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Sensor, Signal, and Imaging Informatics in 2017

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Summary

Objective: To summarize significant contributions to sensor, signal, and imaging informatics literature published in 2017.
Methods: PubMed® and Web of Science® were searched to identify the scientific publications published in 2017 that addressed sensors, signals, and imaging in medical informatics. Fifteen papers were selected by consensus as candidate best papers. Each candidate article was reviewed by section editors and at least two other external reviewers. The final selection of the four best papers was conducted by the editorial board of the International Medical Informatics Association (IMIA) Yearbook.
Results: The selected papers of 2017 demonstrate the important scientific advances in management and analysis of sensor, signal, and imaging information.
Conclusion: The growth of signal and imaging data and the increasing power of machine learning techniques have engendered new opportunities for research in medical informatics. This synopsis highlights cutting-edge contributions to the science of Sensor, Signal, and Imaging Informatics.

Keywords

Signal processing; biomedical imaging; deep learning; radiomics

Introduction

The discipline of "Sensor, Signal, and Imaging Informatics" (SSII) continues to grow and forms a vibrant area of scientific growth within the broader field of biomedical informatics. Advances in sensor technology and growing adoption of wearable devices have yielded greater quantities and varieties of signal and sensor data. Medical imaging has been a dynamic field for applications of automated approaches for image segmentation, classification, and diagnosis. Advances in machine learning and the rise of deep learning techniques in a wide spectrum of clinical applications have had significant impact in fields related to signals and imaging. The large scale and high dimensionality of signal and imaging datasets make them well suited for machine learning approaches to identify spatial and temporal patterns.

The many important contributions of medical informatics research in the fields of medical signals and imaging are illustrated by the publications from 2017 reviewed here. The four articles selected as 2017 best papers demonstrate the high quality of research conducted in this area. In addition, the survey paper by Nagarajan et al. reviews the application of deep learning techniques on biosignals [1].

About the Paper Selection

To compile a list of eligible papers, we conducted a search of the PubMed/Medline® and Web of Science® electronic databases in December 2017 to identify peer-reviewed journal articles published in 2017, in the English language and related to SSII research in medical informatics. As in previous years, a wide spectrum of MeSH® keywords and topics was considered, including image and signal processing, pattern recognition and information extraction, telemedicine, sensor monitoring, and computer aided diagnosis. Keywords used included both free-text and coded keywords. PubMed/Medline® was queried to test keywords in an iterative process. Consequently, two queries were built: one based on MeSH® terms used to search the major topics in the PubMed/Medline® database, the second one based on free-text keywords searched in titles or abstracts through PubMed/Medline® and Web of Science® databases. We also added keywords that had been trending this past year such as deep learning. One of the three section editors (WH) performed the searches. In addition to the search of electronic databases, manual searches of key themes were performed in leading journals of biomedical informatics, imaging informatics, and imaging specialty journals, such as *Journal of the American Medical Informatics Association*, *Journal of Digital Imaging,* and *Radiology*.

The search results were reconciled into a single list of 441 papers. The three section editors independently screened the titles and abstracts to identify relevant papers. The section editors classified the papers into three categories: accepted, rejected, or pending. They then reviewed in detail the accepted and pending full-text articles to finally reach a consensus list of 15 candidate papers. Papers were considered according to their originality, scientific and/

or clinical impact, and scientific quality. In accordance with the IMIA Yearbook selection process, the 15 candidate best papers were evaluated in detail by the section editors and by at least two additional external reviewers. Four papers were selected as best papers (Table 1). A content summary of the selected best papers can be found in the appendix of this synopsis.

Results

Machine learning has been widely applied to discern patterns in biomedical images and signal data, and 2017 has seen further advances in this area. Deep learning – a particular form of machine learning that typically applies multiple layers of neural networks – has been applied to numerous challenges in medical imaging. Larson et al. developed and tested a deep-learning convolutional neural network model for the interpretation of children's hand radiographs; their model estimated skeletal maturity with accuracy similar to that of expert radiologists [2]. In patients with suspected acute stroke, the time to diagnosis and treatment is critical to preserve brain function. Prevedello et al. applied deep learning to identify hemorrhage, mass effect, or hydrocephalus on head computed tomographic (CT) examinations, and achieved 90% sensitivity and 85% specificity [3]. Dawes et al. applied semi-automated segmentation of magnetic resonance (MR) images of the heart to create a three-dimensional model of right ventricular motion, from which their machine-learning survival model predicted patient outcomes independent of conventional risk factors in patients with newly diagnosed pulmonary hypertension [4]. Deep learning is an emerging field in the analysis of histological images, as well. Sharma et al. explored deep learning methods for computer-aided classification in hematoxylin and eosin (H&E)-stained histopathological whole slide images of gastric carcinoma to classify cancers based on immunohistochemical response and to detect tumor necrosis [5].

