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Original paper

Image reconstruction of optical computed tomography by using the algebraic reconstruction technique for dose readouts of polymer gel dosimeters

Cheng-Ting Shih [a,1], Yuan-Jen Chang [b,1], Jui-Ting Hsu [c], Keh-Shih Chuang [a], Shu-Jun Chang [d], Jay Wu [e,*]

[a] National Tsing Hua University, Department of Biomedical Engineering and Environmental Sciences, No. 101, Section 2, Kuang-Fu Road, Hsinchu, Taiwan, ROC
[b] Central Taiwan University of Science and Technology, Department of Management Information Systems, No. 666, Buzih Road, Beitun District, Taichung, Taiwan, ROC
[c] China Medical University, School of Dentistry, No. 91, Hsueh-Shih Road, Taichung, Taiwan, ROC
[d] Atomic Energy Council, Institute of Nuclear Energy Research, Health Physics Division, No. 1000, Wenhua Road, Jiaan Village, Longtan Township, Taoyuan, Taiwan, ROC
[e] National Yang-Ming University, Department of Biomedical Imaging and Radiological Sciences, No. 155, Sec. 2, Linong Street, Taipei, Taiwan, ROC

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ABSTRACT

Optical computed tomography (optical CT) has been proven to be a useful tool for dose readouts of polymer gel dosimeters. In this study, the algebraic reconstruction technique (ART) for image reconstruction of gel dosimeters was used to improve the image quality of optical CT. Cylindrical phantoms filled with *N*-isopropyl-acrylamide polymer gels were irradiated using a medical linear accelerator. A circular dose distribution and a hexagonal dose distribution were produced by applying the VMAT technique and the six-field dose delivery, respectively. The phantoms were scanned using optical CT, and the images were reconstructed using the filtered back-projection (FBP) algorithm and the ART. For the circular dose distribution, the ART successfully reduced the ring artifacts and noise in the reconstructed image. For the hexagonal dose distribution, the ART reduced the hot spots at the entrances of the beams and increased the dose uniformity in the central region. Within 50% isodose line, the gamma pass rates for the 2 mm/3% criteria for the ART and FBP were 99.2% and 88.1%, respectively. The ART could be used for the reconstruction of optical CT images to improve image quality and provide accurate dose conversion for polymer gel dosimeters.

Introduction

Optical computed tomography (optical CT) has been used as a tool to scan tissue-equivalent gels since 1996 [1]. It has the advantages of high spatial resolution and high sensitivity to polymerization changes of gels, which are important in measuring three-dimensional dose distributions of gel dosimeters [2]. Unirradiated gels are transparent to visible light. When they are exposed to radiation, the molecular structure of gels undergoes polymerization and becomes dense. Optical CT uses a laser as the light source; when the laser passes through the gel, it is scattered by the dense molecular structure and subsequently detected by solid-state detectors. After acquiring $0^\circ - 180^\circ$ projection data from the gel, an image corresponding to the radiation dose distribution can be created.

The filtered back-projection (FBP) algorithm is frequently used to reconstruct optical CT images. It has the advantages of computational speed and high contrast resolution; however, the image quality of the FBP is affected by noise, unstable detector responses, and other factors [3]. Several artifacts and quantitative errors, such as ring artifacts and star artifacts, can occur, causing inaccurate dose readouts of the polymer gels [4]. Gordon et al. [5] proposed an algebraic reconstruction technique (ART) to create X-ray radiography images. Because of the

* Corresponding author. Tel.: +886 2 2826 7217; fax: +886 2 2820 1095.
E-mail address: iamjaywu@gmail.com (J. Wu).
[1] Co-first authors: Cheng-Ting Shih and Yuan-Jen Chang contributed equally to this work.

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superior image quality, the ART has further been used for computed tomography (CT) [6] and ultrasound tomography [7]. In addition, the ART has been modified to incorporate simultaneous rebinning [8] and multiplicative correction [9] to accelerate the iterative process. Other studies have introduced regularization during the iterative process, such as total variation (TV) minimization [10], to reduce the noise and artifacts in CT images.

To improve the image quality of optical CT for dose readouts of polymer gels, the ART was implemented in the measurement system used in this study. An iterative reconstruction schema was applied, and two dose distribution cases were delivered to the polymer gel dosimeters for verifying the ART algorithm. The results were compared with the images reconstructed using the FBP. This study aimed to improve the image quality of optical CT for gel readouts and promote the use of polymer gels as a three-dimensional quality assurance tool for dose measurements in clinical radiotherapy practice.

