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Quantitative image-based registration metrics for re-irradiation validation

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Innovation/Impact: As re-irradiation becomes more common in radiation therapy, many prominent authors including Brock et al.[1], Murr et al.[2], and Osorio et al.[3] strongly recommend a quantitative evaluation of the CT-CT registration that forms the basis of dose summation. Unfortunately, these tools are often lacking in commercially available products. Our work presents a readily available toolbox that can be useful for physicists and physicians to measure the registration trustworthiness on a 0 to 100 scale.

(1) https://doi.org/10.1002/mp.12256 (2)https://doi.org/10.1016/j.radonc.2023.109527 (3) https://doi.org/10.1016/j.radonc.2023.109585

Purpose

Dose summation for re-irradiation requires a transformation of the dose from the previous plan on CT data set CT1 onto a new plan on CT data set CT2. The dose transformation corresponds to the CT1-CT2 image transformation. Therefore, the validity of the sum dose depends directly on the validity of the image transformation. Many authors have noted that quantitative image registration metrics essential to validate the corresponding plan sum metrics are often lacking in commercially available products performing deformable image registration. This work presents a platform to compute four metrics without user input on a 0 – 100 scale suitable for physician review.

Methods

CT1 and CT2 dicom data sets were imported into Matlab with the imaging toolbox. The images can be cropped to analyze a specific region of interest. A representative bladder case study which qualitatively appeared unsatisfactory was chosen to demonstrate the process using standard Structural Similarity (SSIM), Cross-Correlation (CC), Mean Square Error (MSE), and an innovative Hounsfield Unit Difference (HUD) metric indicating the mean percentage of points with a CT1-CT2 difference less than 20%. The metrics were presented as a Trustworthiness (T) bar graph including the results for both Rigid and Deformable registration as well as their difference as an analytical measure of deformation.

Results

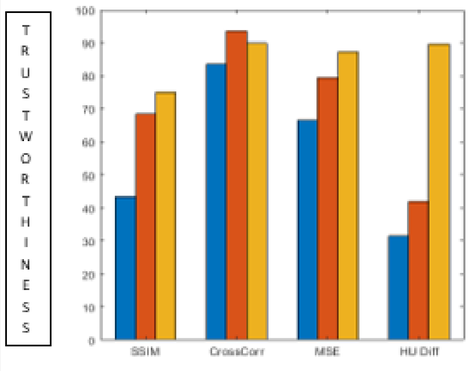
SSIM (T=68.4%) which includes luminance, contrast, and structure is the recommended clinical metric.

Absolute HU difference (T=41.9%) is also very sensitive and but it is best used in conjunction with a positional display.

Graphical bar graph presentation of all metrics is useful for physician review.

Conclusion

Deformable image registration is prone to non-unique solutions and therefore plan sums should be presented with an indication of trustworthiness. Matlab provides users the ability to compute and present relevant vendor neutral quantitative metrics effectively so that physicians can perform an informed evaluation.



ALL metrics normalized to 0 – 100 scale

BLUE: Rigid Transformation (Rigid)

RED: Deformable Image Registration (Deformed)

ORANGE: 100 – (Deformed - Rigid)

Structural Similarity Index (**SSIM**), including Luminance, Contrast, and Structure

