Anatomical landmark based loss functions for intensity-based X-ray to CT registration

Project Management and Software Development
for Medical Applications

General Info

Project Title: Combining anatomical landmark detection with intensity-based X-ray to CT registration

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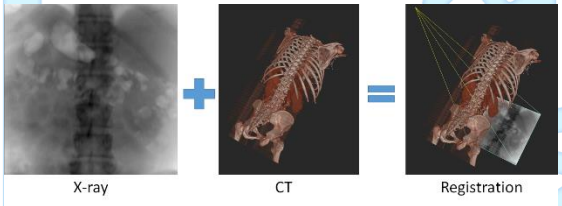
Project Abstract

In this project, students will investigate how standard intensity-based X-ray to CT registration algorithms can be enhanced by utilizing the output of anatomical landmark detection. To put it in more concrete words, they will start coming up with their own cost functions by incorporating the information from the landmark detection into the normal intensity-based loss function.

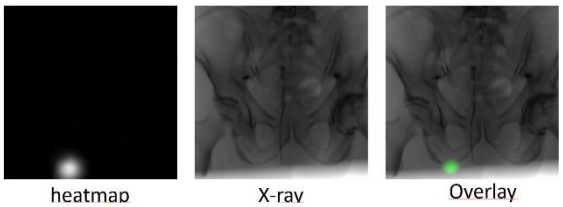
Background and Motivation

Image registration deals with problem of finding an optimal transformation from one coordinate space to another. In a medical context, this is usually done to match preoperative and intraoperative data. The preoperative data is used for surgical planning and guidance, whereas the intraoperative data is needed to utilize that planning inside the OR (with the help of the registration).



In this project, we are looking at the case where the preoperative data are CT scans and the intraoperative data are X-rays. The registration task in this case is solved using an **intensity-based registration**. This makes use of the fact that X-ray and CT share the same underlying modality, and hence X-rays can be easily simulated realistically from CTs (digitally reconstructed radiographs; DRRs). Using this, an intensity-based registration starts from a given initialization, an optimization algorithm (e.g. BOBYQA, Powells Method, etc) is used to iteratively optimize the six degrees of freedom of the pose of the C-arm (= the device that acquires X-rays). This is done by for each pose simulating the corresponding DRR and then comparing the DRR and the X-ray using a suitable similarity metric. This metric is used as cost function to the optimizer, which then tries to change the parameters in order to find the ideal set of poses.

Recently, anatomical landmark detection has been introduced to the task of X-ray to CT registration, in order to compute an initialization to the intensity-based registration. