Automated CT-CT Deformable Image Registration QA Using Virtual Phantoms

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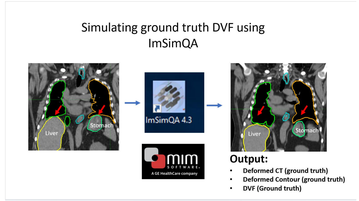
Purpose

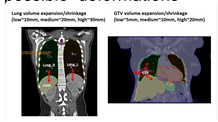
To address the labor-intensive nature of Quantitative Deformable Image Registration (DIR) QA in MIM Maestro™ 7.3.8 for Lung and Head & Neck disease sites.

Introduction and Motivation

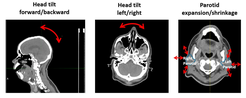
- Virtual Phantoms are obtained from anonymized patients.
- Given a virtual phantom, ImSimQA™ can produce a series of deformations using the software's built-in site-dependent biomechanical models, resulting in deformed CTs, contours, and deformation vector fields (DVFs) for benchmarking MIM's performance.



- ImSimQA™ supports basic manual benchmarking against the ground truth. However, manual analysis becomes unsustainable for analyzing multiple patients considering the number of possible deformations generated by ImSimQA™:
  - 14 Lung deformations per patient: expansion/shrinkage (low~10 mm, medium~20 mm, high~30 mm) and gross tumor volume expansion/shrinkage (low~5 mm, medium~10 mm, high~20 mm).



  - 33 H&N deformations per patient: head tilt forward/backward/left/right (low~15 mm, medium~25 mm, high~35 mm and parotid expansion/shrinkage (low~3 mm, medium~5 mm, high~8 mm).



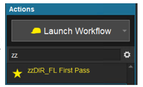
- An automated deformation, registration, and analysis are needed to scale the quantitative QA process over multiple virtual phantoms for thorough DIR commissioning.

Methods

1 Auto Import

A DICOM watcher in MIM was configured to detect and import batch-processed exports from ImSimQA.

2 Semi-auto DIR



A custom MIM workflow was implemented to perform registration, export Deformation Vector Fields (DVFs) and automatically calculate Dice Similarity Coefficient (DSC) and Hausdorff Distance (HD) between structures deformed by MIM and the corresponding ground truth. This workflow embeds specific keywords into the DICOM series descriptions, triggering downstream Python scripts to automatically identify, pair, organize, and analyze the data

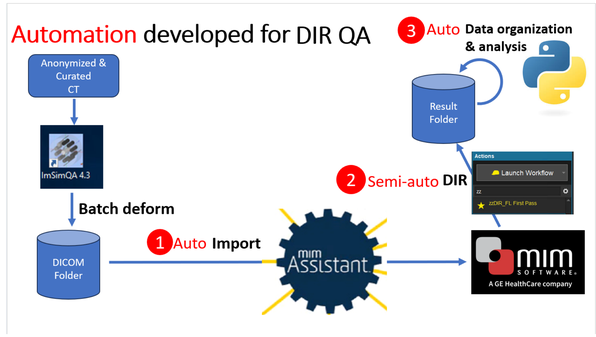
3 Auto Data organization & analysis

MIM's deformable REG object DVF_{deform} does not contain initial rigid registration DVF_{rigid} which is a DICOM object with 16 parameters.

The full ground truth DVF DVF_{full} needs to be calculated by end user using the following formula

$$DVF_{\text{full}} = inv(DVF_{\text{rigid}}) + DVF_{\text{deform}}$$

The DVF generated by MIM is then imported into ImSimQA for DVF QA which gives a distribution of DVF errors for each structure. The result is exported so that a final python script can parse to produce final commission report.



Results

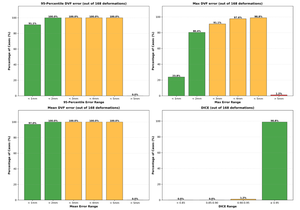
- This streamlined process completes the DIR QA for MIM 7.3.8, completing a single deformation scenario in the order of a few minutes.
- The platform successfully processed all contours without manual intervention. For Lung, 1.1% (315 out of 29105) of the contours tested have 95-percentile DVF larger than 2 mm, with 78% of those out-of-tolerance cases come from medium or high deformations. For HN, 1.5% (63 out of 4308) of the contours tested have 95-percentile DVF larger than 2mm, with all out of tolerance come from medium or high deformations.
- This work establishes a scalable, high-throughput platform for DIR QA using clinical data. By automating data import via DICOM watchers and analysis via keyword-embedded workflows, the labor required for commissioning was significantly reduced.

Innovation

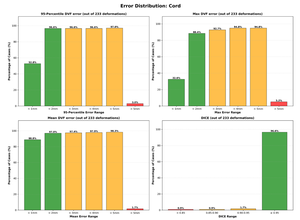
- **Automated Ingestion:** DICOM Watcher automatically imports and processes outputs from ImSimQA™
- **Keyword-Driven Workflow:** MIM workflow embeds specific identification keywords into the output DICOM series descriptions for downstream automation using Python scripting.

Examples

Lung DIR QA example results for cord



Head & Neck DIR QA example results for cord



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