AAPM 2021
JULY 25–29 | VIRTUAL
63RD ANNUAL MEETING & EXHIBITION
CREATIVE SCIENCE. ADVANCING MEDICINE.

A direct machine-specific parameters incorporated Spot-scanning Proton Arc (SPArc) algorithm

Gang Liu

Cancer Center, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, China
Department of Radiation Oncology, Beaumont Health System, Royal Oak, MI, United States

Disclosure:

- The study in part is supported by Ion Beam Application S.A.
- There is an issued patent related to the proton arc therapy

Purpose

- Challenges:
  - Each proton system has its own spot irradiation sequence
  - Each gantry or couch has its mechanical limitations

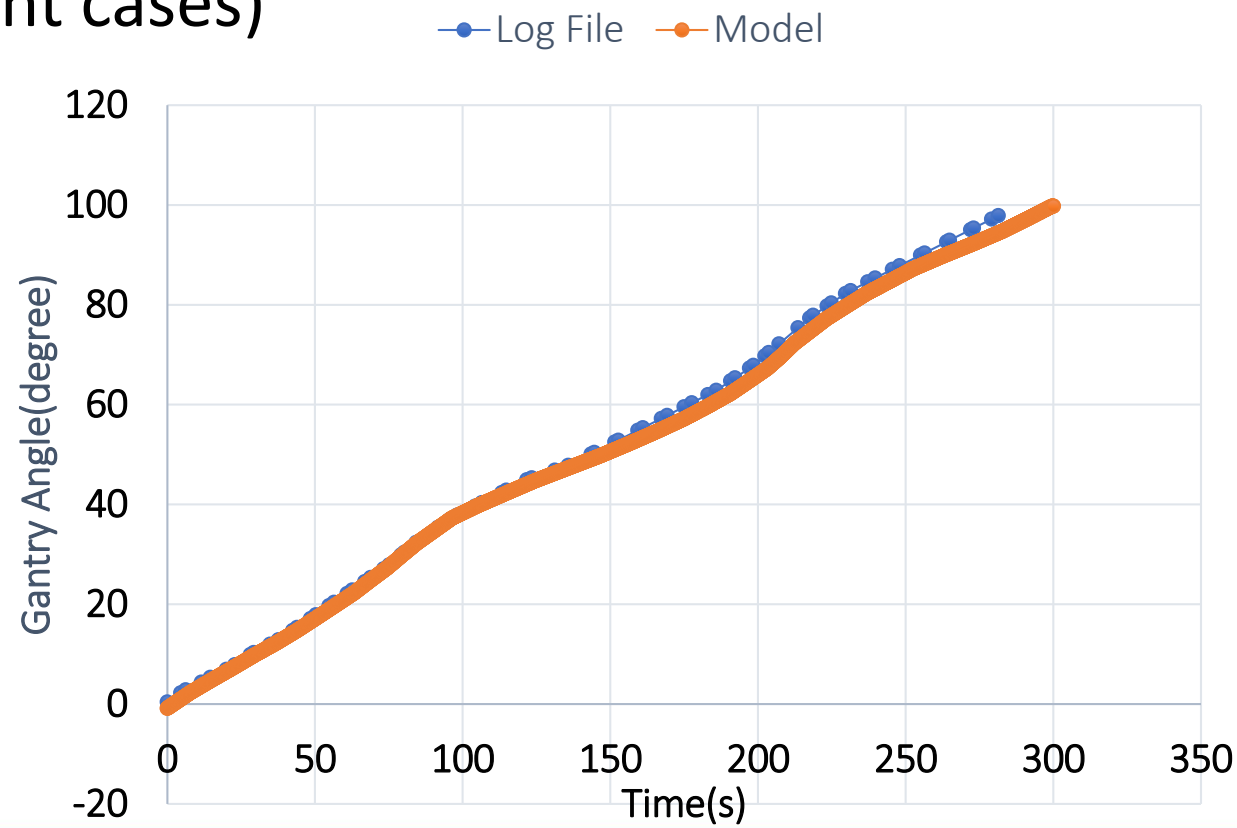
- To address the challenges of generating a deliverable and efficient SPArc plan for a specific proton therapy system.

Method and Material

- Incorporate the machine-specific parameters (machine limitation and spot delivery sequence) into SPArc optimization
- SPArc delivery sequence (DSM_{arc}) modelling
  - (a) machine specific parameter modelling
    - including maximum gantry speed, acceleration, and deceleration speed
  - (b) irradiation parameter modelling
    - including energy switching and spot switching, spot delivery sequence and time
- SPArc delivery sequence (DSM_{arc}) can predict gantry rotation speed and beam status(ON/OFF) accurately.

