Electrical Capacitance Tomography for Dynamic Process Imaging

Electrical capacitance tomography (ECT) is a technique to quantify the dielectric permittivity distribution in the interior of an object (e.g., a closed vessel) from external capacitance measurements. Comparing with conventional tomographic techniques, ECT has the advantages of higher portability, robustness, no radiation hazard, and low-cost. ECT has found numerous applications in the industry, e.g., measurement of gas/liquid and gas/solids flows in pipelines, detection of leakage from buried water pipes, etc. Since ionized species are created when fuel burns, ECT presents an effective metrological tool to monitor changes in the dielectric constant of the combustion volume, from which the relationship between the flame ionization and relative permittivity can be established. This provides the basis for ECT as a sensing method to quantify the spatiotemporal distribution of the flame inside the closed environment to gain insight into the governing mechanism in the combustion processes, without disturbing the process itself (see **Fig. 1**).

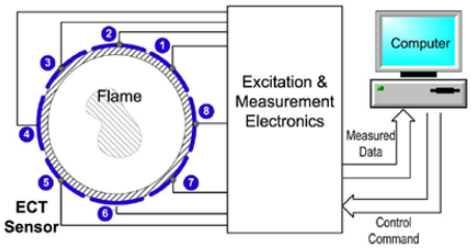

Fig. 1 Major components in an ECT system

Research in the Electromechanical Systems Laboratory (EMS) has led to the invention of a new method to improve the ECT imaging speed rate. Instead of the traditional time-sequential method where one excitation signal is applied to one electrode at a time, the Multiple Excitation Capacitance Polling (MECaP) method progressively applies an increasing number of multiple excitations to multiple electrodes, and measures the capacitance values simultaneously, thereby increasing the image scanning speed significantly [1-3] (**Fig. 2**).

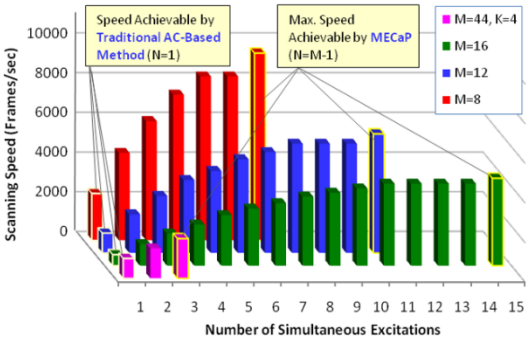

Fig. 2 ECT image scanning speed increase by multiple excitation capacitance polling

In collaboration with Pratt & Whitney, the MECaP scheme had been further expanded and led to the invention of the Multiple-Excitation-Multiple-Receiving (MEMR) method for combustion visualization [4]. The method optimizes the number of excitation signals (e.g.,, $f_1, f_2, \ldots f_N$) applied to and received by the N pairs of electrodes in an ECT measurement system. The received signals are separated by a series of lock-in amplifiers whose central frequencies are synchronized with the excitation frequencies (**Fig. 3**).

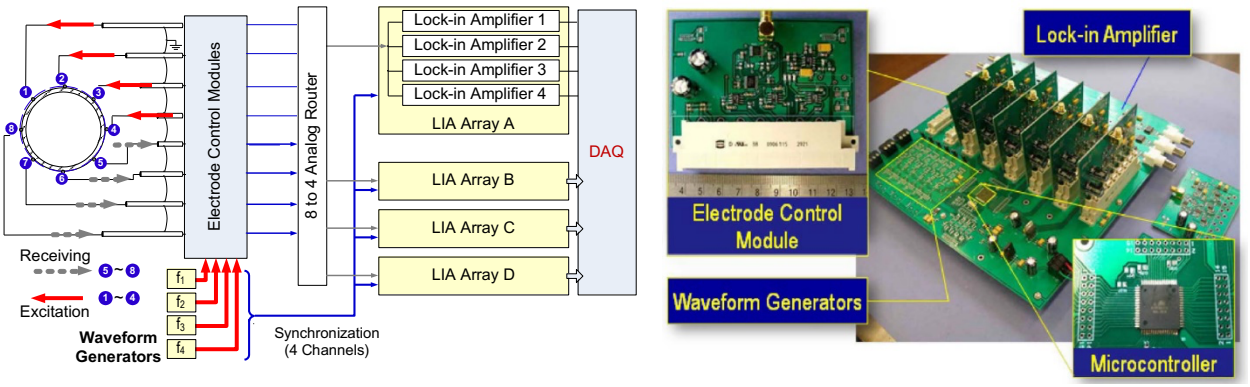

Fig. 3 MEMR system design and prototyping: with functional modules (left) and circuit board (right)

Experimental evaluation of the invented technique has demonstrated the ability of the improved ECT system in increasing the image scanning rate by an order of magnitude as compared to the traditional methods. This represented the fastest ECT system in the world at the time of the invention, according to the literature. A joint patent with Pratt & Whitney has been issued [4]. Further research is envisioned to advance ECT as a low-cost and non-intrusive sensing method to monitor fast changing process dynamics with improved time resolution.

Representative Publications

[1] Z. Fan and R. X. Gao, "An adaptive total variation regularization method for electrical capacitance tomography," in *2012 IEEE International Instrumentation and Measurement Technology Conference Proceedings*, Graz, Austria: IEEE, May 2012, pp. 2230–2235. doi: 10.1109/I2MTC.2012.6229582.

[2] Z. Fan and R. X. Gao, "Enhancement of Measurement Efficiency for Electrical Capacitance Tomography," *IEEE Trans. Instrum. Meas.*, vol. 60, no. 5, pp. 1699–1708, May 2011, doi: 10.1109/TIM.2011.2113010.

[3] Z. Fan and R. X. Gao, "Speed Improvement in Electrical Capacitance Tomography Through a Multiple Excitation and Receiving Method," in *ASME 2011 Dynamic Systems and Control Conference and Bath/ASME Symposium on Fluid Power and Motion Control, Volume 2*, Arlington, Virginia, USA: ASMEDC, Jan. 2011, pp. 153–158. doi: 10.1115/DSCC2011-6031.

[4] R. Gao and Z. Fan, "Multiple Excitation Capacitance Polling for Enhanced Electronic Capacitance Tomography", U.S. Patent No. 8,762,084, June 2014.

[5] Z. Fan, R. Gao, J. Lovett, and L. Smith, "Multiple-Excitation Multiple-Receiving (MEMR) Capacitance Tomography", U.S. Patent No. 9,170,224, October 2015.