Important notice!

The work presented here had excellent results on simple sites with few objectives.

Unfortunately, when generalizing to complex cases with more objectives, the method of fast re-planning using Lagrangian multipliers behaved unpredictably. Not too bad, but also not good enough for clinical application.

As such, this poster is useful to learn about what does not work.

Sorry!

Fast Online Plan Adjustment For Adaptive Radiotherapy Evaluated For Prostate And Cervical Cancer

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Introduction

To account for anatomy changes during treatment, the CTV is expanded to a PTV, and additionally couch translations based on markers can be used. However, they cannot correct for (unexpected) large deformations, like e.g. the seminal vesicles for prostate patients or the uterus in cervical cancer.

Online re-planning based on an in-room acquired CT-scan can compensate for any anatomical change, while reducing the dose to healthy tissue. For online adaptive treatment planning, the re-planning has to be fast (thus automated), and the resulting plan has to be clinically acceptable.

Material and Methods

Automated treatment planning using wish-lists

Our automated treatment planning [1] uses a wish-list, which consists of constraints and prioritized objectives. The wish-list is optimized using our 2-phase ϵ-constraint ($2p\epsilon c$) method [1]. In the $2p\epsilon c$ method, all constraints are strictly obeyed in the final plan. The objectives are optimized in priority, and then constrained to maintain the current quality of the plan.

In the wish-list for the cervix-uterus site (table 1), constraints are defined for the maximum-dose in the CTV (107% of the prescribed dose), bladder and skin. Also, a ring of $10\ mm$ thick at $10\ mm$ distance of the CTV is constructed with a maximum-dose of 85% of the prescribed dose to enforce conformity.

For the objectives, the highest priority is to irradiate the target as well as possible, using a TCP model. The attained target dose then becomes a constraint to guarantee that the quality does not deteriorate when minimizing the dose to the rectum. The attained dose to the rectum is then also constrained when minimizing the dose to the bladder, and later to the unspecified tissue.

A wish-list can be used as a template for a site and results in high-quality treatment plans, which are created without user-interaction. However, the iterative nature of the $2p\epsilon c$ method results in several optimizations.

Fast re-planning

To overcome the disadvantage of having many optimizations, a new method was developed [2]. With the theory described in [1], information in the form of *Lagrange multipliers* from the optimization for the planning CT is used to generate a new treatment plan for a repeat CT, in just a single optimization.

Application: Best plan-of-the-day or cumulative?

The practical workflow of the method is proposed as follows: Prior to treatment, a plan is made using the $2p\epsilon c$ method. Then for each fraction, a repeat CT is acquired in-room and segmented. Then a new treatment plan is generated using the fast Lagrange multiplier method.

Two adaptive strategies have been researched for the plan generation of the current fraction: 1) a *best plan-of-the-day* and 2) a *cumulative* approach that takes into acount the already delivered dose in the previous fractions, based on deformable image registration.

The plans made were based on the CTV. We have validated our fast online planning method on 2 cervix-uterus cases with hypothetical IMRT boost, and 10 prostate patients. 7 beams were used for both sites.

The wish-list for the prostate site is similar to the one for the cervix-uterus, however it has 2 CTVs: prostate and seminal vesicles with prescribed doses of $78\ Gy$ and $72.2\ Gy$ respectively, and has thus 5 objectives. The maximum-doses are defined accordingly. The cervix-uterus is assumed to be treated in 2 fractions, the prostate in 3.