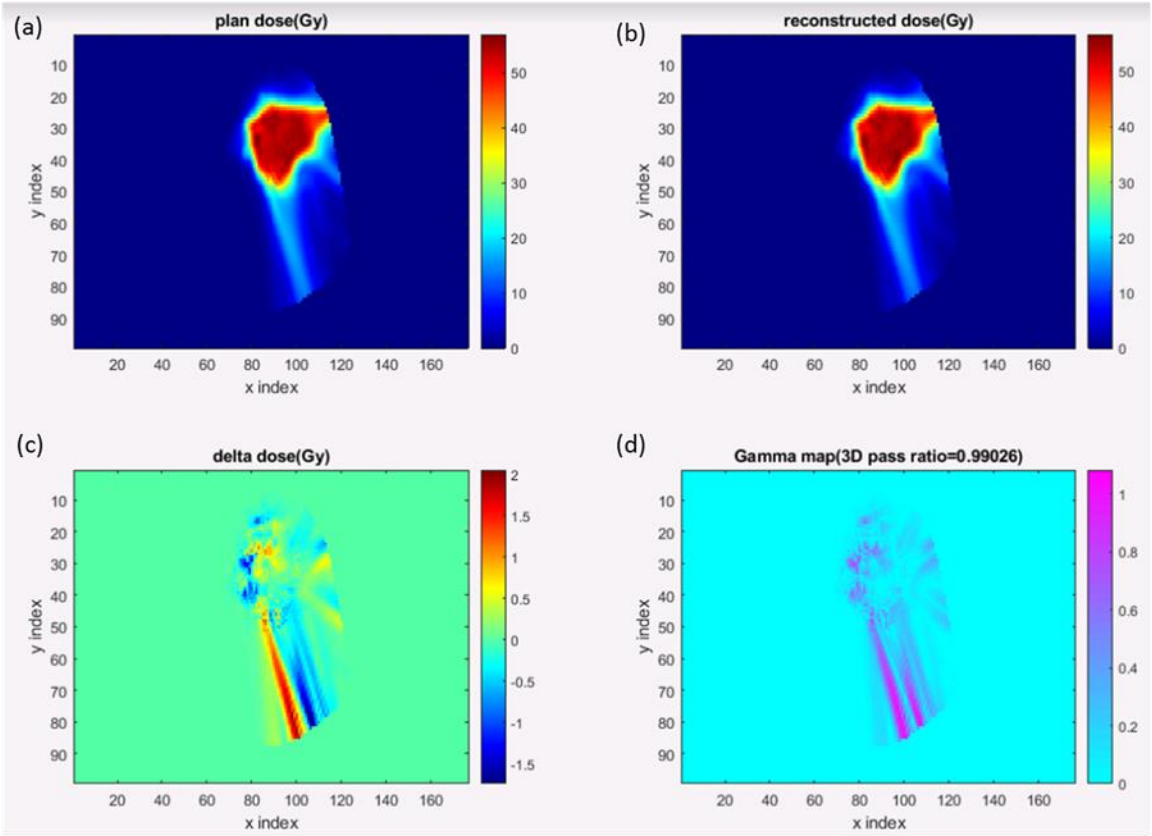
Method and Material

- The gantry angle vs. delivery time showed a good agreement between the DSM_{arc} and log file.(delivery time difference:6.1%±3.9% on average for eight cases)



