



Quantitative evaluation of an image registration method for a NIPAM gel dosimeter



Yuan-Jen Chang^{a,b}, Chun-Hsu Yao^{c,d,e}, Jay Wu^f, Bor-Tsung Hsieh^g,
Yuk-Wah Tsang^h, Chin-Hsing Chen^a

^a Department of Management Information Systems, Central Taiwan University of Science and Technology, No. 666, Buzih Rd., Beitun District, Taichung City, Taiwan (R.O.C.)

^b Institute of Biomedical Engineering and Materials Science, Central Taiwan University of Science and Technology, No. 666, Buzih Rd., Beitun District, Taichung City, Taiwan (R.O.C.)

^c School of Chinese Medicine, China Medical University, Taichung, Taiwan (R.O.C.)

^d Department of Biomedical Imaging and Radiological Science, China Medical University, Taichung, Taiwan (R.O.C.)

^e Department of Biomedical Informatics, Asia University, Taichung, Taiwan (R.O.C.)

^f Department of Biomedical Imaging and Radiological Sciences, National Yang-Ming University, Taipei, Taiwan (R.O.C.)

^g Department of Biomedical Imaging and Radiological Sciences, Central Taiwan University of Science and Technology, Taichung, Taiwan (R.O.C.)

^h Department of Radiation Oncology, Ditmanson Medical Foundation Chiayi Christian Hospital, Chiayi, Taiwan (R.O.C.)

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ABSTRACT

One of the problems in obtaining quality results is image registration when a gel dosimeter is used in conjunction with optical computed tomography (CT). This study proposes a passive alignment mechanism to obtain a precisely measured dose map. A holder plate with two pin-hole pairs is placed on the gel container cap. These two pin-hole pairs attach the gel container to the vertical shaft and can be precisely aligned with the rotation center of the vertical shaft at any time. Accordingly, a better reconstructed image quality is obtained. After obtaining a precisely measured dose map, the scale invariant feature transform (SIFT)-flow algorithm is utilized as an image registration method to align the treatment plan software (TPS) image with the measured dose map image. The results show that the gamma pass rate for the single-field irradiation increases from 83.39% to 94.03% when the algorithm is applied. And the gamma pass rate for the five-field irradiation treatment plan increases from 87.36% to 94.34%. The translation, scaling, and rotation occurring in the dose map image constructed using an optical CT scanner are also aligned with those in the TPS image using the SIFT-flow algorithm. Accordingly, improved gamma comparison results and a higher gamma pass rate are obtained.

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1. Introduction

A technology that enables the highly accurate, high-resolution, 3D measurement of intricate dose distributions associated with modern radiation treatments, such as intensity-modulated radiotherapy (IMRT), tomotherapy, cyber knife, proton therapy, intensity-modulated arc therapy, and volumetric-modulated arc therapy, is necessary [1]. Polymer gel dosimetry has become a popular technology because of its great potential to validate 3D dose distributions for radiation therapy. One of these polymer gels is the N-isopropyl acrylamide (NIPAM) polymer gel based on a less toxic monomer (i.e., NIPAM) proposed by Senden et al. [17]. An advantage of the NIPAM gel is that it can be prepared on a benchtop in normal atmospheric conditions in a laboratory because of the addition of antioxidants (e.g., ascorbic acid and tetrakis (hydroxymethyl) phosphonium chloride). The charge-coupled device (CCD)-based optical CT scanner presents the most

number of advantages among the numerous imaging modalities for gel dosimetry, such as magnetic resonance imaging (MRI), optical CT, X-ray CT, and ultrasound. These benefits include a simple mechanism structure and the capability to capture a complete 3D dose distribution rapidly. These advantages indicate that a low-cost and high-resolution CCD-based optical CT scanner can be developed [2]. MacDougall et al. [3] claimed that only a few studies have generated sufficient quality results for polymer and Fricke gels from the clinical perspective. MacDougall indicated that the basic dosimeter qualities of accuracy and precision have yet to be fully quantified for polymer and Fricke gels at clinically-relevant dose levels. Moreover, whether or not a single batch of gel contains variations during manufacture because of the inhomogeneity of chemical distribution in the gel is unclear. In addition to direct evidence of precision and accuracy, indirect evidence relating to the chemical response of the gel is also observed to affect accuracy and precision.

Acquiring pre- and post-irradiation scans is one of the most important steps in the methodology of gel dosimetry. However, these processes may induce two types of errors. The first type is the positioning error. Xu and Wu claimed that a maximum uncertainty of up to 2.49% is caused by the inaccuracies in the positioning process when the high-speed optical CT scanner developed by MGS Research is adopted [4]. The markers are generally placed on the flask to align the pre- and post-irradiation images [5,6]. Ibbott utilized a glass rod for image registration in the gel phantom to align the measured dose distributions with those in the treatment plans [6]. The second error type is the geometrical distortion of the reconstruction image as measured by an optical CT scanner [7]. The best fit refractive index of the matching liquid may be adopted to reduce image distortion in optical density measurement [8]. However, the alignment of a distorted dose map image with a treatment plan software (TPS) image remains a challenge [9].

Although image registration methods have been investigated in many medical image applications [14,15,16], only a few studies have investigated the registration technique for high-speed optical CT scanners [5]. Therefore, this study proposes an improvement of the registration method to align the images in the dose map of TPS and those measured with an optical CT scanner.

