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Proton range validation by using a novel 4D ion chamber detector with deep learning technique

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PURPOSE

Conventional ion chambers cannot provide satisfactory proton radiography due to the limitation of proton scatter. This work proposes a novel proton radiography method using deep learning and the newly designed 4D array ion chamber detector to characterize patient anatomy and validate dose calculation algorithm.

METHOD

4D detetor has 2 mm and 0.3 ms spatial-temporal resolutions of 128Lx128Wx64D channels. Deep convolutional neural networks (CNNs) were used to assist data analysis from the substantial amount of spatial-temporal measured data using 41x41 proton spots per 4 mm spacing. The anthropomorphic phantom was irradiated with an anterior beam and the exit dose was measured with the 4D detector and conventional MatriXXPT. Water equivalent thickness (WET) map were derived by matching measurements with RayStation 8A dose calculation.

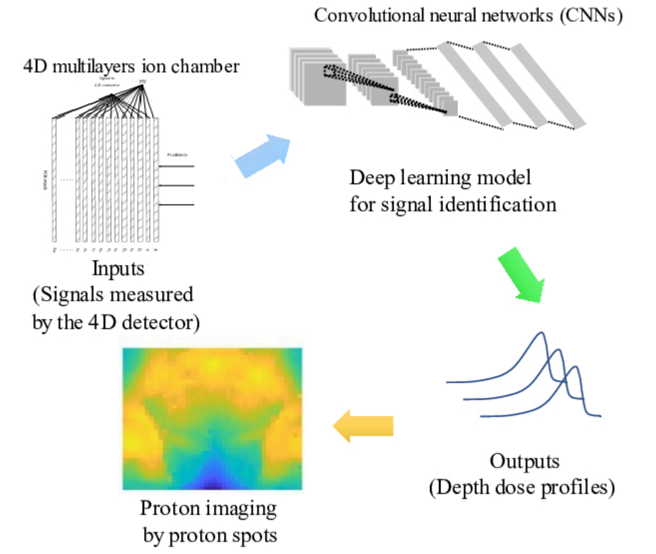

Figure 1. Workflow for the usage of deep learning models to analyze spatial-temporal data measured by a 4D multiarray ion chamber.

RESULTS

Derived WET maps agree between 2 mm for the most parts and large discrepancies of 4-8 mm often happen near the edge of dens bone that involve high heterogeneity. The results indicate that the proton radiography image can be improved with 4D detector by de-convolution of proton scatter involved in MatriXX PT measurements. The difference of WET maps increased with the complexity of clinical sites.

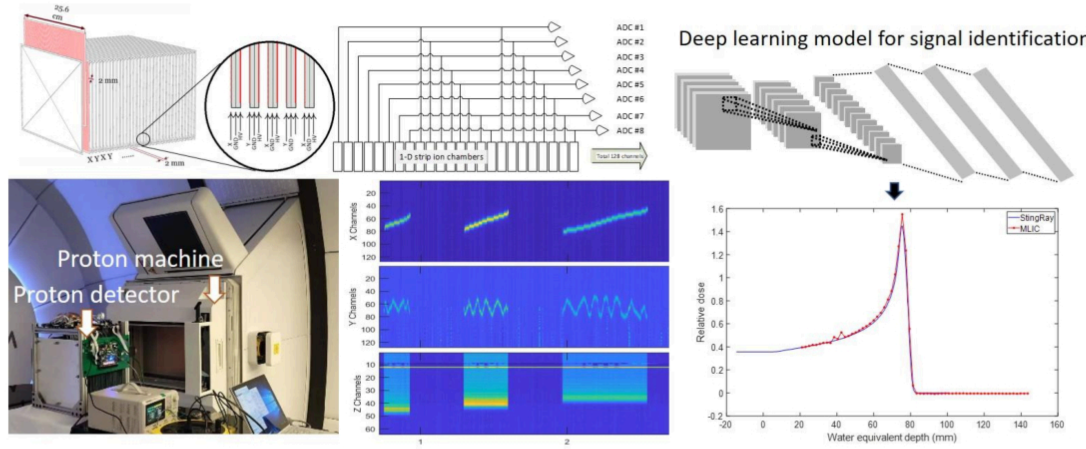

Figure 2. Top row: the design and data extraction of the 4D detector. From left to right: schematic diagrams; CNN model for identification of spot data over time domain; conversion of multi-layer strip data to Bragg peaks. Bottom row: the 4D detector prototype and initial results. From left to right: The actual prototype; the measurement of spot x,y position and depth during PBS delivery in Emory; the CNN extracted spot data; conversion of extracted individual spot data to a Bragg peak; measured PR from multiple spots.