Radiomics is an emerging field that extracts quantitative data from radiological images to enable phenotypic profiling of tumors. Extracting that information

Table 1 Best paper selection of articles for the IMIA Yearbook of Medical Informatics 2018 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

- Bote JM, Recas J, Rincon F, Atienza D, Hermida R. A modular low-complexity ECG delineation algorithm for real-time embedded systems. IEEE J Biomed Health Inform 2018;22(2):429-41.
- Grossmann P, Stringfield O, El-Hachem N, Bui MM, Rios Velazquez E, Parmar C, Leijenaar RT, Haibe-Kains B, Lambin P, Gillies RJ, Aerts HJ. Defining the biological basis of radiomic phenotypes in lung cancer. ELife 2017;6.
- Larson DB, Chen MC, Lungren MP, Halabi SS, Stence NV, Langlotz CP. Performance of a deep-learning neural network model in assessing skeletal maturity on pediatric hand radiographs. Radiology 2018;287(1):313-22.
- Satija U, Ramkumar B, Manikandan MS. Automated ECG noise detection and classification system for unsupervised healthcare monitoring. IEEE J Biomed Health Inform 2018;22(3):722-32.

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requires software tools that yield reliable segmentation of tumors and consistent imaging features to overcome the inherent inter-rater and intra-rater variability. Lee et al. evaluated the reliability and quality of radiomic features in glioblastoma using semi-automated tumor segmentation software [6]. Grossman et al. used radiomic information to identify relationships between imaging features, immune response, inflammation, and survival in patients with lung cancer [7].

Radiology procedure codes are fundamental to most radiology workflows, such as ordering, scheduling, billing, and image interpretation. Wang et al. described an extensible standardized nomenclature that harmonizes the Radiological Society of North America (RSNA) RadLex Playbook with the Logical Observation Identifiers Names and Codes (LOINC) standard to promote interoperability of imaging information [8]. As public collections of medical images become increasingly available for machine-learning investigations, such imaging data can engender privacy concerns. In particular, Parks and Monson found that individuals could be identified with moderately high probability from large collections of photographs based on the facial images extracted from medical image data [9]. Thus, the facial image data inherent in CT and MRI data may need to be considered as potentially identifiable information.

Information and communication technologies such as smart phones, smart watches, smart glasses, and portable health monitoring devices have made mobile

health (mHealth) an emerging research area. Wearable biomedical sensors can provide a wealth of data; their increased use promises to herald significant advances in health monitoring. Despite numerous advances, battery runtime remains a critical limitation for the practical use of wearable sensors. Tobola et al. described a "self-powered" sensor platform that incorporates an efficient body heat harvester [10]. Coronary heart disease is a leading cause of premature death worldwide, and there is a growing demand for a reliable system to detect critical cardiac abnormalities that lead to sudden death. Sahoo et al. described a novel cardiac data acquisition method for combined analysis of electrocardiography (ECG) and multi-channel seismocardiography (SCG) data that achieved 88% accuracy as an early warning system [11].

Monitoring of sensor devices and analysis of signal data require careful attention to eliminate noise and correctly delineate the meaningful information. Satija et al. described a novel unified framework for automatic detection, localization, and classification of single and combined ECG noises, which achieved an average sensitivity of 99.12% and specificity of 98.56% [12]. Bote et al. presented a new, modular, low-complexity algorithm to perform highly accurate real-time ECG analysis on resource-constrained embedded systems. Such a platform could be useful in ultralow-power mobile or wearable devices [13]. ECG data often are accompanied by high-frequency electromyographic (EMG) noise, which is difficult to filter due to overlapping frequency spectra. Christov et

al. developed a dynamic filter that strongly suppressed EMG noise while preserving ECG high-frequency components [14]. Te et al. developed a novel signal analysis method to identify the origin of idiopathic right ventricular outflow tract ventricular tachycardia (RVOT-VT) during sinus rhythm; their approach predicted the VT origins with 92% sensitivity and 78% specificity [15]. Sleep-disordered breathing is both a clinical and a social problem. Mobile health sensor technologies were explored to simplify screening and diagnosis. Młyńczak et al. investigated the sensitivity and specificity of a novel wireless system in detecting breathing and snoring episodes during sleep [16].

