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Dose verification of fast and continuous scanning in proton therapy

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PURPOSE

- The interplay between organ motion and pencil beam scanning impairs the homogeneity of the delivered dose distribution [1]. Applying the same field multiple times with proportionally reduced dose – so-called rescanning – can average out such interferences [1, 2].
- However, rescanning accumulates dead time when irradiating in a discretized ‘step-and-shoot’ manner. Thus, fast and continuous scanning could be desirable for such cases, which necessitates a dedicated beam monitoring and verification system to ensure safe treatment.

BEAM MONITORING ON GANTRY 2

- PSI Gantry 2 is clinical operation since November 2013 using spot scanning (a form of discrete dose delivery).
- It is designed for fast, continuous dose delivery and offers an additional mode of operation – line scanning.
- The present beam monitoring system in the nozzle [3] comprises (a) two planar ionization chambers to measure the dose at one strip monitor to reconstruct the lateral beam position
- The enhancements to this system required for operation in line scanning mode are subject of this study.

WHAT IS LINE SCANNING?

- Scanning the beam continuously along straight lines without turning it off yields a significant reduction in dead time compared to spot scanning [4].
- We modulate the dose [5] by adjusting (a) the scan speed v and (b) the beam current I.
- Regions of low dose correspond to a high local v or/and a low I (cf. figure 2).
- The delivery of highly modulated fields requires an exceptionally high frequency of speed and current modulation.
- The verification system must be able to react on the same time scale.

DOSE VERIFICATION CONCEPT

- Aim: monitor beam current and beam position during patient irradiation to fulfill current safety standards
  - Level 1: Real-time verification to prevent radiation accidents
    (a) continuous monitoring of the beam current with nozzle dose monitors as well as (b) continuous monitoring of the beam position with hall probes in the scanner magnets
  - Level 2: Online verification to assess and examine delivery accuracy
  - Level 3: Validation of line profiles with the nozzle strip monitor after the application of each line

REAL-TIME VERIFICATION – MONITORING BEAM CURRENT AND POSITION

- Beam current: signal of the primary dose monitors in the gantry nozzle
- Beam position: signal of the Hall probes in the scanner magnets

ONLINE VERIFICATION – VALIDATING INTEGRAL LINE PROFILES

- Step 1: A single line is delivered under real-time verification before its integrated signal in the strip monitor is read out.
- Step 2: The expected line profile is calculated from the speed and current modulation contained in the delivery tables.
- Step 3: Measured and predicted profiles are compared (e.g. strip sum, center of gravity, residuals, 1D y analysis) [6].

CONCLUSION & OUTLOOK

- We consider line scanning well-suited for efficient rescanning of moving targets because of its minimized dead time.
- The combination of real-time and online verification ensures safe beam delivery.
- Clinical integration of the prototype verification system requires precise synchronization of beam delivery and monitoring. Additionally, strategies on how to resume after interlocks triggered during and after line application must be implemented (cf. figures 9 and 10).
- Furthermore, line scanning requires enhancements to the treatment planning system. Optimizations could run on line segments instead of beam spots.

REFERENCES


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