

An Improved Normalisation Approach for Electrical Capacitance Tomography

W Q Yang*

Department of Electrical Engineering and Electronics, Process Tomography Group,
UMIST, P O Box 88, Manchester M60 1QD, UK, email w.yang@umist.ac.uk

M Byars

Process Tomography Ltd, 86 Water Lane, Wilmslow, Cheshire SK9 5BB, UK,
email MByars@tomography.com

Abstract -- An electrical capacitance tomography (ECT) system is calibrated at the upper and lower values of permittivity. The measured capacitances are usually normalised and then used for image reconstruction. The conventional normalisation approach assumes that the distribution of the materials is in parallel and hence the normalised capacitance is a linear function of the measured capacitance. This approach is not appropriate in most situations. In this paper an alternative normalisation approach is derived from a series sensor model. Preliminary experimental results show that the quality of reconstructed images can be improved with the new normalisation approach for the situations tested.

Keywords: Capacitance measurement, Physical modelling, Image reconstruction, Capacitance tomography

1. INTRODUCTION

Electrical capacitance tomography (ECT) is a technique to visualise the distribution of two dielectric components. Its basic principle is to measure the changes in capacitance from a multi-electrode sensor, and then reconstruct a permittivity distribution, i.e. image, using the measured capacitance data. Currently most ECT systems are calibrated using a lower permittivity material and a higher permittivity material, so that the high permittivity material distribution can be imaged in the low permittivity material background. It is common practice to use normalised capacitance data for image reconstruction. The conventional normalisation approach assumes that the distribution of the two materials is in parallel and the normalised capacitance is a linear function of the measured capacitance [1].

$$I = \frac{C_m - C_l}{C_h - C_l} \quad (1)$$

where, λ -- the normalised capacitance between a pair of electrodes, C_m -- the measured capacitance, C_l , C_h -- the capacitances when the ECT sensor is full of the lower and higher permittivity materials used to calibrate the sensor, respectively.

From equation (1), the normalised capacitance will be "0" when the sensor is full of the low permittivity material, and "1" when it is full of the high permittivity material. When the sensor is partially filled with the high permittivity material and the rest part is filled with the low permittivity material, the normalised capacitance is treated as linear interpolation. However the capacitance is, in practice, a complex function of permittivity distribution and the fraction of the high permittivity material, as shown in equation (2) [1]

$$C = \frac{\epsilon_0}{V_c} \int_{(x,y) \in \Gamma} \epsilon_r(x,y) \nabla \phi(x,y) d\bar{\Gamma} \quad (2)$$

where, ϵ_0 -- the permittivity of free space, $\epsilon_r(x,y)$ -- the relative permittivity distribution in the sensor, V_c -- the potential difference between the two electrodes, $\phi(x,y)$ -- the potential distribution in the sensor, Γ -- the spatial location.

From equation (2) it is clear that the measured capacitance is non-linearly related to the fraction of the high permittivity material present, i.e. concentration [2]. Consequently the relationship between the normalised capacitance and concentration is severely non-linear, and the accuracy of the image reconstructed from the normalised data is reduced. This paper will analyse the capacitance model and introduce an alternative, but improved normalisation approach

* W Q Yang is a member of the Virtual Centre for Industrial Process Tomography

which is more appropriate in most situations than the current one.

2. ALTERNATIVE NORMALISATION APPROACH

Fig.1 shows an 8-electrode ECT sensor containing a cylindrical high permittivity object in air. Take the capacitance between electrodes 1 and 4 as an example. The measured capacitance can be considered as three capacitances in series, where C_1 and C_3 are the capacitances corresponding to the empty space (i.e. the lower permittivity material) and C_2 is the capacitance corresponding to the object (i.e. the higher permittivity material). Since C_1 and C_3 correspond to the same material, they can be considered as just one capacitance, C_4 . Now the two capacitances, C_4 and C_2 , are effectively in series. These two capacitances approximately form a composite parallel-plate capacitance [3], as shown in Fig.2.

