ON THE MATTER OF FORWARD VERSUS BACK PROJECTION

for Radiotherapy 3D Dose Reconstruction

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Introduction

Both forward and back projection 3D dose reconstruction techniques have been researched for several years, with commercial solutions utilizing both approaches. This document aims to explain differences of the two techniques with respect to in-vivo patient QA.

- **3D Forward Projection:** The delivered fluence upstream of (before) the patient is computed and then forward-projected into an image of the patient to reconstruct the delivered dose. Forward projection techniques can utilize a measurement device upstream or downstream of the patient.
- **3D Back Projection:** The delivered fluence downstream of (after) the patient is computed and then back-projected into an image of the patient to reconstruct the delivered dose. Back projection techniques always utilize a measurement device downstream of the patient.

There can be a perception that 3D back projection techniques are preferable due the fact that the exit detector measurement contains patient information. It will be described herein why this perception is not actually correct and why a forward projection technique is, in fact, preferable.

Discussion

Forward projection techniques generally follow a two-step process for dose reconstruction[1,2]

1. Compute the delivered fluence.
2. Calculate (forward project) dose to the patient.

This two-step process offers the advantage of being able to isolate and evaluate the different components of the radiotherapy delivery. For example, if MLC leaf positions are measured independently of panel image intensity variations caused by output and patient changes, then the effect of errors caused by MLC leaf motion can be accurately represented in the reconstructed dose. This is, in fact, the method used by Sun Nuclear's PerFRACTION™ pre-treatment and in vivo monitoring modules for the dose reconstruction process. The impact of each component is identified and computed individually.

Back projection techniques[3] implicitly combine these two steps into one. This is detrimental to isolating and addressing the source of errors, as all variations – including machine and patient-related errors as well as other beam perturbations that would have no impact on the delivered patient dose – are aliased as fluence errors when the exit detector signal is converted to delivered fluence in the back projection process. Thus:

- a patient set-up error will manifest as a fluence error
- a gantry rotation error will manifest as a fluence error
- a patient anatomy change will manifest as a fluence error
- an accelerator output variation will manifest as a fluence error
- an error in an MLC leaf or leaves will manifest as a fluence error
- objects in the path of the exit beam will manifest as a fluence error
- variations in panel response will manifest as a fluence error

Discussion *Continued*

As a result, 3D back projection makes it very difficult – if not impossible – to isolate both the source and impact of the errors that can occur in a radiotherapy delivery. Stated in another manner:

1) Aliasing the detector data into fluence is often inconsistent with reality and will often produce an inaccurate delivered fluence
2) This fluence often yields an inaccurate patient dose reconstruction
3) Inaccurate patient dose reconstruction results in many errors being misrepresented or even lost.

The situation also results in the need for several steps and corrections in processing the EPID image data[3], leading to an inherent uncertainty and additional questions regarding the accuracy of the final dose distribution that is created.

Example: Patient Weight Loss

Inaccurate patient dose reconstruction, via 3D back projection, can be illustrated in an example commonly encountered in radiotherapy: patient weight loss. In such circumstances, the dose to the target can become errantly inhomogeneous as the radiological pathlengths upstream of the target are reduced. Furthermore, high dose regions just distal to the target will extend further downstream for the same reason. These changes would be correctly represented by a dose reconstruction technique that first, accurately quantifies the delivered fluence, and second, computes patient dose with an image taken at the time of treatment (e.g. CBCT).

For back projection techniques however, weight loss will result in an increased signal in the EPID and be interpreted as an increased delivered fluence. When back projected onto the planning CT (or an image based on the planning CT), the dosimetric impact of this higher fluence would most likely be incorrectly represented as increased dose throughout the patient. It's of interest to note that this is the same dosimetric result that would occur in the event of a real errant increase in accelerator output since all errors are aliased as fluence errors with standard back projection techniques. It would therefore be difficult to correctly identify the root cause of the dose increase. And if CBCT images were utilized, this error could in fact be doubled if not accounted for properly, as the perceived increased fluence would be back-projected into the reduced patient volume.

Conclusion

The most accurate way to identify and understand the impact of errors on the 3D dose deposited in the patient during a radiotherapy treatment is to utilize a 3D forward projection technique.

The process consists of the following steps:

1. Compute the delivered fluence based on an accurate accounting of each of the fluence constituent components
2. Compute dose resulting from that fluence using a 3D image of the patient taken either during treatment or as close to treatment time as possible.

Such an approach allows for proper understanding and quantification of the dosimetric impact of the various errors that can occur in a radiotherapy treatment.

1 Kapatoes JM, Olivera GH, Balog JP, Keller H, Reckwerdt PJ, Mackie TR. On the accuracy and effectiveness of dose reconstruction for tomotherapy. Phys Med Biol. 2001 Apr;46(4):943-66.

2 Lin MH, Li J, Wang L, Koren S, Fan J, Forkal E, Ma CM. 4D patient dose reconstruction using online measured EPID cine images for lung SBRT treatment validation. Med Phys. 2012 Oct; 39(10):5949-58.

