Optimizing an analytical dose calculation algorithm for fast 2D calculations ☆

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Abstract

Previously, an analytical dose calculation algorithm for MLC-based radiotherapy was developed and commissioned, which includes a detailed model of various MLC effects as a unique feature [1]. The algorithm was originally developed as an independent verification of the treatment planning system's dose calculation and it explicitly modeled spatial and depth dependent MLC effects such as interleaf transmission, the tongue-and-groove effect, rounded leaf ends, MLC scatter, beam hardening, and divergence of the beam, which in turn resulted in a gradual MLC transmission fall-off with increasing off-axis distance. Originally the algorithm was implemented in Mathematica^{TM} (Wolfram). To speed up the calculation time and to be able to calculate high resolution 2D dose distributions within a reasonable time frame (<2 s) the algorithm needs to be optimized and to be embedded in a user friendly environment.
To achieve this goal, the dose calculation model is implemented in VisualBasic 6.0, which decreases the calculation time moderately. More importantly, the numerical algorithm for dose calculation is changed at two levels: the dose contributions are split into their x- and y-contributions and the calculation is aperture- rather than as originally point-based.
Implementing these three major changes, the calculation time is reduced considerably without loosing accuracy. The time for a typical IMRT field with about 2500 calculation points decreased from 2387 seconds to 0.624

Optimierung eines analytischen Dosisberechnungsalgorithmus für eine schnelle 2D-Berechnung

Zusammenfassung

Bereits in einer früheren Studie wurde ein analytischer Dosisberechungsalgorithmus für MLC-basierte Strahlentherapie entwickelt und kommissioniert. Als einzigartige Eigenschaft beinhaltet dieser Algorithmus ein detailliertes Modell für verschiedene MLC-Effekte [1]. Ursprünglich wurde dieser Algorithmus zur unabhängigen Überprüfung der Dosisberechnung des Bestrahlungsplanungssystems (TPS) entwickelt. Dafür wurden verschiedene koordinatenabhängige MLC-Effekte berücksichtigt, wie z.B. Interleaftransmission, Tongue-and-Groove-Effekt, abgerundete Leaf-Enden, MLC-Streuung, Strahlaufhärtung und die Strahldivergenz, die dazu führten, dass die Transmission mit zunehmendem Abstand zum Zentralstrahl immer mehr abnimmt. Bisher war dieser Algorithmus in Mathematica^{TM} (Wolfram) implementiert. Um die Berechungszeit zu verkürzen und 2D-Dosisverteilungen innerhalb einer akzeptablen Zeit (<2 s) berechnen zu können, muss der Algorithmus optimiert und in eine benutzerfreundliche Oberfläche eingebunden werden.
Um dieses Ziel zu erreichen, wird der Algorithmus in VisualBasic 6.0 implementiert, was die Berechnungszeit bereits etwas reduziert. Wichtiger ist jedoch, den Algo-

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seconds (a factor of about 3800). The mean agreement of the optimized and the not optimized calculation algorithm at the isocenter for a fairly complex IMRT plan with 23 fields is better than 1% relative to the local dose at the measuring point.

Keywords: Dose calculation, MLC transmission, independent verification

rithmus selbst auf zweierlei Arten zu ändern: Erstens wird der Dosisbeitrag in seinen x- und y-Anteil aufgeteilt und zweitens wird die Berechungsmethode dahingehend verändert, dass sie nicht mehr punktbasiert sondern öffnungsbasiert durchgeführt wird.
Die Realisierung dieser drei genannten Änderungen führt dazu, dass die notwendige Berechungszeit beträchtlich reduziert wird, ohne dabei an Genauigkeit einzubüßen. Die Berechnungszeit für ein typisches IMRT-Feld mit ungefähr 2500 Berechnungspunkten wird so von 2387 Sekunden auf 0,624 Sekunden reduziert (das entspricht einem Faktor von ungefähr 3800). Die mittlere Übereinstimmung des optimierten und des nicht optimierten Berechnungsalgorithmus im Isozentrum für einen ziemlich komplexen IMRT-Plan mit 23 Feldern ist besser als 1% relativ zu der lokalen Dosis am Messpunkt.

Schlüsselwörter: Dosisberechnung, MLC-Transmission, unabhängige Verifikation

1. Introduction

For a safe delivery of radiation, the dose calculated by a treatment planning system (TPS) should be verified independently either by performing an independent dose calculation and/or by a direct measurement [2–4]. An independent dose calculation algorithm was previously developed, commissioned and implemented in routine clinical use for point dose verification [5]. However, for an accurate dose calculation in the case of complex IMRT fields, a detailed MLC model is required [1]. An analytical MLC model, including spatially and depth dependent effects such as interleaf transmission, the tongue-and-groove effect, rounded leaf ends, MLC scatter, beam hardening, and the effect of beam divergence on the spatial dependency of leaf leakage, has already been published [6,7] and was used in the above mentioned dose calculation algorithm [1]. In this algorithm, each of those MLC effects can be switched on and off before starting dose calculation to analyze their impact on specific radiation fields.

To use the dose calculation algorithm not only as a point dose verification tool but rather for 2D calculation or even to extend it to 3D calculation, which would enable the user to analyze the impact of the above mentioned MLC effects in 3D, the algorithm needs to be optimized. This paper describes the method of optimizing the numerical algorithm and its implementation in Visual Basic 6.0 (VB6) with the intention of a fast calculation in a plane perpendicular to the beam axis. Because the physical beam model was experimentally validated using an ion chamber array [1], here we restrict ourselves to comparisons with the previously implemented numerical calculation in Mathematica 5.2.

2. Materials and Methods

The dose calculation algorithm is based on the summation of rectangular pencil beams defined by the leaf-pairs and it can calculate dose at any point in a homogenous phantom. The physical dose model is however more general and can be utilized to extend the dose calculation to an inhomogeneous phantom as well. The physical basis of the dose model and its details were described previously [1,5] and the principle is only recapitulated schematically in this context to explain the modifications made to its original version from a well defined starting point.

2.1. A. Point dose calculation

In the previous formulation, contributions from a MLC shaped field to one single point in the phantom were considered. For each point all contributions from all rectangular "beamlets" (direct dose through openings between one leaf-pair and attenuated dose by either of the leaves) and all "subfields" (either segments in case of a step and shoot IMRT field or control points in case of a dynamic MLC field) are summed up. The influence of phantom scatter is modeled with error-functions (erf), the tissue-phantom ratio (TPR) and the head scatter factors are modeled with exponential functions.