Materials and methods

Algebraic reconstruction technique

Considering the projection data collected by optical CT, the formula for the ART is

$$f_j^{(k+1)} = f_j^{(k)} + \frac{g_i - R_{i,j} f_j^{(k)}}{N_i}, \tag{1}$$

where $f_j^{(k)}$ and $f_j^{(k+1)}$ represent the values of pixel j obtained after the kth and $k+1$th iteration, respectively. g_i is the projection data for the ith beamlet, $R_{i,j}$ is the contribution to g_i from pixel j and is also called the measurement matrix, and N_i is the total contribution of the ith beamlet. In this study, a zero matrix was used as the initial guess ($f_j^{(0)}$). The f approached the real scattering coefficient of visible light after successful convergence through the iterative process. The measurement matrix was calculated according to the geometry of the optical system. The field of view was 20×20 cm^2 covered by 200×200 pixels; each pixel was divided into 10×10 subpixels. The contribution of photon scattering from a specific pixel to a projection bin was calculated based on the number of subpixels covered by the beamlet.

Stopping criterion for the iterative schema

Data consistency between the reconstructed projection data and the measured projection data is defined as

$$\varepsilon^k = \left\| Rf^k - g \right\|_2^2, \tag{2}$$

where ε^k is the fidelity after the kth iteration, f is the reconstructed image, g is the measured projection data, and R is the measurement matrix. As the number of iteration increases, ε continuously decreases and the reconstructed projection information approaches the measured projection data [10]. However, a lower ε is not always favorable because the measurement contains undesirable factors such as noise. Excessive iterations increase the computation time with no further improvement in the image quality.

The optimum fidelity, which corresponds to the optimum image quality, is unknown before executing the iterative process. In this study, a circular dose distribution was irradiated by the volumetric modulated arc therapy (VMAT) to determine the suitable fidelity and iteration number. The difference of fidelity between each iteration is

$$\Delta\varepsilon_{k-1,k} = \varepsilon^{k-1} - \varepsilon^k. \tag{3}$$

The ratio of fidelity difference (RFD), $\Delta\varepsilon_{k-1,k}/\Delta\varepsilon_{1,2}$, was calculated after each iteration, and the reconstructed image was compared with the output of the treatment planning system (TPS) for gamma evaluation. The RFD corresponding to the highest gamma pass rate was used as the stopping criterion.

Gel preparation and irradiation

A modified *N*-isopropyl-acrylamide (NIPAM) polymer gel comprising gelatin, NIPAM monomers, *N*,*N*′-methylene-bis-acrylamide (BIS), and tetrakis (hydroxymethyl) phosphonium chloride (THPC) was fabricated [11]. Initially, 5 wt% gelatin (300 Bloom Type A, Sigma–Aldrich, MO, USA) was added to 87 wt% deionized water, and the mixture was stirred for 10 min at 22 °C. The gelatin solution was then heated to 45 °C until the solution became transparent. Subsequently, 3 wt% BIS (Merck, Germany) and 5 wt% NIPAM (97%, Sigma–Aldrich, MO, USA) were added to the gelatin solution, and the solution was continuously stirred for approximately 15 min

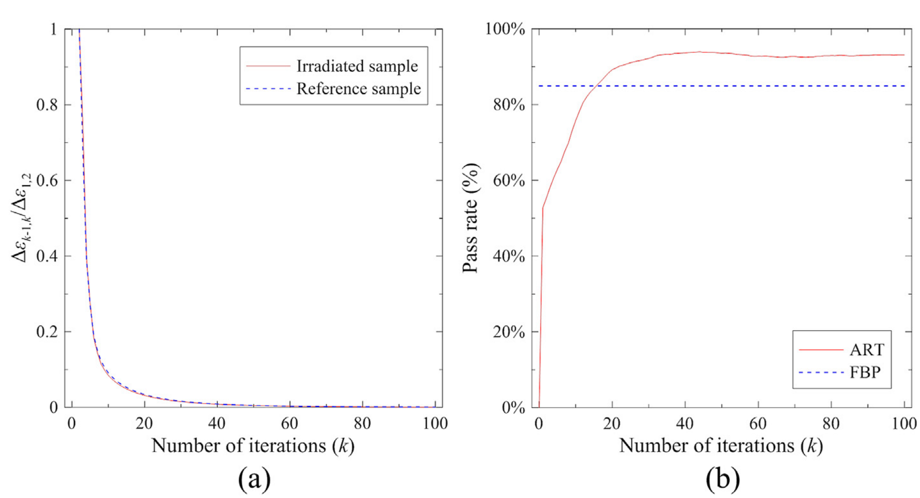

Figure 1. (a) RFDs and (b) gamma pass rates as a function of the iteration number for the 17-cm-diameter phantom. The pass rate achieved a maximum value of 93.5% at the 38th iteration.