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Andreas Böhler

Collimator-Based Tracking with an Add-On Multileaf Collimator

Modification of a commercial collimator system for realtime applications

Springer

Andreas Böhler
R’n’B Medical Software Consulting GmbH
Linz, Austria

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Preface

The dissertation is without doubt one of the most important theses (or book!) an ongoing scientist writes throughout his career. While working on the topic is sometimes fun, sometimes frustrating and sometimes rather tedious, writing down the results is often considered boring.

It took me quite some time to push myself until I got started, but once the first few pages were there on the screen, I knew I was on the right track. A few weeks later, I had finished the first version of my thesis as a manuscript.

As usual, it took some iterations until most of the typing errors were fixed and all illustrations correctly formatted. Finally finishing my studies and being awarded the doctor's degree felt great – and I thought I was done with my dissertation.

Until almost a year later, an e-mail from my university arrived, asking if I would consent to be nominated for the Springer MedDiss 2015 programme. Of course I said "yes" without any hesitation, thinking to myself that it was an honour to be nominated, but that the chances of being actually selected for publication were not very high.

To my great delight, though, I was proven wrong, and the formatting and typesetting work started all over again – but knowing, while typing these sentences, that they would find their way into a "real" book rather soon is another good and rewarding feeling. Given the fact that a lot of dissertations end up in the university library and are never read again, this feeling is even better.

Although, at first glance, the book at hand seems rather thin, it is the result of over three years of research work. For technically-oriented work that involves a lot of software, it is sometimes hard to describe what you've done without just printing the source code.

Instead, I tried to describe on a not-too-detailed level what the main focus of the research was and how the system works in general. The first part gives an insight into the motivation of performing the work. A literature overview gives the reader the necessary knowledge of two different "worlds". On the one hand, there is the clinical background which focuses on the relevant literature. On the other hand, there is the technical background that requires a more elaborate description of the available literature and provides the reader with the necessary skills and tools to understand the concepts behind the work. The goal of the project is described briefly in chapter 3, while more attention is paid to the Materials & Methods in the following chapter. Here, the technical details of the system and the measurements performed are described. The usual section "Results" lists the insights gained and the chapters "Discussion" and "Conclusion" give a critical insight into the work.

Institution Profile

Institute for Research and Development on Advanced Radiation Technologies (radART) at the Paracelsus Medical University Salzburg

The institute was founded in 2007 (scientific head: F. Sedlmayer, administrative director: H. Deutschmann) to conduct applied research, develop technology, create methods and produce results for the advancement of treatment precision in radiotherapy. Optimized and safe healthcare solutions in the areas of medical physics, information technology, robotics, biology and radiation are being researched. Subsequently, these are implemented in patient care at the Salzburg county clinics where they are evaluated and continuously improved.

Prototypes and concepts are being developed and tested in collaboration with the medical and pharmaceutical industry. The integration of this new technology in the workflow of a clinical environment thus introduces innovations to industry and ensures that promising, new technological developments in Salzburg are widely supported by commercial partners.

The institute's priority is to be innovative in the clinical field and to ensure that prototypes, procedures and methods are developed to improve radio-therapeutic treatment of cancer patients. Thereby the Institute makes a decisive contribution to a more comprehensive use of efficient solutions in hospitals worldwide.

MedAustron

In 2012, a large-scale cooperation with the MedAustron facility was contracted, involving the development of concepts and software for the MedAustron centre built in Wiener Neustadt. MedAustron, a cancer treatment and research centre, is one of the most advanced facilities for research and ion therapy in Europe. The heart of this 200 million-euro investment, which is established and operated from the province of Lower Austria, is a particle accelerator developed in collaboration with CERN. The synchrotron (80 m ring diameter and 700 t of steel) accelerates the ions to 2/3 the speed of light and applies it precisely to the tumour.

To apply the radiation dose exactly to the tumour, a patient arrangement within millimetre precision is needed via advanced robotic patient positioning. The scientists of the radART Institute are renowned experts in this sector and provide the necessary software package to the total control of a linear accelerator in a software solution named ORA-ION. This program is derived from the institute's proprietary radiotherapy platform "open radART" (CE certified). Open radART has been developed over many years and is established in clinic mode at the University

Clinic for Radiotherapy and Radiation Oncology.

Imaging Ring

In addition, in the course of this cooperation, an innovative solution for Image guidance in photon- and ion beam therapy was designed, which is meanwhile installed at MedAustron: the so-called Imaging Ring. For construction, manufacturing and development as certified medical product, a spin-off company (Med Photon Ltd., CEO: H. Deutschmann) was founded in 2012. The unique design is based on two arms carrying X-ray source and flat panel detector mounted on a ring which is made of a highly strong aluminium-alloy. This solution, corresponding to a very light volumetric computed tomography (CT), is integrated within the patient treatment table, thus guaranteeing for utmost near-time position control prior to irradiation.

In total, the radART Institute is committed to rapid translation of scientific findings and technical developments into clinics, which is guaranteed by both: specific research focus and strong cross-linking to the Department of Radiotherapy and Radio-Oncology at the Paracelsus Medical University Clinics Salzburg.

Academic revenue is gained by publication of research results in renowned scientific journals, primarily supported by the work of students engaged within a PhD program (Dr. scient med.). The institute employs between 16 and 20 assistants and trainees, primarily IT engineers. To date, 12 doctoral theses are in preparation, another six students have already earned their doctoral degree.

Among them, Dr. Andreas Böhler's work has undoubtedly contributed to technical progress in adaptive radiotherapy, with a focus on tracking of moving targets. In a meticulous re-engineering and re-programming process, he developed a commercially available hardware device (Siemens Moduleaf), which was initially constructed for static fine conformation of field shapes only, towards a dynamic collimator, enabling real-time tracking of slowly moving tumours. Fortunately, but not surprisingly, the high quality of his dissertation was also recognized by acceptance for full-paper publication in "Physics in Medicine and Biology", one of the highest ranked scientific journals in the field.