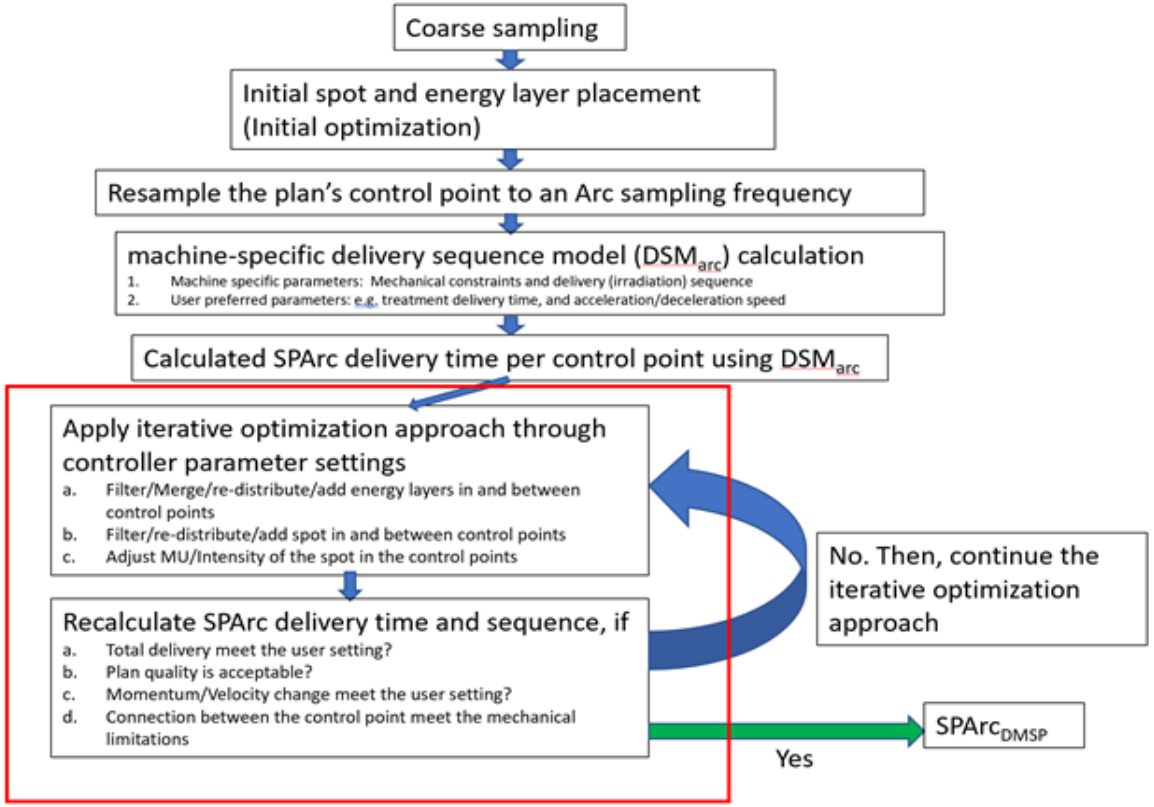
Method and Material

- 3D gamma pass ratio with criteria 3mm, 3% between reconstructed dose and initial plan dose are greater then 98% for all validated cases.



Method and Material

- $SPArc_{DMSP}$ resamples and adjusts each control point's delivery speed based on the DSM_{arc} calculation through the iterative approach.



Framework of $SPArc_{DMSP}$ iterative optimization algorithm.

a.Control point resample;
b.Energy layer redistribution and filtration;
c.Predict delivery time and gantry rotation speed per control point;
d.Spot redistribution and spot intensity modulation
e.Spot filtration

Method and Material

- Four representative cases(brain, head neck, liver and lung cancer patients) were selected to test $SPArc_{DMSP.}$
- Two kinds of SPArc plans were generated using the same planning objective functions:
- A.$SPArc_{DMSP}$ plan meeting the maximum allowable gantry acceleration speed(0.6deg/s^2);
- B.$SPArc_{DMSP\text{-}user\text{-}speed}$ plan with a user pre-defined delivery time and constraint the acceleration speed<0.1deg/s^2.
- Simulated arc delivery sequence based on the DSM_{arc} was compared.

Result

- The plan parameters(objective value, total energy layers,spots, delivery time) are similar.

No.	Plan Model	Number of Energy Layer	Number of Spots	Delivery Time(s)	Cost Function Value	Gantry Velocity		
						Mean (degree/s)	Standard Deviation	
							Absolute (degree/s)	Relative
1	A	37	2577	137	0.0663	0.73	0.17	23.78%
	B	37	2294	122	0.0762	0.73	0.06	8.44%
2	A	36	2981	140	1.55	0.67	0.16	24.09%
	B	35	2453	146	1.6935	0.69	0.07	10.24%
3	A	38	10272	269	0.4502	0.38	0.04	10.19%
	B	38	9158	262	0.422	0.39	0.03	7.20%
4	A	36	7362	208	0.8585	0.48	0.18	37.19%
	B	36	7322	221	0.7805	0.45	0.06	12.35%