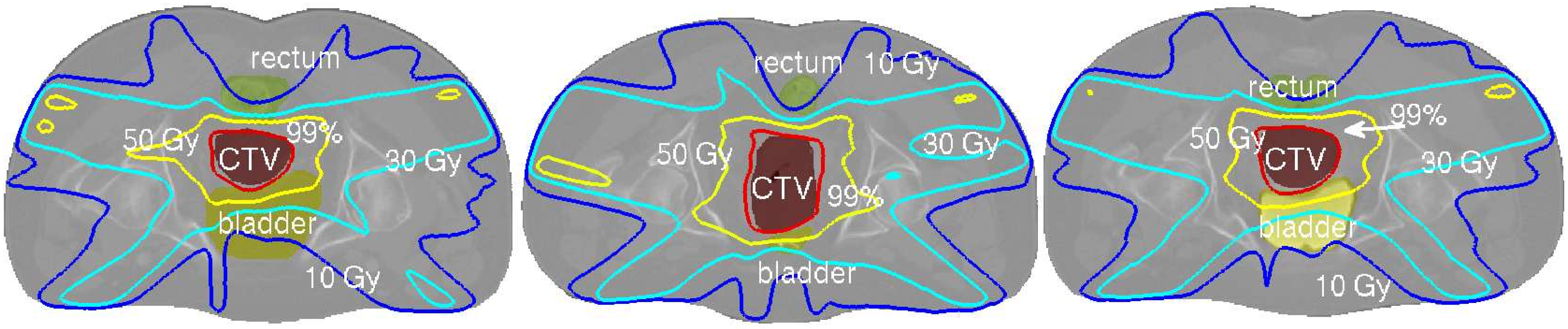

Figure 1: Dose distributions for the cervix-uterus case. Depicted are the CTV, rectum and bladder and isodose lines for 99% (red) of the prescribed dose, $50\ Gy$ (yellow), $30\ Gy$ (cyan) and $10\ Gy$ (blue). The bladder filling changes significantly: the volume for the planning CT (left) was $234\ cc$, $31\ cc$ for the 1st fraction (middle) and $78\ cc$ for the 2nd fraction (right). Despite the large bladder volume changes and CTV deformations, the dose adjusts accordingly.

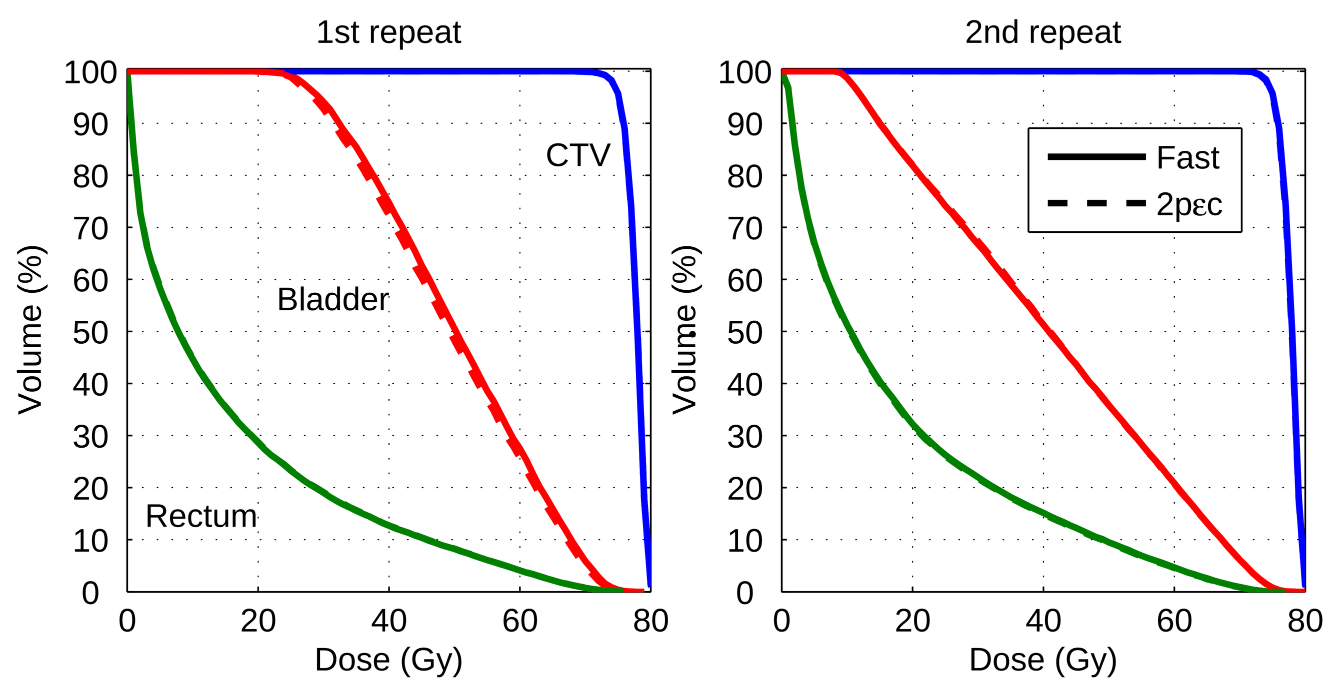

Figure 2: Comparison between full $2p\epsilon c$ optimizations and fast optimizations. Our Fast online method results in nearly identical plans.

