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Ultrasonic image reconstruction based on maximum likelihood expectation maximization for concrete structural information☆

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ABSTRACT

Many problems in measurement data are the physical quantities which are used to reconstruct an image for non-destructive testing. Time of flight data ultrasonic computed tomography is used in concrete non-destructive testing. Here the maximum likelihood expectation maximization (MLEM) algorithm and ultrasonic time of flight data is used to evaluate concrete filled steel tubes. When the image is reconstructed with the measurement data, the image shows many artifacts and therefor it is difficult to find useful information from the reconstruction image. To obtain a high quality image, time of flight data interpolation and normalization are proposed for image reconstruction system. Experimental results indicate the successful identification of the steel tube position and shape, which is not filled with concrete. The results imply that the time of flight data for ultrasonic computed tomography as an effective method of using the time of flight tomography to enhance the soundness of evaluation for concrete filled steel tubes.

1. Introduction

A concrete filled steel tube is a composite material comprised of a thin-walled steel tube and a concrete filling, so it has the trait of high strength in construction. Because the conditions of the concrete filled steel tube's construction is nonvisual [1], its quality is not easily determined [2]. Now mainly nondestructive testing (NDT) in concrete filled steel tubes is ultrasonic [3,4]. The shortfall of this method is that the testing precision is low [5,6], and the type of damage cannot be distinguished from the signal [7]. Hence, it is quite important to develop a fast, nondestructive, and accurate technique for the inspection of the construction quality of concrete cores [8,9].

The basic principle of ultrasonic testing for a concrete filled steel tube is to detect a defect using the propagation characteristics of an ultrasonic wave [10,11]. Putting the ultrasonic transducers at opposite sides of the concrete filled steel tube, the ultrasonic wave will propagate from the transmitting transducer to the receiving transducer through the steel tube and the filled concrete [12,13]. As one of the most commonly used nondestructive testing techniques in the industrial field, ultra-

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sonic computed tomography (CT) testing is considered to be a promising technique for the construction quality inspection of concrete filled steel tubes, and there have been a number of practical applications [14,15]. The filtered back projection (FBP) algorithm was used for a reconstruction method in the reports [16,17]. However, the reconstructed image of FBP has a problem with the emergence of negative pixel values [18]. Maximum likelihood expectation maximization (MLEM) is an image reconstruction method based on ultrasonic paths. The MLEM algorithm has several advantages for image reconstruction over the conventional filtered back projection [19,20].

An approach for a concrete filled steel tube inspection testing method by using ultrasonic time of flight data with the MLEM algorithm is proposed in this paper. Defects of concrete filled steel tubes have been discussed in detail by using concrete filled steel tube phantoms in CT images.

The paper is structured as follows. In the next section, the maximum likelihood expectation maximization image reconstruction algorithm is described based on maximum likelihood estimation and maximum a posteriori estimation. Section three presents the ultrasonic time of flight data measurement method and data interpolation and normalization methods. Experimental and image reconstruction results are presented in section four. In section five, the effectiveness of the proposed system and future research are discussed.

2. Image reconstruction algorithm

MLEM is proposed and implemented for tomographic reconstruction based on maximum likelihood estimation, and reconstructs images by repeatedly maximizing likelihood functions. The MLEM process gives positive values for the pixels [21,22], whereby the reconstructed images obtained using the MLEM algorithm tend to become noisy as the number of iterations increases [23]. The noisy reconstructed images may yield projections that are very close to the measured noise projections.

2.1. Maximum likelihood estimation

The maximum likelihood estimation method provides given observed data to assess the model parameters, and the samples are independently distributed [24,25]. Generalization of a problem in the computational model, where $p(x)$ is the probability density, and $p(\overrightarrow{X}|\lambda)$ is called the likelihood function. x_1, x_2, $\cdots$, x_n is independently obtained from the exponential distribution $Ex(1/\lambda)$, so $\frac{1}{\lambda}e^{-x}(0 \le x)$ is the probability density. Samples $\overrightarrow{X} = [x_1, x_2, \cdots, x_n]$ are independent distributions, concentration λ is the probability density of samples $\vec{X} = [x_1, x_2, \cdots, x_n]$, since a combination of probability densities can be measured simultaneously, such as n times measured by a separate event. Thus the model can be expressed as Eq. (1).

$$p(\vec{X}|\lambda) = \prod_{i=1}^{n} e^{-\lambda}\frac{\lambda^{x_i}}{x_i!} \tag{1}$$

The combination of samples $\vec{X} = [x_1, x_2, ..., x_n]$ of the obtained results are random, so the maximum likelihood function in the most random time is the same. λ is substituted by various changes in the likelihood function to acquire the maximum value. In order to maximize λ, it exists in both sides of Eq. (2) in the logarithm whereby,

$$\ln p(X|\lambda) = \sum_{i=1}^{n}(-\lambda + x_i \ln\lambda - \ln x_i!) \tag{2}$$

Targeting in the calculation of the actual differential operation parameter λ is calculated by Eq. (3). So, the most probable value of λ is equal to the average value.

$$\lambda = \frac{\sum_{i=1}^{n} x_i}{n} \tag{3}$$

2.2. Maximum a posteriori estimation

The noise characteristics obtained with a penalized likelihood reconstruction (maximum a posteriori, MAP) have been compared to those obtained with post smoothed maximum likelihood reconstruction, for emission tomography applications requiring uniform resolution [26]. The anatomical information is incorporated in the initialization of the MAP algorithm, and is therefore incorporated during MAP reconstruction. Because the pre-whitening filter is a shifted variant and object dependent, MAP reconstruction is a more efficient method [27]. Thus, absorption, scattering and resolution can be corrected easily in the MLEM process. The MAP algorithm is statistically described in Figs. 1 and 2. The method of MAP estimation can be used to obtain a point estimate of an unobserved quantity on the basis of empirical data. It is closely related to Fisher's method of maximum likelihood, but employs an augmented optimization objective which incorporates a prior distribution over the quantity which is to be estimated. MAP estimation can therefore be seen as a regularization of maximum likelihood estimation.

Concentration (MBq) of λ is detected by x in different directions by the detection of n times, and the contribution rate of the detection is C. The optimal estimate value for *ß* of x is calculated by Eq. (4). Using Eq. (5) an optimal estimated value