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Web platform for research on IMRT algorithms

***Abstract**. The recent trends in software development force the transition from classical desktop-based programs into distributed systems offered over the Internet. The authors adapt this approach to the design of a collaborative radiotherapy planning system. The end users of the system are radiotherapy physiologists, medical staff, software developers and researchers developing new algorithms. A general concept and necessary components of such a system are presented.*

Streszczenie.** Aktualne trendy w rozwoju oprogramowania dyktują coraz powszechniejsze zastępowanie programów przeznaczonych do pracy na systemach stacjonarnych w systemy rozproszone dostępne za pośrednictwem sieci Internet. Autorzy niniejszego artykułu wykorzystują tę ideę do stworzenia systemu oprogramowania wspierającego współpracę fizyków radiologów, lekarzy, programistów oraz badaczy zajmujących się rozwojem algorytmów planowania radioterapii z modulowaną intensywnością dawki (IMRT). Artykuł przedstawia ogólna koncepcję takiego systemu oraz podstawowe komponenty z jakich powinien się składać. **(Internetowa platforma do badań nad algorytmami IMRT)

Słowa kluczowe: IMRT, radioterapia, system wspomagający współpracę badawczą, system Internetowy
Keywords: IMRT, radiotherapy, research collaboration software, Internet system

Introduction

Modern intensity modulated radiotherapy (IMRT) planning is based on sophisticated, expensive treatment planning software (TPS) designed to work with an IMRT apparatus (linear accelerator - LINAC). The main purpose of this software is to calculate control parameters for the LINAC to deliver prescribed by the therapist dose of radiation to the targeted tumor. At the same time it is necessary to minimize doses delivered to a healthy tissue with special attention paid to sensitive organs. These requirements are satisfied by searching for a Pareto-optimal solution of a multi-objective, constrained optimization problem.

The paper presents a concept of a general, web based, open source software for radiotherapy planning along with a proof of concept implementation of two scenarios of usage: ROI transformation used for replanning during the therapy and fluence map optimization. Such a system is not intended to replace commercial codes, but can serve as an effective and convenient playground for development and testing of new algorithms. The modular back-end of the system is based on open-source scientific code which provides flexibility, scalability and extensibility. Besides researchers the service is also targeted on medical staff, thus the primary goal of the system is user friendliness and reliability. The goal was achieved with carefully designed user interface oriented for medical view on radiotherapy planning.

The overall concept

The typical usage scenario of the system starts with uploading a dataset prepared by medical staff (see Fig. 1). The dataset contains CT images of a patient with delineation of ROIs (regions of interest). These usually are: PTV (planning target volume) representing the region which must be irradiated with the highest doses, OAR (organs at risk) and NT (normal tissue). Additionally the user may provide information about configuration of the radiating beams (positions of radiating head and its angle) and constraints about the doses which should be applied to the specified ROIs. Having the information the system optimizes intensity patterns of each beam to obtain desired doses in the ROIs. As a result patterns of fluences (maps of intensities of radiation for each beam) is produced in the format suitable for radiotherapy device.

To provide a system suitable for a development by different scientific groups we propose a distributed, multi-platform code built as a collection of modules cooperating on the web-service based platform. This approach encourages potential developers to build their own codes and to merge them with the existing system, thus reusing already existing infrastructure and functions.

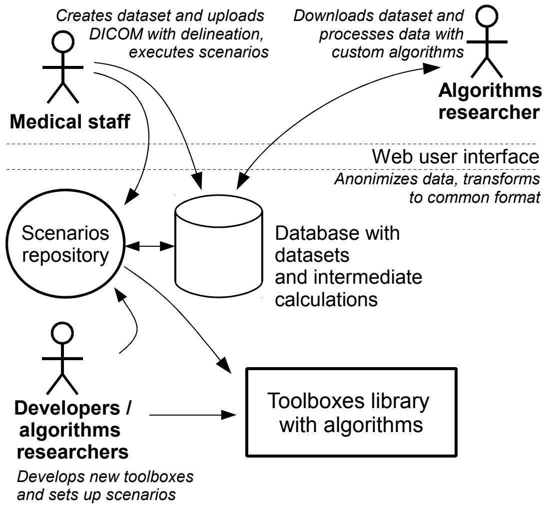
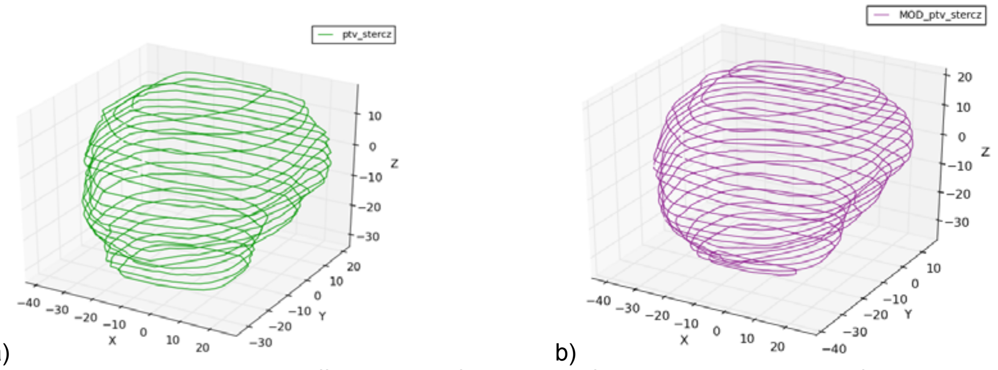


