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Optical tomography verification for single and mixed modalities

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ABSTRACT

Modelling and experiments are pragmatic methods for verifying the performance of any design. Fundamentally, modelling is the first step to ensure that a design is created according to the desired characteristics. The experimental approach allows the examination of the modelling behaviour in a real environment and the verification of the design's correctness. In this research, the accuracy of an optical tomography system is evaluated by comparing the graph pattern generated through modelling and experimental procedures. Both are conducted in two different projections: single and mixed projections called the parallel beam (PB) projection and the mixed projection of parallel and fan beams left and right (MPFBLR) respectively. The evaluations confirm that the experimental and modelled patterns are consistent. This indicates that the developed optical tomography system has the desired characteristics. In this paper, a novel technique of threshold value, called filtered back projection (FBP) using averaging grouping colour (AGC), is presented. It is found that the more complex the object's location in a pipe, the higher the normalized mean square error (NMSE) and the lower the peak to noise ratio (PSNR).

1. Introduction

A tomography system is set up by arranging and mounting a number of sensors onto the outer layer of a pipeline and monitoring the inner flow as well as changes in the pipeline. An optical tomography system normally contains a set of light sources and photo detectors to get a parallel view of the pipeline. A light beam is projected through some medium from one boundary point and then detected at another boundary point. At the receiving point, the voltage level is measured, and its reduction is proportional to the size of any object in the pipe or vessel. It indicates that an optical tomography system detects the signal attenuation.

Although it can be regarded as the simplest type of tomography, it has a drawback. Light can propagate through non-opaque objects. Therefore, non-opaque objects cannot be used because no readings will be given at the receiving end. In addition, though opaque materials are most suitable to be tested, if two objects are located in the pipe, it is difficult to distinguish them. This can be solved by using multiple projections and by combining the parallel and fan beams.

The previous research by Khairi et al. [6] focused on single projection: the parallel beam (PB) projection. Rahim et al. [10] found that single projection could not cover a certain area. This is because the parallel beam only directs light in a straight line; therefore, other areas are blind spots [11]. As for the fan beam, the longer switching time of each transmitter affects the real-time component of the tomography system [7]. Fan beam (FB) projection should be mixed with parallel projection to cover the areas unsupported by PB projection, and simultaneously the angle of the FB projection should be reduced to overcome the longer switching time.

In this study, the performances of both single and mixed projections are explored through modelling and experiments. The experimental and modelled results give the same graph patterns. This confirms the accuracy of the developed hardware.

This paper has seven sections. The first section is an introduction to the topic of tomography, using single and mixed projections. The second part focuses on the modelling approach implemented in the design of the tomography system. The third section discusses the type of sensors used in the research. Section 4 contains a detailed explanation of the projections. Section 5 describes the measurement parameters used in the modelling and experiment.

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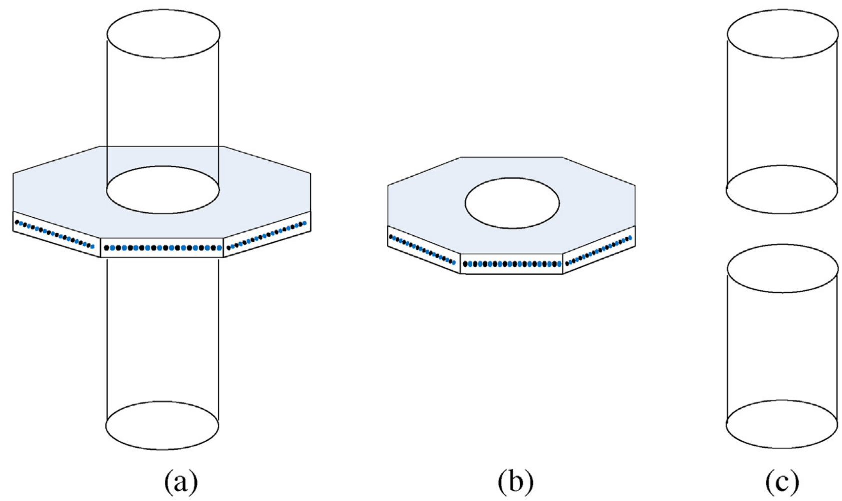

Fig. 1. The developed sensor jig. a) The overall view. b) The sensor jig model. c) Acrylic pipe separation.

Section 6 presents the experiment conducted for multiple objects. The analysis of multiple objects is presented in the last section of this paper.

2. Modelling

Modelling in process tomography is important to make qualitative or quantitative predictions in all possible states [1], as all the possibilities that a real system can exhibit cannot be imagined. The model should have the same relationships between each input and output as in real systems [13].

2.1. Optical attenuation model

The following assumptions were made in this research. (a) The attenuation factors of air and solid particles are assumed to be 0 and 1, respectively. Thus, light incident on the surface of solid particles has high optical absorption [4]. (b) The light scattering and beam divergence effects are neglected. There are two reasons for making this assumption:

1) *Sensor jig development.* As shown in Fig. 1, a sensor jig is inserted between two acrylic pipes. Therefore, light from the transmitter is directly incident on objects in the pipe. Thus, scattering, reflection, and refraction by the pipe are eliminated.
2) *Mode of projection.* In this research, both PB and FB projections are applied in the same sensor jig using the switching technique. In the switching mode, each transmitter and receiver pair corresponds in dissimilar time. This gives the receiver the opportunity to obtain a genuine signal from the transmitter because it acquires the signal when the transmitter transfers its signal. This is different from the old method of parallel projection by Rahim et al. [10], where all transmitters are activated simultaneously: if reflection and scattering occur, it is difficult to differentiate the source of the true signal. The new arrangement enables the fan beam mode to be applied in this system as the transmitter signals can be widely accepted by the receivers in the opposite arrangement. Therefore, the parallel and fan beam modes can be easily combined.

2.2. Linear model of optical tomography

In this section, the evaluation of a linear model of optical tomography is presented. The effect of the object size on the amount of light that is received by the receivers is discussed. The light beam

Fig. 2. Maximum Voltage, , for the receiver.

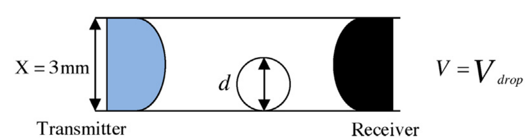

Fig. 3. Object with a diameter '*d*' in mm situated between the transmitter and the receiver results in the voltage drop, V_{drop}.

with a diameter of 3 mm propagates from a transmitter before its absorption by a photo detector on the receiver side.

Fig. 2 shows the maximum voltage, $V_{\max}$ obtained when there is no obstacle between the transmitter and the receiver.

The decrease in voltage due to an obstacle between the transmitter and the receiver is defined as V_{drop}, as can be seen in Fig. 3.

Therefore, the voltage drop at the receiver side can be obtained using the following formulas [9]:

$$V_{drop} = V_{\max} - V_{loss} \quad (1)$$

$$V_{loss} = {}^{d}\!/_{dl} \times V_{\max} \quad (2)$$

Therefore,

$$V_{drop} = V_{\max} - \left({}^{d}\!/_{dl} \times V_{\max} \right) \quad (3)$$

where

$V_{drop} =$ the predicted voltage drop when there is an obstacle

$V_{\max} =$ the maximum voltage when there is no object

$V_{loss} =$ the voltage loss

d = the particle size in millimetres

$dl =$ the diameter of the light beam

The predicted voltage drop value is obtained using Eq. (3). For example, in Fig. 4, there is an obstacle having a diameter of 1 mm