3 van Elmpt W, McDermott L, Nijsten S, Wendling M, Lambin P, Mijnheer B. A literature review of electronic portal imaging for radiotherapy dosimetry. Radiother Oncol. 2008 Sep; 88(3):289-309.

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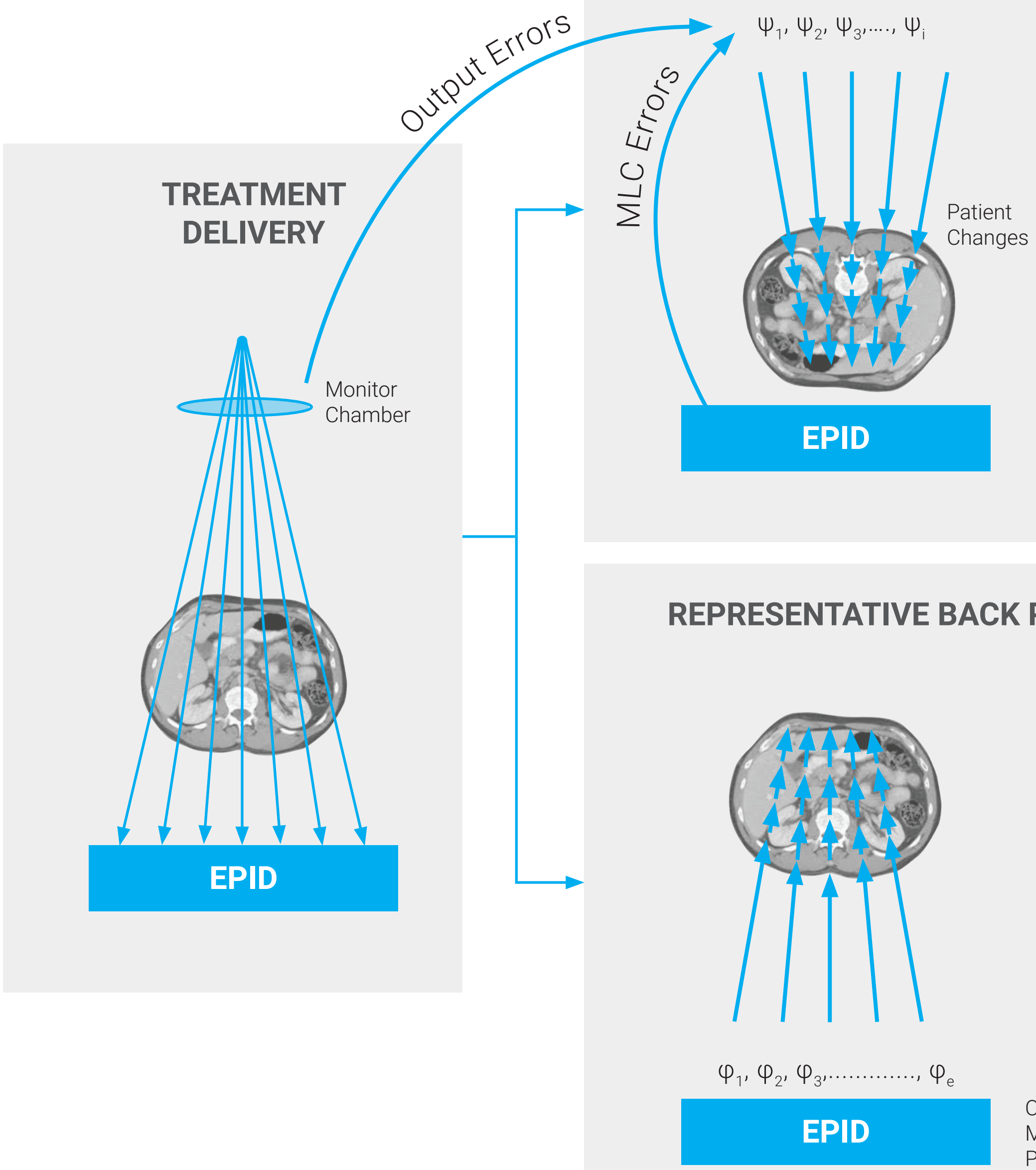

PerFRACTION FORWARD PROJECTION TECHNIQUE

Impacts of output and MLC are accounted for separately in computing fluence values $\psi_1 \ldots \psi_i$

Patient set-up and patient anatomy errors are accounted for by using the daily CBCT.

When a CBCT is not available, any discrepancy in EPID signal due to patient set-up or anatomy error can be quantified because output and MLC errors are known though $\psi_1 \ldots \psi_i$

REPRESENTATIVE BACK PROJECTION TECHNIQUE

Impacts of output, MLC, Patient set-up, and Patient anatomy errors are all aliased into the fluence values $\varphi_1 \ldots \varphi_e$ leading to poor specificity.