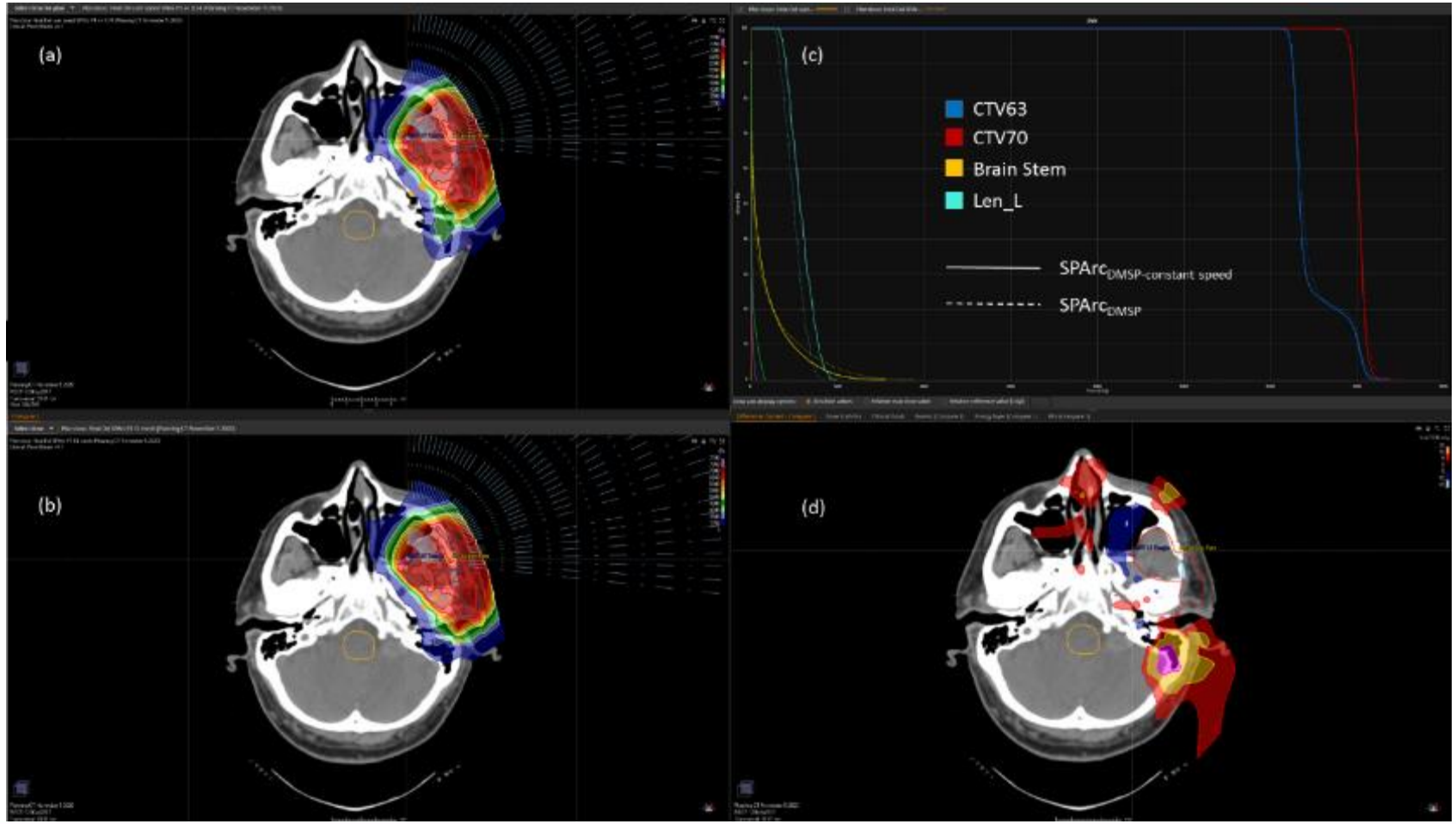
Abbreviation: A: spot-scanning proton arc(SPArc) incorporated mechanical maximum allowable constraints (0.6deg/s^2) and delivery sequence (SPArc$_{DMSP}$),

B: SPArc$_{DMSP\text{-}user\text{-}speed}$ with user pre-defined treatment delivery speed and gantry acceleration constraint <0.1deg/s^2.

Result

华中科技大学同济医学院附属协和医院

Plan quality is similar.

