Physiological Measurement

IPEM Institute of Physics and Engineering in Medicine

ACCEPTED MANUSCRIPT

Focus on advances in electrical impedance tomography

To cite this article before publication: Richard H Bayford *et al* 2018 *Physiol. Meas.* in press https://doi.org/10.1088/1361-6579/aad93e

EDITORIAL

Overview

This focus collection aims to highlight recent advances in electrical impedance tomography (EIT) including novel developments in hardware, algorithms, and clinical applications. It is an exciting time for the EIT community as the number of commercial EIT systems and clinical trials evaluating this technology continues to grow. This collection provides an opportunity for the EIT community to report on its broadening outlook into new areas of clinical application and new technologies and on its expanding interaction with the wider medical industry community focusing on commercializing EIT.

EIT continues to provide researchers with new challenges and attract more researchers into this field of study. The high quality of the research papers in this focus issue demonstrates the significant advances that continue to be made in the field. It is also encouraging to see an increase in the number of industry companies fabricating EIT imaging systems and the expanding clinical interest in EIT. At present there are three companies producing and distributing clinically-approved machines. Although considerable effort has been undertaken in EIT, many new innovations do not find their way into clinical applications; the translation of extracting meaningful clinical parameters from images remains a key challenge. Despite these challenges, the hardware, algorithms and clinical applications included in this focus issue represent a number of innovative developments that have the potential to find their way to clinic.

Advances in EIT Hardware

EIT hardware was initially developed to provide a generalizable data acquisition platform. There is a strong motivation to design EIT systems with specific clinical applications in mind to ensure the highest fidelity impedance signatures are captured to meet a specific clinical need. As an example, *Sophocleous et al* describes a novel textile-based interface that improves electrode contact with the neonatal chest to optimize thoracic imaging; neonate's skin can be damaged by adhesive electrodes and this development represents a compromise to achieve the measurement sensitivity required in this population of patients. The emerging field of neuronal imaging requires high-speed EIT systems to capture fast temporal dynamics of neuronal activity; *Dowrick et al* describe a phase division multiplexed system that provides enhances temporal resolution. As new hardware is being designed to meet the requirements for specific clinical applications it is paramount that imaging phantoms that accurately mimic both the anatomic geometry and underlying tissue bioimpedance are developed to test and validate these imaging systems prior to clinical deployment. One such example of a novel phantom is the realistic pelvic phantom described by *Dunne et al*. for use in bladder fullness detection.

Advances in EIT Algorithms

The goal of EIT image reconstruction is to use sparse data typically recorded from the boundary of an anatomic site of interest and estimate the spatial distribution of the tissue bioimpedance within the bounded domain. Advances in both generalized approaches to optimizing image reconstruction and in clinical application-specific optimizations continue to be made. *Hamilton et al* describe a direct approach to 2D absolute image reconstruction using D-bar methods, which represents a robust, high-speed, non-iterative method to solving the EIT problem. Accurate modeling the anatomy of interest provides improved estimation of the internal electrical property distribution; *de Gelidi et al's* description of torso shape detection enables more accurate thoracic modeling for lung imaging. One approach to improving imaging sensitivity in open-domain applications is to acquire impedance measurements far from the electrode array; a fused-data approach is described by *Murphy et al* that couples measurements from an transrectal EIT probe with measurements recorded from a biopsy needle to improve prostate imaging. Finally, *Polydorides* presents a finite element model based image reconstruction algorithm that leverages a J-substitution approach for Lorentz force EIT.

Exploration of Clinical Applications

EIT continues to be explored for deployment in a variety of clinical applications ranging from dynamic lung and cardiac imaging to cancer imaging and more recently neural imaging. The most advanced clinical deployment of EIT remains in the thoracic imaging arena, where several clinical trials in Europe are underway. A variety of novel developments continue to be made to optimize thoracic imaging with many of them described in this focus issue. *Zhao et al* present a study that describes the influence of tidal volume and positive end-expiratory pressure on ventilation efficacy based on EIT monitoring of patients; studies like this highlight the value of using EIT to explore clinical questions. The need for respiratory-monitoring in neonatal populations is driving the Continuous Regional Analysis Device for neonate Lung (CRADL)(cradlproject.org) project; *Khodadad et al* describe three algorithms to optimize breath detection in this sensitive population of patients. *Mueller et al* show how EIT can be used to derive ventilation-perfusion index maps to specifically identify regions of air trapping in the lungs of cystic fibrosis patients. In addition to lung imaging, cardiac and vascular imaging within the thorax represents a unique, but challenging opportunity for EIT. *Braun et al* highlights the challenges in monitoring stroke volume and pulmonary arterial pressure and *Wodack et al* assesses the potential of detection thoracic vascularity using EIT. EIT-based applications in neural and intracranial imaging continue to be explored. *McDermott et al's* work in symmetric difference EIT is explicitly focused on detecting intracranial lesions for use in stroke assessment, while *Faulkner et al's* work characterizes the frequency response of rat brain impedance changes during evoked physiological activity. Finally, *Hope et al's* description of a model for using EIT for neuronal-prosthetic control represents a novel EIT-application that leverages the emerging field of EIT-based neuronal imaging.