Fig.1. General concept and functional use case

The model of communication between the components is based on centralized database with datasets collecting intermediate calculations. This allows to achieve general compatibility at a low cost and forces only minimal requirement on each component. Additionally a message queue with a central dispatcher makes it possible to provide inter-component communication on a satisfying level of safety and/or confidentiality.

Data formats and implementation

DICOM format is the obvious choice for a medical software. It is widely accepted and used in practically all other systems, thus it must be the basic format of all input and most of the output files produced by the system. However, DICOM is old and often ineffective when size and speed of data transfer are considered. For those reason we must accept that some modules can use other formats, tuned for their needs. Web service model is especially tolerant for data conversions. Practically any data format can be used inside the system, assuming that a proper converter is provided.



a) b)

Fig.2. a) Original delineation done by medical staff and b) modified regions of interest – a screen-shot of the real system. The ROI is translated by 5 mm along Y axis and Z axis. The translation is visible by inspecting the values on the axes.

Distributed architecture of the designed system causes extra problems that have to be addressed. Apart from the most important one, which is the protection of the sensitive medical data of patients, a problem of large amount of data which need to be transferred for remote processing over the Internet and interchanged between processors. Data transfer over the Internet is protected with the SSL protocol thus providing the confidentiality. A large amount of data is reduced by providing the possibility to upload compressed archives of data (e.g. folders with DICOM datasets compressed with DEFLATE algorithm).

The data interchange between processors is optimized with the use of common storage space available to all processors. Instead of transferring the whole dataset to different computational processors a reference to the objects (files) in this common dataset is transferred.

The core of the system is written in Python running under Ubuntu operating system. The user front-end is based on Python Flask web framework, painlessly integrating itself with the computational modules also written in Python and allowing to create a simple, yet intuitive and powerful user interface. The processing tools employ algorithms from VTK 5 library [2].

Example 1 – ROI transformation

One of the steps of Radiotherapy planning is a delineation of ROIs on the basis of CT or MRI images which is performed by a physician. This activity is tedious and time consuming and it should be done at least semi-automatically. Additionally, between the time that the delineation has been prepared and the real treatment is started, the internal structure of the patient can change. The change can be due to the patient's weight loss, difference in hollow organ or cavity filling, or could be related to the change in patient's position during the therapy. Such changes can be detected and estimated using a few X-ray images taken just before the treatment. In order to alleviate the need of manual redelineation of the tumor volumes and organs at risk, an automatic tool developed by the authors could be used. The tool applies a set of medical imaging algorithms and is composed of a few steps. More details on the processing tool can be found in [3].

In the presented scenario a physician uploads a dataset which contains a file with RT Structure Set (ROIs) and an optional slice image to automatically detect voxel resolution. After selecting the ROI for processing a form with transformation parameters is presented. The user can prescribe:

- translation in three axes x, y and z (dx, dy, dz),
- rotation angles around the axes (α, β, γ),
- mode of rotation (around the ROI's center of gravity or around the center of the base of the ROI),
- smoothing factor.

The scenario proved to be a useful tool for radiotherapy replanning - mainly due to its friendly user interface, a relatively small number of required parameters and the visualization of the results of transformations (see Fig. 2).

When the results are satisfying to the physician he can download a modified dataset with additional ROI and use it for preparing an updated plan which now takes into account the changed internal organ structure.

Example 2 – Fluence map optimization

In IMRT the patient is treated with several beams delivered to the body by the LINAC head placed at different positions around the patient's body. The head is equipped with a device called multileaf collimator made up of multitude (usually from 80 to 160) of thin leaves which can move independently. As the head rotates around the body, the leaves change the aperture shape, shaping the beam of radiation to deliver prescribed dose of radiation to the tumor and minimize dose received by healthy cells.

The key part of IMRT planning is optimization of the multileaf opening. For the planning purpose the radiation beam is divided into many (several thousand) small slices called beamlets. Each beamlet may have different intensity of radiation. These intensities, named fluences, become design variables for the optimization. This kind of approach is referred to as Beamlet-based Inverse Planning (BBIP). Each position of the LINAC's head is represented by a fluence map (consisting of hundreds to thousands of beamlets) and all maps are optimized in search for the best dose distribution. The active beamlets set contains only these beamlets which intersect the targeted volume (PTV), thus the search space for the optimization is reduced.