Conclusions and Outlook

The selected papers provide a small sampling of the many efforts that are advancing the science of informatics in healthcare. The growing volumes of biomedical signal data and medical imaging, increasingly powerful approaches to analyze and classify these data, and advances in computing power have created new opportunities to support precision medicine. In future, we expect more applications and systems integrating the novel sensors into signal and image analysis pipelines.

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Appendix: Content Summaries of the Selected Best Papers for the IMIA Yearbook 2018 "Signals, Sensors, and Imaging Informatics" Section

Bote JM, Recas J, Rincon F, Atienza D, Hermida R

A modular low-complexity ECG delineation algorithm for real-time embedded systems

IEEE J Biomed Health Inform
2018;22(2):429-41

The electrocardiogram (ECG) signal is essential to monitor the heart and evaluate its condition. Most techniques for automated ECG analysis can be computationally intensive, which limits their applicability in low-power wearable devices. The authors present a new modular, low-complexity algorithm that requires a reduced number of operations per second and smaller memory footprint to perform real-time ECG analysis on resource-constrained embedded systems. The system delineated and located the peaks and boundaries of the different ECG waves, such as the P wave, the QRS complex, and the T wave with reduced mathematical complexity. The algorithm achieved similar or better accuracy than other more advanced and computationally intensive state-of-the-art techniques, and could be useful for use in ultralow-power mobile or wearable devices.

Grossmann P, Stringfield O, El-Hachem N, Bui MM, Rios Velazquez E, Parmar C, Leijenaar RT, Haibe-Kains B, Lambin P, Gillies RJ, Aerts HJ

Defining the biological basis of radiomic phenotypes in lung cancer

ELife 2017;6:e23421

Radiomics is an emerging field that aims to extract specific quantitative features from medical images to define a patient's "imaging phenotype." In cancer imaging, radiomics has been associated with several clinical endpoints, but the complex relationships of radiomics features, clinical factors, and tumor biology are largely unknown. The authors identified a relationship between imaging features, immune response, inflammation, and survival, which was validated by immunohistochemical staining. Several imaging features showed predictive value for activity of specific pathways: for example, intra-tumor heterogeneity predicted RNA polymerase transcription, and intensity dispersion predicted autodegradation of an ubiquitin ligase. The model achieved the highest prognostic accuracy from the combination of radiomic, genetic, and clinical data.

Larson DB, Chen MC, Lungren MP, Halabi SS, Stence NV, Langlotz CP

Performance of a deep-learning neural network model in assessing skeletal maturity on pediatric hand radiographs

Radiology 2018; 287(1):313-22

Assessment of radiographic "bone age" typically has been a manual task that requires reference to a standard atlas of children's hand radiographs. The authors automated this process using a collection of more than 14,000 radiographs and corresponding clinical reports to train and test their model. They found that a convolutional neural network model can estimate skeletal maturity with an accuracy similar to that of an expert radiologist and to existing automated models. The authors' results provide an important example that suggests that deep learning models may be broadly applicable to a variety of diagnostic imaging tasks without requiring specialized subject matter knowledge or image-specific software engineering. The dataset from this project was used subsequently to support the Radiological Society of North America (RSNA) 2017 Pediatric Bone Age Challenge, in which more than 230 teams competed.

Satija U, Ramkumar B, Manikandan MS

Automated ECG noise detection and classification system for unsupervised healthcare monitoring

IEEE J Biomed Health Inform
2018;22(3):722-32

Electrocardiogram (ECG) signals are often corrupted by noise and artifacts, which can make it almost impossible to analyze the morphology and beat-to-beat interval of the signals. However, most existing ECG analysis systems are designed to handle relatively noise-free ECG signals. The authors proposed a novel framework to automatically detect, localize, and classify single and combined ECG noise. Evaluation on five benchmark ECG databases showed an average sensitivity of 99.12% and specificity of 98.56% to detect the presence of noise. The authors' approach achieved better noise detection and classification than the current state-of-the-art methods, and also accurately localized short bursts of noise that were present in ECG signals.