Acknowledgements

Scientific work usually cannot be done by one person only. A number of people contributed to this, either morally, by providing valuable input or by carrying out certain tasks.

Above all, Univ.-Prof. Prim. Dr. Felix Sedlmayer provided not only valuable clinical input, but was always available for urgent questions or requests. Equally helpful by providing physical and technical input has proven Mag. Heinz Deutschmann, chief physicist, throughout the years at the institute.

Siemens OCS kindly provided background and development information about the Moduleaf system, including tools and design documents. Without their support, a re-engineering of this size wouldn't have been possible.

It is the people in the office who are responsible for a good working atmosphere. My colleagues at the radART institute provided continuous support in technical details and were always up for an interesting discussion. Furthermore, Christoph Gaisberger helped in evaluating the Gafchromic measurements while Harald Weichenberger and Markus Neuner assisted in hardware and software development work.

Last but not least I would like to thank my family. I want to especially mention my parents for offering me all the possibilities one can think of, their care and support throughout the years and their respect for all my decisions.

Thank You.

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Abstract

Radiotherapy is one of the most important methods used for the treatment of cancer. Irradiating a moving target is also one of the most challenging tasks to accomplish in modern radiotherapy.

In this thesis, a tracking system was developed by modifying an add-on collimator, the Siemens Moduleaf, for realtime applications in radiotherapy. As the add-on collimator works almost completely autonomously of the linear accelerator (LinAc), no modifications to the latter were necessary.

The adaptations to the Moduleaf were mainly software-based. In order to reduce the complexity of the system, outdated electronic parts were replaced with newer components where practical.

Verification was performed by measuring the latency of the system as well as the impact on applied dose to a predefined target volume, moving in the leaf's travel direction.

Latency measurements in software were accomplished by comparing the target and current positions of the leaves.

For dose measurements, a Gafchromic EBT2 film was placed beneath the target 4D phantom, in between solid water plates, and moved alongside with it.

Comparing the dose distribution on the film with a moving target between "tracking disabled" towards "tracking enabled" functions resulted in penumbra widths of 23 mm to 4 mm for 0.1 Hz sinusoidal movements with an amplitude of 32 mm, respectively. The maximum speed was therefore 20 mm/s. Latency was measured to be less than 50 ms for the signal runtimes.

Based on the results, a tracking-capable add-on collimator seems to be a useful tool for reducing the margins for the treatment of small, slow-moving targets.

1. Introduction

Radiotherapy is one of the most important methods to treat cancer. Based on the tumour statistics from 2006, more than 50 % of cancer patients in the USA, Australia and the UK could benefit from the use of radiation therapy throughout their treatment (Delaney et al. 2005).

During treatments with a linear accelerator (LinAc), high energy photons are irradiated onto the human body which cause secondary electrons in human tissue. These electrons then result in DNA damage, thus destroying cells if the damage is not repaired.

In order to increase the effect on cancerous tissue, this irradiation is performed in multiple fractions, maximising the effect of different repair mechanisms in healthy tissue and tumour cells (Ahmad et al. 2012).

During external beam radiotherapy, optimal field conformation is a prerequisite for delivering curative doses to a target volume while sparing critical organs at risk (OAR).

In physical terms, this means that as much dose as possible must be applied to the tumour, but as little dose as possible has to be applied to the remaining tissue.

The introduction of MultiLeaf Collimators (MLCs) into daily routine enabled individual adaptation of treatment fields to a given shape of the target volume. Multiple, individually movable leaves shield the radiation where it is not desirable.

If the target is moving, however, organ motion may lead to a blurring of dose distributions, bearing likewise the danger of significant underdosages within the planning target volume (PTV) and overdosages in adjacent, normal tissues. The specific treatment technique is not as important as are the characteristics of the motion and the amplitude of the movement (Mzenda et al. 2010; Bortfeld, Steve B Jiang, and Rietzel 2004).

There are several strategies to apply sufficient dose to a moving target, two of them are mentioned here for comparison: The first possibility is to increase the irradiation margins, so that the tumour remains within the treatment fields throughout its entire movement (T. Inoue et al. 2013). As a consequence, however, a large amount of healthy tissue is included in the high-dose area.

Another possibility is the continuous adaptation of a treatment field to the moving target. This, however, requires the close cooperation of various subsystems, such as sensing system, control system and beam shaping tools (Geoffrey et al. 2012; Guckenberger et al. 2009; Voort van Zyp et al. 2009; Herk 2004).

As of today, only several simulations have been performed and some reference systems have been installed, investigating the use of built-in, dynamic MLCs for tracking applications. For instance, the Siemens (Siemens AG, Erlangen, Germany) 160 MLC was upgraded with tracking algorithms, using the built-in onboard kilovoltage (kV) imaging system as tracking input (Tacke et al. 2010; Krauss et al. 2012).

Another feasibility study demonstrated the use of the Varian (Varian Medical Systems, Palo Alto, USA) Millenium dynamic MLC (DMLC) in combination with an independent realtime position monitoring system for intensity modulated radiotherapy (Sawant et al. 2008; Paul J. Keall et al. 2006).

The CyberKnife system (AccuRay Inc., USA), however, is to our knowledge the only clinical implementation of a system capable of tracking moving targets (Hoogeman et al. 2009; Jereczek-Fossa et al. 2013).

In this thesis, a system using an add-on MLC to dynamically adapt the shape of the beam to changed conditions is presented. This device works almost completely autonomously, without interfering with the LinAc, which, therefore, does not need to be modified.