Cross-Correlation (**CrossCorr**) normalized to max

Mean Squared Error (**MSE**) normalized to max

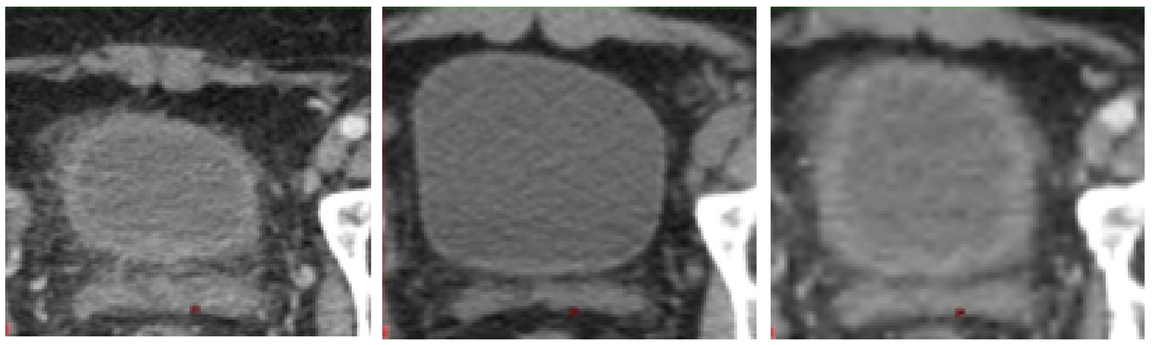
Mean AbsVal (Treatment CT – Registered CT) < 20(**HU Diff**)

Bar Chart above is a graphical summary of quantitative registration trustworthiness and consequently dose summation for re-irradiation commonly expressed as EQD2 suitable for easy review by radiation oncologist.

SSIM is most sensitive comprehensive single metric and with the largest (Deformed – Rigid) difference suggesting major deformation changes that may lead to lower trustworthiness in the EQD2 plan sum.

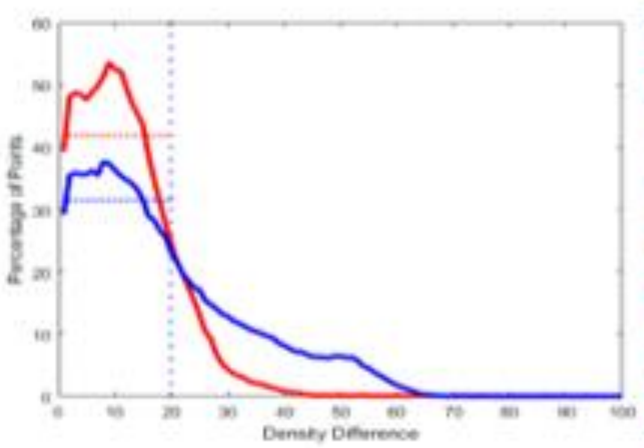
CrossCorr and MSE appear trustworthy, possibly due to normalization, and may inspire false confidence.

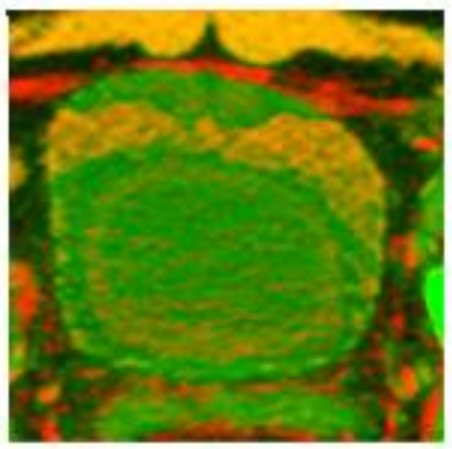
The "100 – (Deformed - Rigid)" metric is an analytical measure of the amount deformation with small (Deformed – Rigid) values indicating relatively small warping and hence high 100 – (Deformed – Rigid) trustworthiness.



Representative data set of previous treatment CT rigid registration (left) and deformable image registration (right) to the current treatment CT (center). Patient had significant changes in the abdomen outer contour.

Analysis was performed in MATLAB with the Imaging Toolbox. Imported datasets can be cropped to review either the entire body within the outer contour or as desired by experts in the field to a specific region of interest such as the bladder as shown above. Four quantitative image-based metrics without user input such as points or contours were then calculated for this suboptimal case to demonstrate a practical worst-case scenario.





HU diff is a new metric proposed in this work best used in conjunction with a difference map to indicate if the difference is in a clinically sensitive area. Analytically, a plot is used to compute HU Diff as mean number of points with difference less than 20. In the visual difference map a yellow to red scale indicates areas with increasing relative density difference.