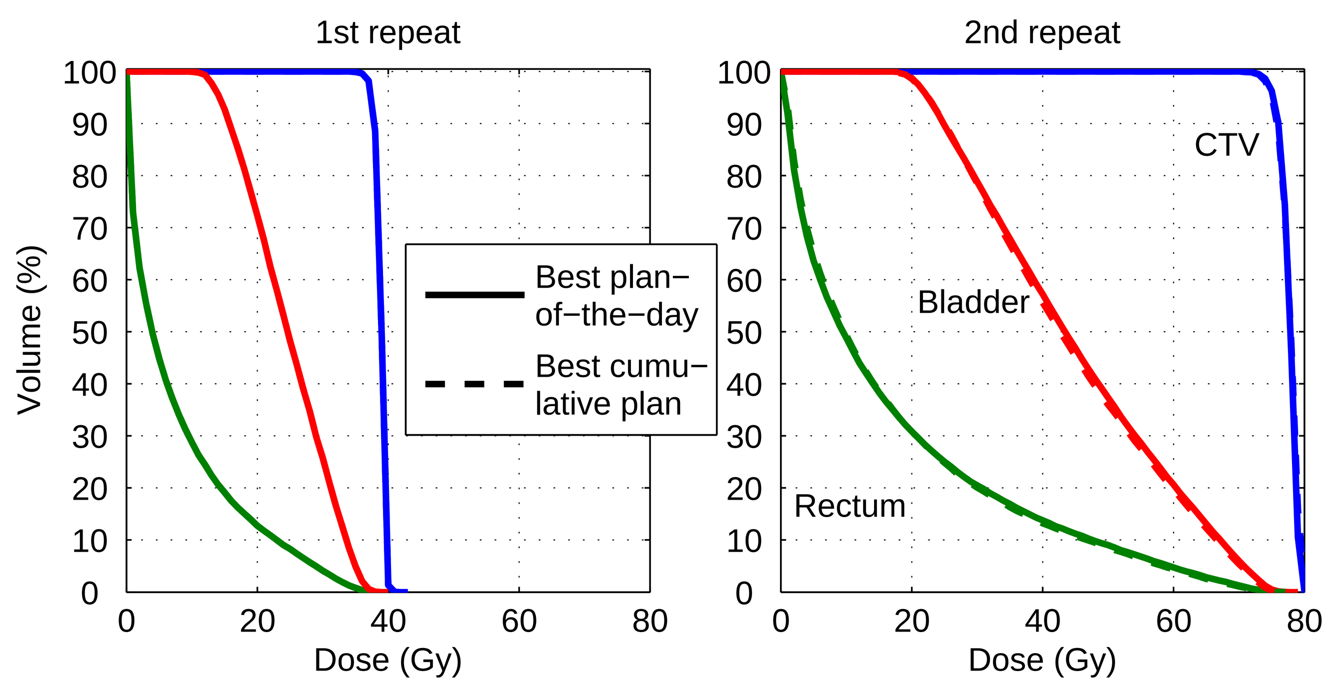

Figure 3: Comparison of accumulated dose between best plan-of-the-day approach and cumulative. Not taking into account previous fraction doses results in nearly identical plans as when accounting for previously delivered dose.

