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AUTOMATED, IMPROVED DEFORMABLE IMAGE REGISTRATION FOR RADIATION THERAPY AND OTHER CLINICAL APPLICATIONS

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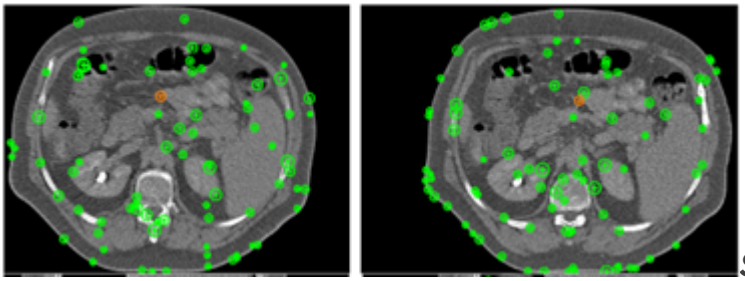
T-017324

Technology Description

Prof. Deshan Yang and colleagues have developed automated systems and software toolkits to provide more accurate deformable image registration (DIR) for adaptive radiotherapy and other clinical applications. In particular, they have automated tedious and labor-intensive DIR verification with landmark pair analysis (figure below) and they have created methods to adjust for complex organ movement without prior segmentation.



Sample automated feature pair dataset (axial view of abdominal 4DCT). *Complete dataset has 12,050 feature pairs relatively distributed uniformly. End-of-inhale phase is on the left and end-of-exhale phase is on the right.*

Radiation treatment planning relies on DIR to match anatomical features from medical images taken at different times (e.g., a simulation CT is co-registered with a CT on the day of radiation treatment). However, conventional DIR methods cannot effectively estimate complex organ motions, particularly when they slide along the tangential direction of organ boundaries. To better estimate human abdominal motion, the inventors developed an “adaptive direction-dependent regularization” filter that applies a Gaussian isotropic filter in the normal direction and a bilateral filter in the tangential direction without needing prior organ segmentation. This ensures a smooth motion field in the normal direction while allowing sliding motion along the organ boundaries.

In addition, DIR must accurately match anatomical “landmark pairs” between the two time points. However, DIR accuracy is often inadequate due to variability in operators, algorithms and image quality. Furthermore, manual verification of DIR is too labor intensive to generate the large number of features necessary to reliably provide high spatial density and precision. This technology solves that problem with a fully automated DIR verification tool that can be performed on a large quantity of landmark pairs in arbitrary patient image datasets (not limited to phantoms). This tool provides a 3-step process with a deep learning model that can quantify DIR errors with increased spatial density, increased position accuracy and increased precision compared to current methods.

Collectively, this toolkit (which includes **WUSTL technologies T-017322, T017324 and T-019063**) could provide faster, more accurate DIR for radiation therapy, image-guided surgery, target definition, contour delineation and tumor response evaluation.

Stage of Research

- **Automated landmark pair analysis:**
  - successfully detected and matched thousands of landmark pairs in a range of clinical CT and MRI images with matching accuracy of 99.1%, averaged over 9000 pairs in 6 CT and MR image pairs
  - analyzed an average of 1886 landmark pairs on each of 10 4D CT lung datasets (between the end-exhalation and end-inhalation phase) that were tested against 300 manually labelled landmark pairs in benchmark datasets with a target registration error (TRE) of 0.73 +/- 0.53 mm with 97% of landmark pairs having a TRE smaller than 2mm
- **Adaptive direction-dependent regularization** – registration with this technique for 4D abdomen CT images:
  - had an average target registration error (TRE) of 4.89 mm
  - performed better than two other regularization methods tested (Gaussian isotropic filtering and bilateral filtering)

Applications

- **Deformable Image Registration (DIR)** in adaptive radiotherapy and other clinical applications such as image guided surgery, anatomy segmentation, target definition, motion estimation, dose accumulation and treatment response evaluation

Key Advantages

- **Fast, automated, precise analysis**
  - autogenerating landmark pairs enables high spatial density and high precision without inter/intra operator variability
  - DIR for sliding organs can be implemented with no prior segmentation
- **Improved accuracy**
  - landmark pair analysis evaluates large number of landmark pairs for high quality DIR analysis, including in low contrast soft tissue regions
  - minimal observer uncertainty
  - network correction process directly predicts shifts to optimally align the landmarks
  - accuracy of landmark pair analysis (0.73 +/- 0.53mm) is significantly better than the best competing approach (0.91 +/- 1.07mm)
  - adaptive direction-dependent regularization adjusts for complex organ movement (e.g., sliding in the tangential direction as well as movement in the normal direction)
- **Patient-specific –** landmark pair analysis can be performed on images from patients without relying on phantoms

Publications

- Fu, Y., Wu, X., Thomas, M. A., Li, H. H., & Yang, D. (2019). Automatic large quantity landmark pairs detection in 4DCT lung images. *Medical physics.*
- Fu, Y., Liu, S., Li, H., & Yang, D. (2017). Adaptive Direction-dependent Regularization for CT Abdomen Deformable Image Registration: su-k-201-11. *Medical Physics*, 44(6), 3024.

- Yang, D., Zhang, M., Chang, X., Fu, Y., Liu, S., Li, H. H., ... & Duan, Y. (2017). A method to detect landmark pairs accurately between intra‐patient volumetric medical images. *Medical physics*, 44(11), 5859-5872.

Patents - Systems and methods for detecting landmark pairs in images (U.S. Patent Application, Publication No. 2018/0314906)

Website - Yang Lab