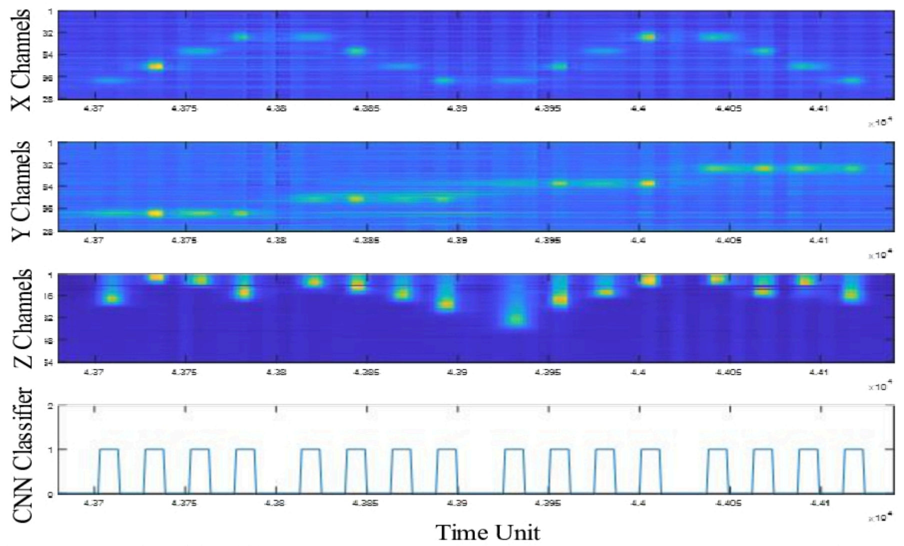

Figure 3. Signal identification using CNNs. The detector outputs include proton spot positions information given by X and Y channels while proton depth doses are given by Z channels. All channels include temporal information and a time unit is equal to 0.32 ms. The CIRS Atom M701 andromorphic phantom was irradiated with anterior beam using 1681 proton spots at 216 MeV, and the exit dose was measured with MatriXX PT (IBA Dosimetry, Germany) and 4D multiarray ion chamber.

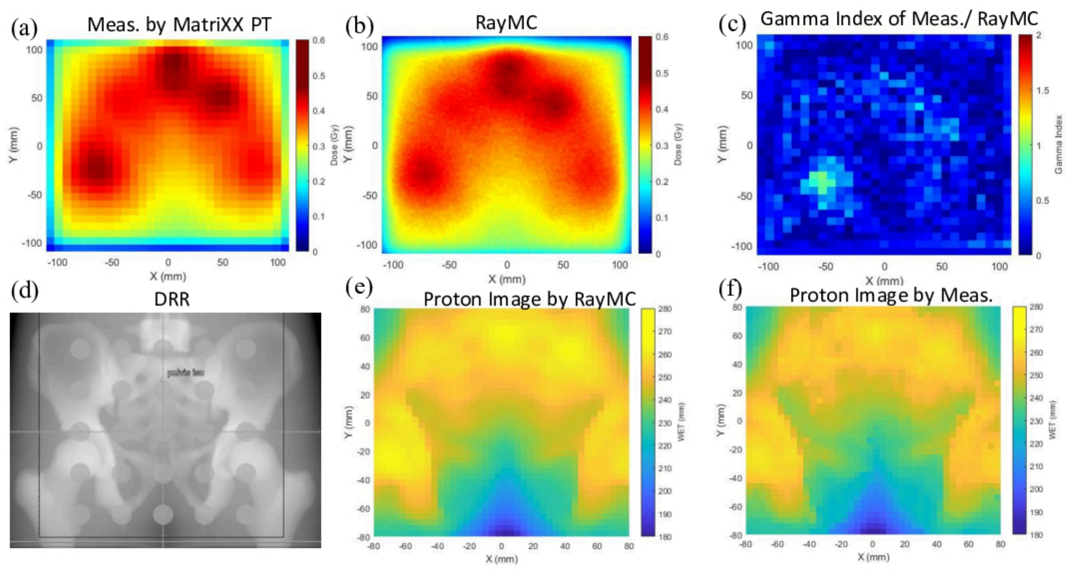

Figure 4. Dose distributions by (a) measurement (Meas.) and (b) RayStation MC algorithm (RayMC) for the pelvis cite with a 219 MeV proton beam. (c) Comparisons of dose distributions using Gamma Index with 4mm/4% criteria between Meas. And RayMC. (d) The digital reconstructed radiograph to show the phantom anatomy. (e) Proton image by (e) RayMC simulation and (f) measurement using 1681 proton spots at 216 MeV. The andromorphic phantom was irradiated with anterior beam and the exit dose was measured with MatriXX PT (IBA Dosimetry, Germany) and 4D multiarray ion chamber.

CONCLUSIONS

The newly designed 4D detector featured in spatial-temporal measurement capability can utilize the pencil beam scanning feature of proton beam, improve accuracy of derived WET maps, shorten the acquisition time and reduce the radiation dose.

CONTACT INFORMATION

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