2. Materials and methods

2.1. Passive alignment design

A novel method is developed to solve the preceding problems. A precise positioning gel holder design is employed to reduce the gel positioning error.

A fast optical CT laser scanner (OCTOPUSTM-10 ×, MGS Research, Inc., Madison, CT, USA) is utilized to scan the gel container. The gel container is gripped by a holder adapter mounted on a vertical shaft in Fig. 1(a). Clamps are used to hold the four edges of the gel container cap. Two screws are loosened, and the arms of the clamp are extended to detach the container from the holder. The gel container is also attached to the clamp, which tightly holds the container cap edges, before re-tightening the screws. As claimed in previous research, this process may induce several position errors when the gel is used during the pre- and post-irradiation scans [3]. The holder adapter of the gel container is redesigned in this study to simplify and speed up the gel container exchange and reduce the positioning errors. A new holder plate with the same dimension as that of the gel container cap is designed in Fig. 1(b). The holder plate with one pin-hole pair is placed on the gel container cap. The two pin-hole pairs easily attach the gel container to the vertical shaft and are precisely aligned with the rotation center of the vertical shaft at any time. Four screws are utilized to fix the gel container and the holder plate tightly in Fig. 1(c). Subsequently, the holder plate is assembled with the vertical shaft of the rotary motor in Fig. 1(d). The entire set is mounted atop the aquarium and positioned with the other pin-hole pair in Fig. 1(e). A photograph of the optical scanner with the new positioning mechanism design is presented in Fig. 1(f). The clearance between the pin and the hole is less than 0.01 mm. Hence, the precise re-positioning of the gel phantom is achieved. The re-positioning error of the gel phantom is reduced for the pre- and post-irradiation scans.

2.2. High-level image alignment

Based on the improved positioning mechanism of the gel container, the correct dose distribution is determined by subtracting the non-irradiated and irradiated gels. A high-level image alignment technique is then utilized to align the dose map of the TPS with that of the measured dose map using the optical CT scanner

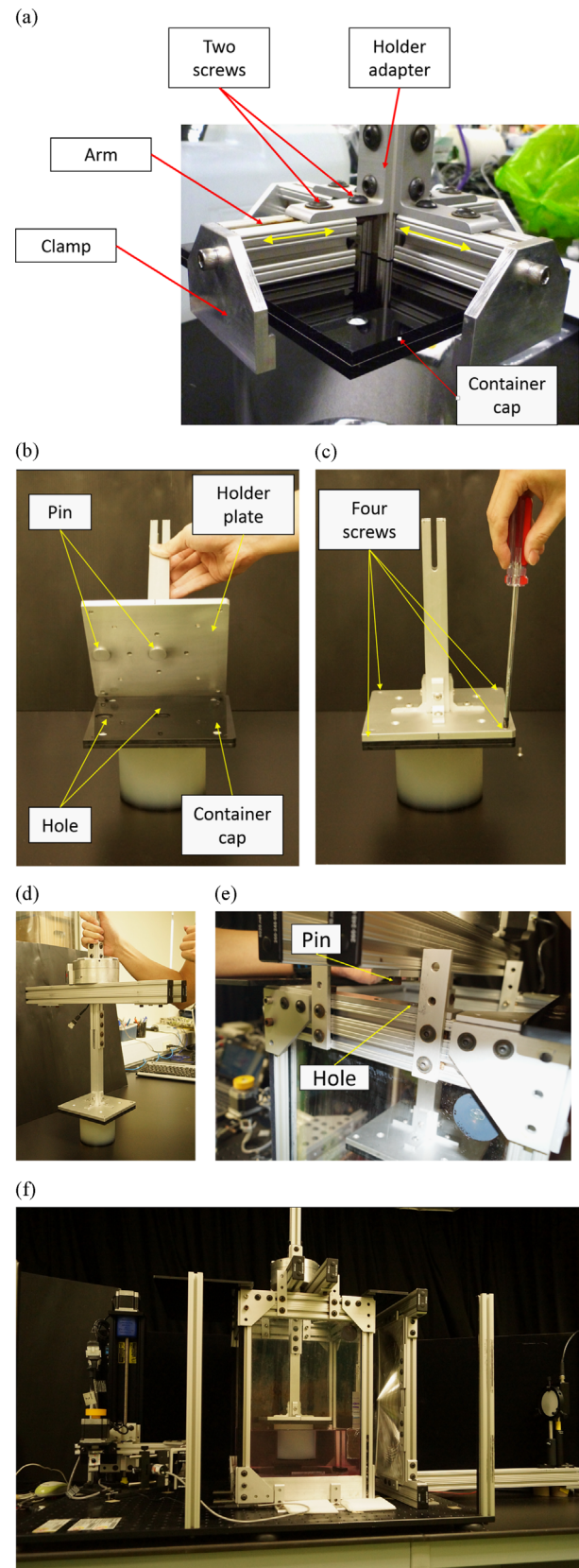


Fig. 1. Passive alignment design for the OCTOPUSTM 10 × optical CT scanner (MGS Research Inc., Madison, CT, USA). (a) Original design of the gel container holder with a four-arm clamp. (b) New design of the container holder with two pin-hole pairs. (c) Assembly of the gel container and the holder plate. (d) Assembly of the gel container holder and the vertical shaft of the rotary motor. (e) Pin-hole alignment mechanism for the horizontal shaft of the rotary motor on top of the aquarium. (f) Photograph of the optical scanner with the new positioning mechanism design.

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