Iterative 2D deconvolution of portal imaging radiographs

Hui Khee Looe [1,2,*], **Dietrich Harder** [3], **Kay C. Willborn** [2], **Björn Poppe** [1,2]

[1] Working Group Medical Radiation Physics, Carl von Ossietzky University Oldenburg, Germany
[2] Clinic for Radiotherapy and Oncology, Pius-Hospital Oldenburg, Germany
[3] Prof. em., Medical Physics and Biophysics, Georg August University, Göttingen, Germany

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Abstract

Portal imaging has become an integral part of modern radiotherapy techniques such as IMRT and IGRT. It serves to verify the accuracy of day-to-day patient positioning, a prerequisite for treatment success. However, image blurring attributable to different physical and geometrical effects, analysed in this work, impairs the image quality of the portal images, and anatomical structures cannot always be clearly outlined. A 2D iterative deconvolution method was developed to reduce this image blurring. The affiliated data basis was generated by the separate measurement of the components contributing to image blurring. Secondary electron transport and pixel size within the EPID, as well as geometrical penumbra due to the finite photon source size were found to be the major contributors, whereas photon scattering in the patient is less important. The underlying line-spread kernels of these components were shown to be Lorentz functions. This implies that each of these convolution kernels and also their combination can be characterized by a single characteristic, the width parameter λ of the Lorentz function. The overall resulting λ values were 0.5 mm for 6 MV and 0.65 mm for 15 MV. Portal images were deconvolved using the point-spread function derived from the Lorentz function together with the experimentally determined λ values. The improvement of the portal images was quantified in terms of the modulation transfer function of a bar pattern. The resulting

Iterative 2D Entfaltung von Verifikationsaufnahmen

Zusammenfassung

Feldkontrollaufnahmen dienen als integrale Bestandteile moderner strahlentherapeutischer Techniken wie der IMRT und der IGRT. Durch regelmäßige Kontrolle der Patientenlagerung sind sie Voraussetzung für den Erfolg der Behandlung. Verschiedene physikalische und geometrische Effekte, die in dieser Arbeit untersucht werden, führen jedoch zur Bildunschärfe und Verringerung der Bildqualität. Hierdurch können anatomische Strukturen nicht immer deutlich abgegrenzt werden, und die präzise Beurteilung der Patientenlagerung wird erschwert. In dieser Arbeit wird ein iteratives Entfaltungsverfahren entwickelt, um die Bildunschärfe zu vermindern. Die zugehörige Datenbasis wird durch getrennte Messung einzelner Unschärfekomponenten geschaffen. Es wird gezeigt, dass der Sekundärelektronentransport und die Pixelgröße des EPID sowie der geometrische Halbschatten, bedingt durch die Quellgröße, am meisten zur Bildunschärfe beitragen, während die Photonenstreuung im Patienten geringere Bedeutung hat. Unsere Untersuchungen zeigen, dass die Linienspreizfunktionen aller dieser Komponenten die Form von Lorentzfunktionen haben. Jede einzelne Linienspreizfunktion und auch deren Kombination kann durch eine einzige Größe, den Parameter λ für die Verteilungsbreite

* Corresponding author.
E-mail: hui.k.looe@uni-oldenburg.de (H.K. Looe).

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clinical images show a clear enhancement of sharpness and contrast.

Keywords: EPID, image blurring, line-spreadkernel, iterative deconvolution

der Lorentzfunktion, parametrisiert werden. Die insgesamt resultierenden λ-Werte liegen bei 0,5 mm für 6 MV und 0,65 mm für 15 MV. Verifikationsaufnahmen werden mit der daraus abgeleiteten Punktspreizfunktion und den experimentell ermittelten λ-Werten entfaltet. Die Verbesserung der Bildqualität wird anhand der Modulationsübertragungsfunktion eines Gittermusters quantifiziert. Klinische Beispiele zeigen eine deutliche Erhöhung der Bildschärfe und eine Verstärkung des Bildkontrasts nach der Entfaltung.

Schlüsselwörter: EPID, Bildunschärfe, Linienspreizfunktion, iterative Entfaltung

1 Introduction

Portal imaging devices are producing radiographs of the interesting body regions of radiotherapy patients, using the therapeutical photon beam to generate projection images. Portal imaging radiographs serve to verify the position relationship of the photon beam with the patient's body. They comprise survey images as well as images produced with single IMRT segments, which might be superposed with the former. The application of portal imaging is recommended as an aid for the adjustment of the patient at the beginning of a treatment series, at regular repetition intervals or in any special situation where control of the position relationship appears to be indicated [1].

Gradual blurring of portal imaging pictures is a well-known phenomenon. It is a recognized obstacle for the precise delineation of certain details of the projection images since the first investigations on the use of portal imaging in radiotherapy [2–3]. Since then, the causes of image blurring have been investigated and characterized through analytical methods, measurements and Monte-Carlo calculations [4–9]. Three component causes can be conceived to contribute to the blurring phenomenon: a) the lateral transport of secondary electrons within the portal imaging device and its pixel size, b) the geometric penumbra due to the finite size of the photon source located at the lower surface of the flattening filter of the therapy machine, c) the Compton scattering of the photons in the patient's body or in the phantom.

The task of the present investigation has been to measure and differentiate the convolution kernels underlying these blurring phenomena and to devise a numerical method by which a 2D deconvolution of blurred portal imaging radiographs can be performed. The success of this deconvolution method had to be demonstrated not only by improved portal imaging radiographs, but also to be quantified in terms of the improvement of the modulation transfer function (MTF). The investigation has been performed on the electronic portal imaging device (EPID) being in use at a Siemens Artiste 6/15 MV therapy machine of the Pius Hospital in Oldenburg (Germany).

2 Materials and methods

2.1 Linear accelerator and EPID

The investigation was carried out at a Siemens Artiste linear accelerator with 6 and 15 MV nominal energy, equipped with an electronic portal imaging system (EPID) (Optivue 1000ST, Siemens, Concord, CA, USA). The detector has a maximum active detection area of 41 cm x 41 cm. The matrix size of the image is 1024 pixels x 1024 pixels with 0.4 mm pixel size. On the radiation entrance side, the radiation sensitive layer is shielded by a copper converter plate of 1 mm thickness. This plate absorbs all secondary electrons coming from outside and serves as the origin of a new generation of secondary electrons which are causing the signal in the sensitive layer. Between the copper plate and the sensitive layer there is a 1 mm thick air gap in which secondary electrons, scattered in the copper layer, can move laterally.

2.2 Determination of the convolution kernel K(x,y)

2.2.1 *Mathematical model of K(x,y)*

Blurring of the portal image produced in an image plane x,y perpendicular to the beam axis was generally conceived as a convolution of the true pixel value image $I_0(x,y)$ with a convolution kernel $K(x,y)$. The convolution kernel was determined by measuring the edge-spread function (ESF): A 7 cm thick edge object made of lead was used to produce an edge profile. The lead block was placed with its edge exactly on and parallel to the central beam axis. The projection of the edge into the x,y plane was adjusted to form an angle of 10° with the y axis of the EPID. Thereby the scanning frequency in the x direction could be enhanced by combining the scanning values of various scanning lines [9]. The line-spread function (LSF) can be