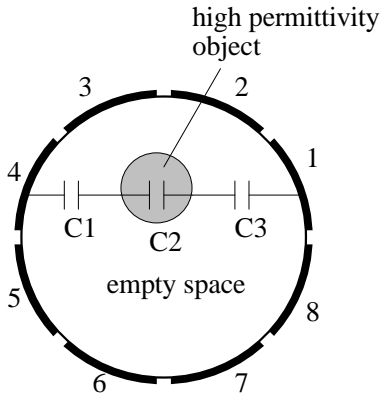


Fig.1 ECT sensor with a high permittivity object in air

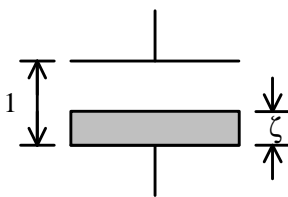


Fig.2 Using a parallel-plate capacitance to model ECT sensor

Assume a unity spacing between the two plates and a thickness of ζ which is also the fraction of the high permittivity material. Because the capacitances when the whole space is completely filled with the lower and the higher permittivity materials are respectively C_l and C_h , the capacitance corresponding to the bottom part in the space can be calculated as C_h/ζ , and that corresponding to the top part as $C_l/(1-\zeta)$. The measured capacitance now can be calculated as

$$C_m = \frac{1}{\frac{z}{C_h} + \frac{1-z}{C_l}} \quad (3)$$

Re-arranging this equation, the high permittivity fraction can be obtained as follows.

$$z = \frac{\frac{1}{C_m} - \frac{1}{C_l}}{\frac{1}{C_h} - \frac{1}{C_l}} \quad (4)$$

This can also be considered to be a normalised capacitance. When the sensor is full of the lower permittivity material, ζ equals "0". When it is full of the higher permittivity material, ζ is "1". If equation (4) is used instead of equation (1), the new normalised capacitance represents the fraction of the higher permittivity material in this case, which is a desirable outcome as this overcomes the non-linearity problem in some extent.

3. EXPERIMENTAL RESULTS

To verify this alternative normalisation approach, the following experiments were carried out using the popular linear back-projection (LBP) algorithm [1].

$$G(p) = \frac{\sum_{i=1}^{N-1} \sum_{j=i+1}^N I_{ij} S_{ij}}{\sum_{i=1}^{N-1} \sum_{j=i+1}^N S_{ij}} \quad (5)$$

where, $G(p)$ -- the grey level of the reconstructed image in the p -th pixel, S_{ij} -- the sensitivity map for the electrode pair i - j , N -- the number of electrodes in the sensor.

Equation (5) is normally used with the conventional normalisation approach. To implement the new method, λ is replaced by ζ , i.e. equation (1) is replaced by equation (4).

In the first experiment, an 8-electrode sensor was calibrated using air as the lower permittivity material and plastic beads as the higher permittivity material. A plastic bar (effectively 19.7% in area) was placed near the sensor wall. Fig.3 shows the images reconstructed using the same LBP algorithm, but different normalised capacitances. The measured concentration from the reconstructed images is 15.1% with the conventional normalisation approach and 22.3% with the new one. Fig.3 also shows the results when the object was placed in the centre of the sensor. Obviously the reconstructed image using the new approach is better than that using the

conventional one. The grey level of the image has been increased significantly (ideally 100%). In this case the measured concentration with the conventional approach drops to 10.6%. In contrast, the concentration value with the suggested approach is almost the same as before, 20.6% which is close to the true concentration.

In the second experiment, glass beads with a known fraction were fluidised in air using a facility as described in [4]. The results obtained using the two normalisation methods are summarised in Table 1. Obviously the measurement accuracy is improved by the new method.