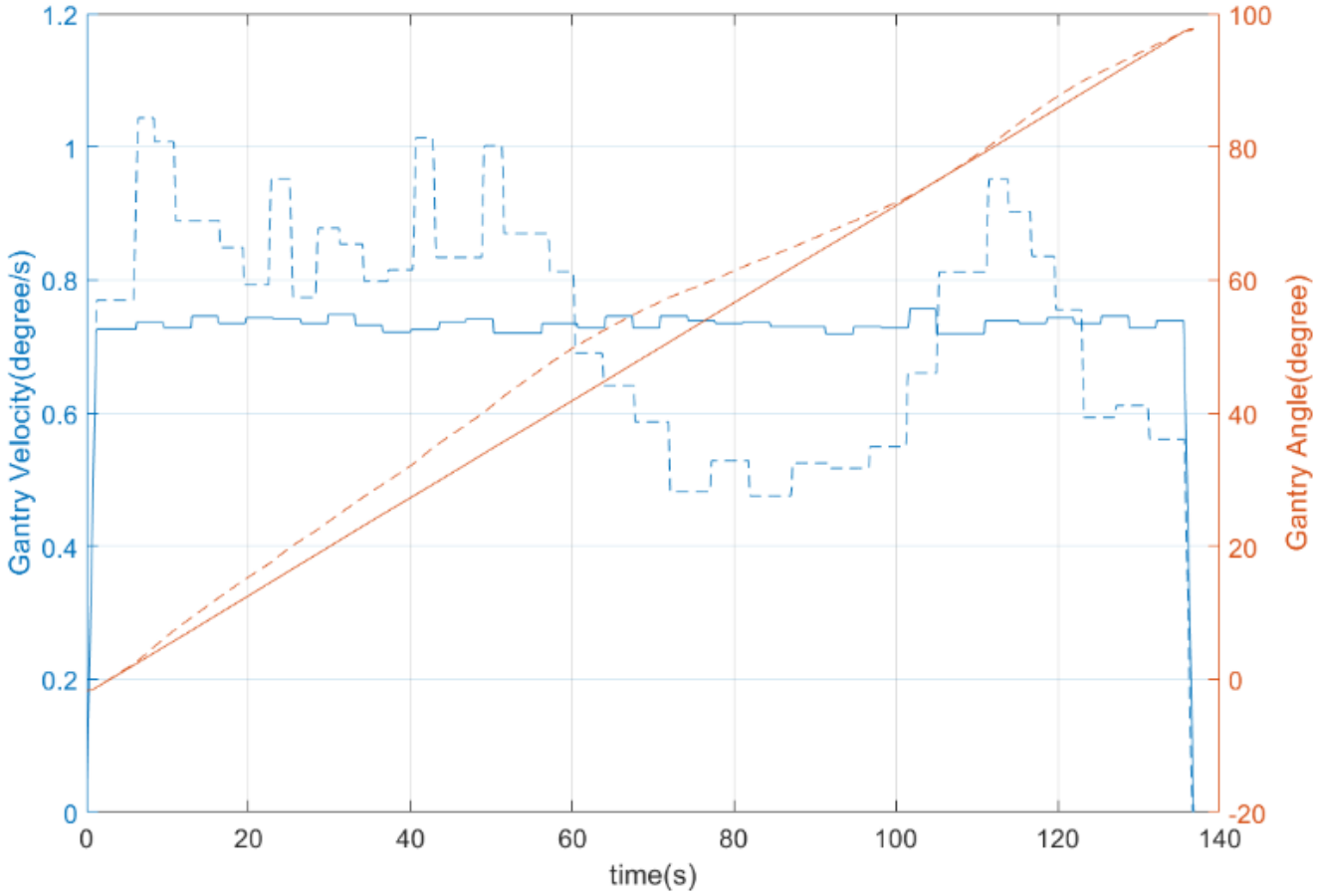


A slice dose of a head neck case for (a) SPArc$_{DMSP\text{-}user\text{-}speed}$ (b) SPArc$_{DMSP}$ (c) the corresponding DVH comparison (d) dose difference.

Beaumont HEALTH

Result

The $SPArc_{DMSP\text{-}user\text{-}speed}$ plan could minimize the gantry momentum change based on clinical users input compared to the $SPArc_{DMSP}$.



The comparison of gantry velocity and gantry angle vs time for $SPArc_{DMSP}$ (dash line) and $SPArc_{DMSP\text{-}user\text{-}speed}$(solid line) using a head neck cancer case as an example.

Conclusion

- SPArc-DSM$_{arc}$ plan could meet the mechanical constraint of the specific proton system.
- Additionally, SPArc-DSM$_{arc}$ can directly optimize the treatment speed and momentum changes of the gantry in the plan optimization process.
- This work paved the roadmap for the clinical implementation of proton arc therapy in the treatment planning system.

Thanks!