The doses are typically calculated on a regular grid covering part of the body exposed to radiation (planning grid). The grid consists of hundreds of thousands to even millions of cubic voxels. A small, relatively rough grid for simplified IMRT study case is presented in Fig. 3.

To optimize the fluence map one needs to calculate partial doses deposed in voxels by every single beamlet. This is the basis to connect objectives with the design variables. The problem is solved by minimization of a few objective functions. The most important are: the sum of deviations between the doses prescribed for tumor volume, the maximal doses in healthy tissue, and maximal doses in OARs. Additionally the constrains restricting the maximum doses in healthy tissue/sensitive organs can be specified.

The fluence map optimization can be realized by many algorithms. The multi-objective optimization can be solved in the sense of searching for Pareto front built of solutions best in terms of at least one objective. The choice of the single solution is then usually done by a human – a decision maker.

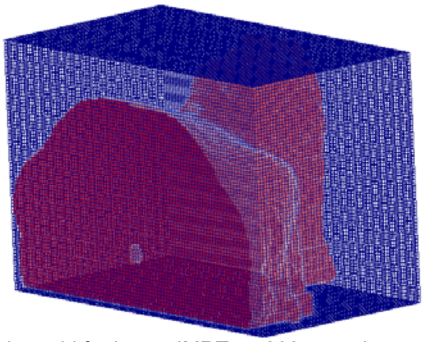


Fig.3. Planning grid for larynx IMRT: 442624 voxels

The framework for multi-objective optimization consists of three basic modules: a pre-processor converting DICOM dataset into text format accepted by optimizers, an optimizer module, and a post-processor which in turn converts the optimizer's output back to a DICOM dataset which can be compared to results from a commercial planning software. In the current paper we focus on the web platform design, so the optimization task will be presented very briefly. We want to emphasize, that the main idea presented in this work is to build a web-accessible framework which allows to test many competitive algorithms in common environment.

In order to check flexibility and modularity of the platform, the authors tested Particle Swarm Optimization of the fluence maps and compared the results with those obtained by a cooperating research group working on application of Genetic Algorithms [6].

Our optimization algorithm uses as its input a preliminary radiotherapy plan prepared with a commercial software (Varian Eclipse [4]). In this plan fluences of all active beamlets are normalized (set to 1.0). The pre-processor prepares a sparse matrix representing doses deposed by all active beamlets in all voxels assigned to the patient's body (the dark red part of the grid in Fig.3). The matrix is huge – its number of rows is equal to the number of body-assigned voxels (181292 in the example shown in Fig. 3) and the number of its columns is equal to the number of active beamlets (3×2688 in the example).

Fig.4. Voxelized' details of the IMRT study case: mandible, spinal cord, brainstem and PTV (larynx tumor)

In the process of simplification (digitization of the model on the basis of the planning grid) we skip some information: the doses are connected with the volume of voxels (we use a stepwise approximation of the continuous dose distribution) and the smooth contours of body organs are represented by stepped volumes build of voxels assigned to them. Example “digital” ROIs from the IMRT study are presented in Fig. 4.

Solution of the problem for reduced number of design variables is shown in Fig. 5. It is quite satisfactory in terms of dose histogram for PTV (66 Gy was chosen as the desired average dose), and seems to be quite promising.

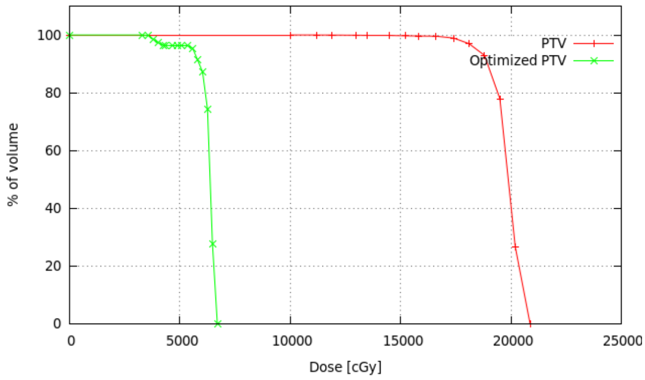


Fig.5. Histogram of doses delivered to PTV obtained after PSO optimization (green line) compared to the initial one (the red line)

Conclusions

The presented concept of a web and cluster based computational back-end and the selected programming tools allowed authors to build very quickly and efficiently a useful system for testing radiotherapy planning algorithms. It proved its value by facilitating the cooperation between the three groups of researchers from Maria Skłodowska-Curie memorial Cancer Center, Polish Academy of Science and Warsaw University of Technology.

The optimization results are not yet comparable to the results of the professional software. Nevertheless, the environment proved to be very effective for development of the new algorithms. Web interface allows to effectively cooperate with a medical staff evaluating the results.

The further development of the system is expected to focus on more elaborate and refined architecture of the back-end of the system supported by additional team cooperation functionality. This will allow a better data synchronization and interchange between research groups. The constant development of new algorithms and refinement of existing ones is also planned.

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