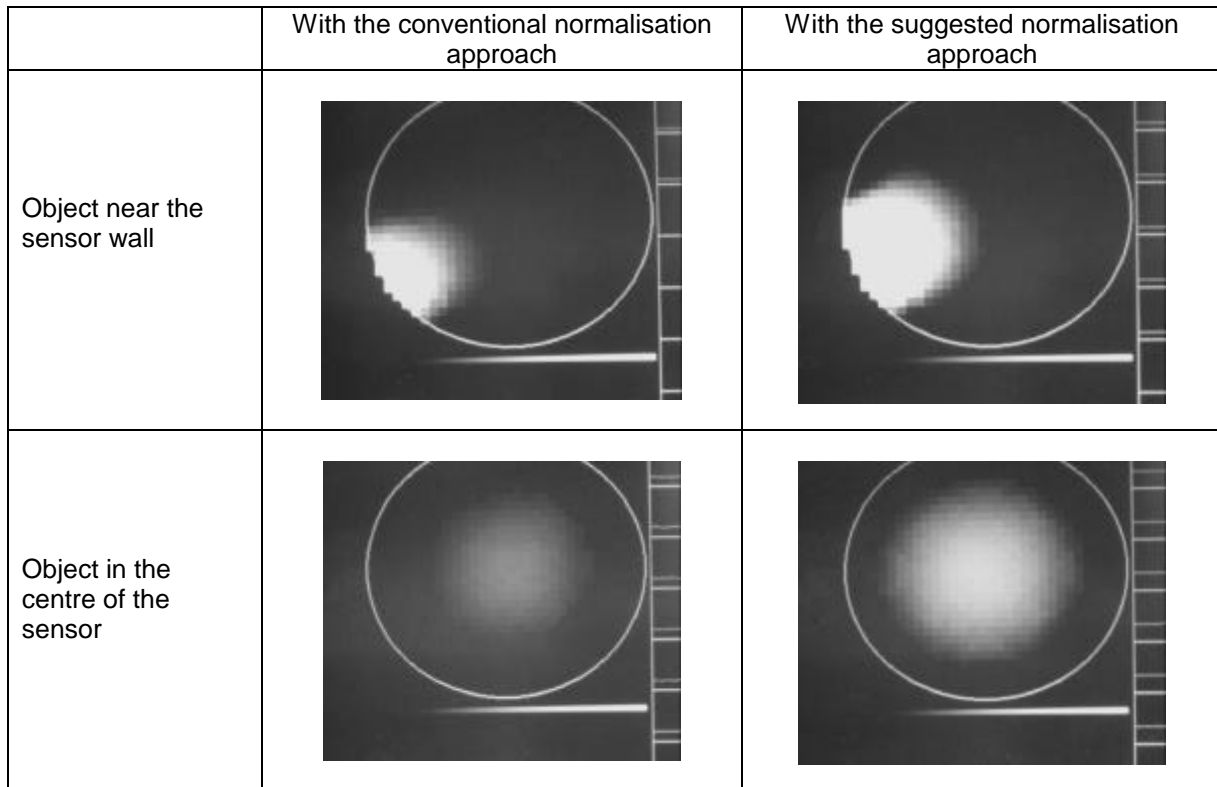


Fig.3 Reconstructed images

Table 1 Concentration measurement with two different methods

Actual volume fraction (%)	Result from old method (%)	Result from new method (%)	Error from old method (%)	Error from new method (%)
14	2	12	-85.7	-14.3
21	6	19	-71.4	-9.5
28	11	30	-60.7	7.1
35	15	36	-57.1	2.9

4. DISCUSSION

The conventional normalisation approach assumes that the distribution of materials is in parallel, which is only appropriate for few situations, e.g. a stratified distribution with the interface in between a pair of horizontally separated electrodes. In most situations this assumption is not appropriate. The series model presented in Fig.2 suits most component distributions and electrode combinations. By modelling the sensor capacitances as two capacitances in series, a different normalisation equation has been derived which is more valid for most distributions than the conventional method.

However the series model is absolutely correct only for an ideal parallel-plate capacitance sensor. For an ECT sensor with non-parallel and curved electrodes, the model is approximately correct only. Future work is planned to allow the appropriate sensor model to be chosen from an initial image adaptively, the parallel model, the series model or their combination.

Preliminary experiments have demonstrated that the suggested approach can improve image quality, sensitivity and concentration measurement accuracy for the situations tested. In this paper, only the simple LBP has been discussed as an example. To further improve image quality, iterative image

reconstruction algorithms have to be used to repeatedly solve the forward and inverse problems, aimed to correct the non-linear effects.

This method can be used not only for tomography to improve image quality, but also for other capacitance concentration transducers to improve their performance, which currently suffer from severe non-linearity, limiting their applications [2].

ACKNOWLEDGEMENT

Mr. W.F.Conway is thanked for the photographs.

REFERENCES

- [1] C.G.Xie, S.M.Huang, B.S.Hoyle, R.Thorn, C.Lenn, D.Snowden and M.S.Beck, "Electrical capacitance tomography for flow imaging: system model for development of image reconstruction algorithms and design of primary sensors", IEE Proc.-G, 1992, 139, pp 89-98
- [2] G.F.Hewitt, "Developments in multiphase metering", IBC Conf. on Development in Production Separation Systems, London, UK, 4-5 March 1993
- [3] W.Q.Yang, "Modelling of capacitance tomography sensors", IEE Proc.- Sci. Meas. and Technol., 1997, 144, pp 203-208
- [4] G.Delmon, R.Faure, B.de Gasquet, G.Giraud and J.P.Clerc, "Measurement of voidage in a fluidised bed using a capacitance sensor", Powder Technology, 1996, 86, pp 149-153