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A Study on an Industrial Emission Tomography using the EM algorithm

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1. Introduction

Imaging systems using radioisotopes are known to be the most suitable for an in-situ industrial inspection practice. The field of applications of an industrial CT extends to chemical engineering, oil recovery, geochemistry and hydrogeology. Especially, Industrial Emission Tomography (IET) technology for visualization of the spatial distribution of radiotracer can supply the dynamic information of process material that seldom can be obtained by the conventional technologies in multi phase flow reactors such as fluidized beds, slurry reactors, bubble columns, etc.[1]

We calculated with Monte Carlo Method the system matrix ($\boldsymbol{h}_{ij}$), the responses of detectors to a point source located at a certain place in the region of interest, which is necessary for cross-section image reconstruction by the Expectation-Maximization (EM) algorithm. Short half-life radionuclide, Tc-99m, was used as a tracer and its behavior inside a cylindrical tank was measured with 24 NaI detectors and it was visualized for different time stages.

2. Methods and Results

In this section the image reconstruction algorithm for IET and the experimental performance for an image reconstruction on IET are described. The obtained experimental data was reconstructed to an image by the image reconstruction program which we developed in the Labview software tool.

2.1 The image reconstruction methods

There are largely two categories of the analytic and the iterative methods for an image reconstruction. The analytic method is based on the inverse Radon transform theory. And the Filtered Back Projection (FBP) is the most representative algorithm using a Radon model.[2] FBP is the correct analytical solution to the Radon transform with no noise, which is only the case in transmission tomography. However, Emission Tomography (ET) has a significant level of noise and FBP becomes inaccurate in this case.[3] Due to the high amount of noise, a reconstruction algorithm for ET needs to compensate for the effects of its physics. The EM algorithm is one of the most suitable iterative methods for ET image reconstruction, because it contains imaging physics such as the geometry, non-uniform attenuation, scatter and so on.
Parameters estimated with consideration of these imaging physics are components of a system matrix($\boldsymbol{h}_{ij}$).

2.2 Expectation Maximization algorithm

The expectation-maximization (EM) algorithm is used as an important statistic tool for finding the maximum likelihood estimates in an image reconstruction. This EM algorithm consists of two major steps which are called the expectation step and the maximization step. The expectation step concerns the unknown underlying variables, using the current estimates of the parameters and conditioned upon the observations. The maximization step then provides a new estimate of the parameters.[4]

$$f_j^{(n+1)} = \frac{f_j^{(n)}}{\sum_{i=1}^{M} h_{ij}} \sum_{i=1}^{M} h_{ij} \frac{g_i}{\sum_{k=1}^{N} h_{ik} f_k^{(n)}} \quad (1)$$

These two steps are repeated until a convergence. The EM algorithm is given by equation (1). Where, $\boldsymbol{f}_k^{(n)}$ is the estimated activity in pixel k for iteration n. The notation $\boldsymbol{h}_{ij}$ represents the probability that a photon emitted from voxel j will be recorded in data bin i. And notation $\boldsymbol{g}_i$ indicates the measurements in projection bin i. Because of the system matrix, the EM algorithm tends to reduce the statistical noise artifact over the FBP algorithm. The EM algorithm is especially useful in an industrial emission tomography, because it does not require the projection data to be equally spaced.[5]

2.3 Decision of system matrix

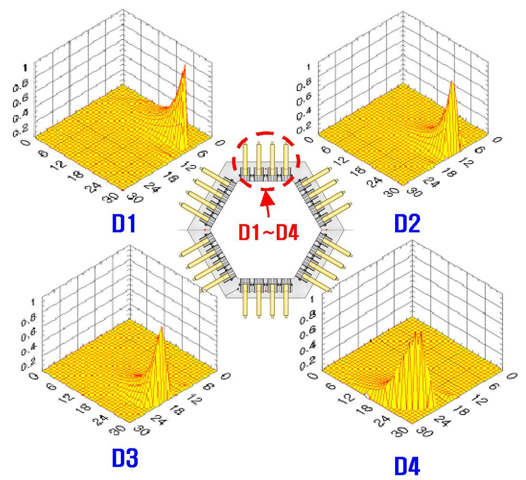

Fig. 1. The system matrix data calculated with Monte Carlo method

Image reconstruction in ET is definitely affected by physical interactions such as a photon attenuation, Compton scatter and detector response. These effects can be compensated for by modeling the corresponding spread of photons within the system matrix.[6] Imaging reconstruction is then performed by inverting this system matrix using the EM algorithm.

