and rapid motion) with an accuracy of more that 90%. A validation with 10 WCE videos interpreted by two gastroenterology experts showed that areas of bleeding, ulceration and obscuring froth can be efficiently detected from the 2D maps and structural or functional anomalies can be detected using a velocity plot. At last, it is shown that the 2D map provides a summarized overview of the WCE videos that increased of 20% the number of lesions detected when compared to conventional WCE video interpretation.