Conclusion

Many of these new developments were presented at the 18th International Conference on Biomedical Applications of Electrical Impedance Tomography, which was held at Dartmouth College, Hanover, NH, US in June 2017. Authors of the 56 abstracts and 26 posters presented were invited to submit full-length papers to this focus collection. Of those submitted, this focus issue represents the most novel and exciting international research being conducted in Electrical Impedance Tomography. It is critical that advances in EIT hardware, reconstruction algorithms, and data analytics like the ones highlighted in this focus issue continue to be developed and optimized. Some of the most exciting work continues to stem from actual clinical deployments that highlight the benefits of EIT and direct the research community to address the challenges that remain in translating EIT to the clinic.

Richard Bayford, Middlesex University, UK

Prof Ryan Halter, Dartmouth College, US

References

Braun F, Proença M, Lemay M, Bertschi M, Adler A, Thiran JP and Solà J 2018 Limitations and challenges of EIT-based monitoring of stroke volume and pulmonary artery pressure *Physiol. Meas.* 39(1) 014003

Dowrick, T and Holder, D, 2018 Phase division multiplexed EIT for enhanced temporal resolution *Physiol. Meas. 39*(3) 034005

Dunne, E, McGinley, B, O'Halloran, M and Porter, E, 2018 A realistic pelvic phantom for electrical impedance measurement *Physiol. Meas. 39*(3) 034001

Faulkner, M, Hannan, S, Aristovich, K, Avery, J and Holder, D, 2018 Characterising the frequency response of impedance changes during evoked physiological activity in the rat brain *Physiol. Meas. 39*(3) 034007

de Gelidi, S, Seifnaraghi, N, Bardill, A, Tizzard, A, Wu, Y, Sorantin, E, Nordebo, S, Demosthenous, A and Bayford, RH, 2018 Torso shape detection to improve lung monitoring *Physiol. Meas.* 39(7) 074001

Hamilton, SJ, Mueller, JL and Santos, TR, 2018 Robust computation in 2D absolute EIT (a-EIT) using D-bar methods with the" exp" approximation *Physiol. Meas.* 39(6) 064005

Hope, J, Vanholsbeeck, F and McDaid, A, 2018 A model of electrical impedance tomography implemented in nerve-cuff for neural-prosthetics control *Physiol. Meas. 39*(4) 044002

Khodadad – Reference pending

McDermott, B, Porter, E, Jones, M, McGinley, B and O'Halloran, M, 2018 Symmetry difference electrical impedance tomography—a novel modality for anomaly detection *Physiol. Meas. 39*(4) 044007

Mueller, JL, Muller, P, Mellenthin, M, Murthy, R, Capps, M, Alsaker, M, Deterding, R, Sagel, SD and DeBoer, E, 2018 Estimating regions of air trapping from electrical impedance tomography data *Physiol. Meas. 39*(5) 05NT01

Murphy, EK, Wu, X and Halter, RJ, 2018 Fused-data transrectal EIT for prostate cancer imaging *Physiol. Meas. 39*(5) 054005

Polydorides, N, 2018 Finite element modelling and image reconstruction for Lorentz force electrical impedance tomography *Physiol. Meas. 39*(4) 044003

Sophocleous, L, Frerichs, I, Miedema, M, Kallio, M, Papadouri, T, Karaoli, C, Becher, T, Tingay, DG, van Kaam, AH, Bayford, R and Waldmann, AD, 2018 Clinical performance of a novel textile interface for neonatal chest electrical impedance tomography *Physiol. Meas. 39*(4) 044004

Wodack, KH, Buehler, S, Nishimoto SA, Graessler MF, Behem CR, Waldmann AD, Mueller B, Böhm SH, Kaniusas E, Thürk F and Maerz A, 2018 Detection of thoracic vascular structures by electrical impedance tomography: a systematic assessment of prominence peak analysis of impedance changes *Physiol. Meas. 39*(2) 024002

Zhao Z, Wang W, Zhang Z, Xu M, Frerichs I, Wu J and Moeller K 2018 Influence of tidal volume and positive end-expiratory pressure on ventilation distribution and oxygenation during one-lung ventilation *Physiol. Meas.* 39(3) 034003