2.3 Experimental set-up

The experiment system for the industrial emission tomography was optimally contrived by Monte Carlo simulation and fabricated to a hexagonal detection geometry as proposed by Monte Carlo estimation. Fig.2 shows the experimental set-up for the industrial emission tomography measurement study.

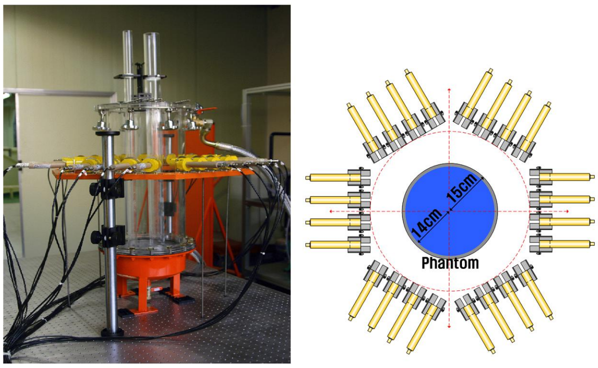

Fig. 2. The industrial emission tomography system fabricated for experiment

The radiation detectors are 0.5 x 1 inch NaI(Tl) scintillation coupled with PM-tube and shielded with Pb collimator for reducing the scattered noise radiation. The collimator has an I.D. of 10mm and an O.D. of 50mm. A vessel filled with water is placed in the center of the measurement system. Tc-99m of 21mCi was introduced at the inlet of the vessel by means of an injection system specifically designed for a radiotracer experiment. During the experiment, the flow-rate of water to the vessel was kept to 6L/min.

2.4 Experimental results

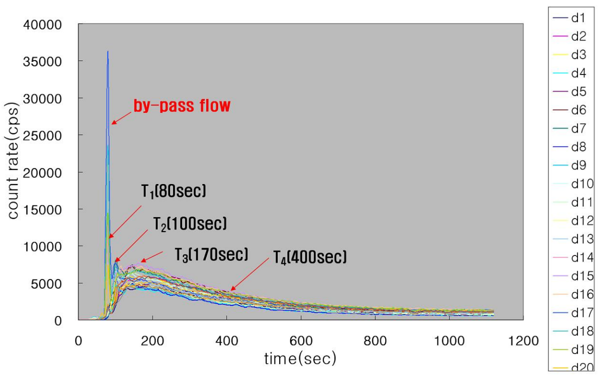

Fig. 3. The responses of detectors to the radioisotope (Tc-99m) injection

Fig.3 shows the responses of the detectors, d1 through d24. Fig.4 is the result of the image reconstruction for the radioactivity distribution in a cross-section of the vessel phantom at time T_1, T_2, T_3 and T_4. The by-pass flow in Fig.3 is deserved in Fig.4 (T_1=80sec) and the corresponding location is clearly identified. The images clearly show that radiotracer was getting uniformly dispersed by a mixing and dilution as time goes on.

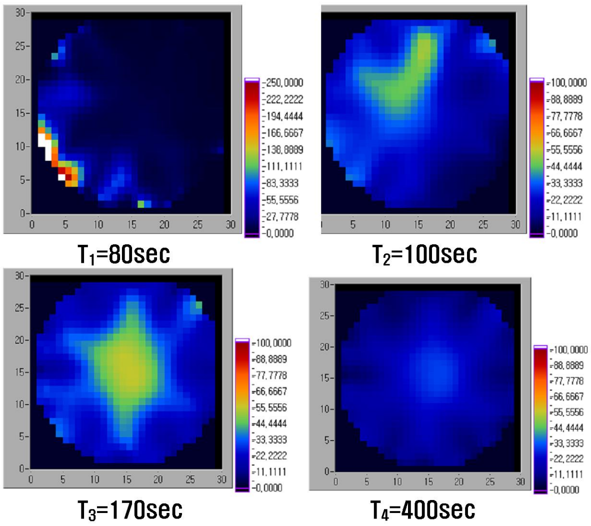

Fig. 4. Spatial distribution of radioisotope at each time stage

3. Conclusions

An image reconstruction of a radioactive tracer was successfully performed with the EM algorithm. It was confirmed that the IET technology can provide more direct diagnosis information than any existing industrial diagnosis. It is expected that an additional study on a more effectual calculation of a system matrix and the designing of measurement system will improve the resolution of the reconstruction images.

Acknowledgement

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