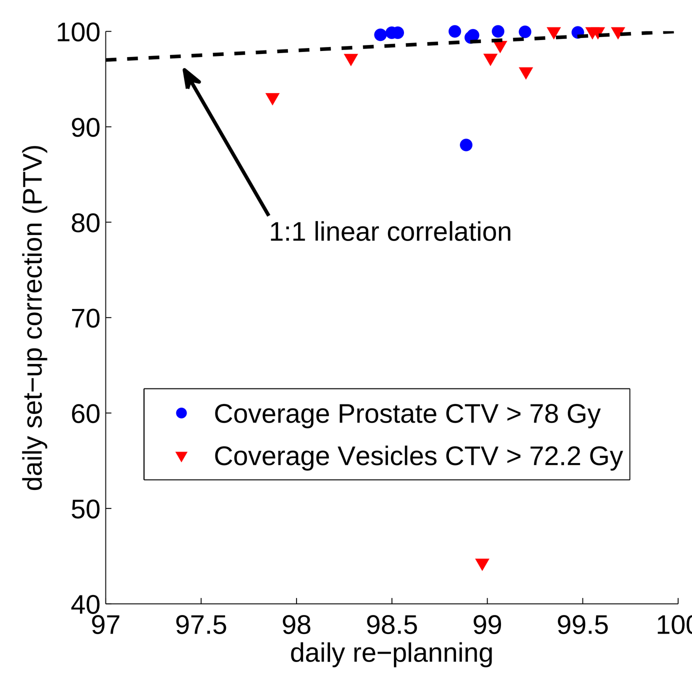

Figure 4: Comparing CTV coverages for 10 prostate patients between the PTV approach with daily set-up corrections and daily re-planning. Daily re-planning yields higher CTV coverages.

Table 1: Wish-list with constraints and prioritized objectives for cervix-uterus.

Constraints

Volume	Type	Limit
Cervix-uterus (CTV)	maximum	$80\ Gy$
CTV Conformity Ring	maximum	$62.9\ Gy$
Bladder	maximum	$70\ Gy$
Skin	maximum	$50\ Gy$

Objectives

Priority	Volume	Type	
1	Cervix-uterus (CTV)	maximize TCP	$D^p = 74\ Gy$
2	Rectum	minimize mean	
3	Bladder	minimize mean	
4	Unspecified Tissue	minimize mean	

Results

Figure 1 shows the dose for the best plan-of-the-day for the planning CT and the 2 fractions for the cervix-uterus case. Both the $2p\epsilon c$ method (planning CT) and the fast method (1st and 2nd repeat CT) result in acceptable plans. Figure 2 compares the DVHs for the $2p\epsilon c$ method and the fast method. Figure 3 compares the best plan-of-the-day approach with the cumulative approach, where the dose given in the previous fractions is non-rigidly transformed to the current CT and then a fraction is planned on top of it.

For the 10 prostate patients, a quantitative study was done comparing the CTV coverages between online re-planning and today's practice, where daily set-up correction is used based on markers and a single PTV plan (the prostate CTV is extended with a $5-5-6\ mm$ non-uniform margin and the seminal vesicles with $8\ mm$ uniform margin). The results are shown in figure 4 and table 2. The mean plan optimization times are given in table 3.

Table 2: See also figure 4. For the adaptive approach, coverage of the CTVs is higher with less variation. Also, dose to the rectum and bladder are lower than for the clinical approach.

	adaptive		clinical	
	mean	SD	mean	SD
coverage Prostate CTV $> 78\ Gy$	98.9%	0.33%	98.6%	3.7%
coverage Vesicles CTV $> 72.2\ Gy$	99.1%	0.58%	92.6%	17.1%
coverage Rectum $> 64.74\ Gy$	9.2%	2.9%	16.9%	6.2%
mean dose Bladder	$26.6\ Gy$	$13.9\ Gy$	$31.9\ Gy$	$15.3\ Gy$

Table 3: Mean optimization times for 10 prostate and 2 cervix-uterus patients.

	prostate	cervix-uterus
Full $2p\epsilon c$	$81\ s$	$39\ s$
Fast online	$18\ s$	$12\ s$
Speedup	$4.5\times$	$3.3\times$

Conclusions

We have presented an online planning method that is capable of producing good treatment plans compared to our more robust $2p\epsilon c$ method. A speed-up factor of $3.3-4.5$ is seen for prostate and cervix-uterus cases, making it possible to produce a new treatment plan online in $12-18$ seconds. Larger speed-ups are possible when more objectives are defined in the wish-list.

References

[1] Breedveld S, Storchi P and Heijmen B 2009 The equivalence of multi-criteria methods for radiotherapy plan optimization *Phys. Med. Biol.* **54** 7199-7209 [2] Breedveld S, Storchi P, Bondar L, Vásquez Osorio E, Hoogeman M and Heijmen B 2010 A fast and accurate automated method for online re-planning in adaptive radiotherapy *submitted*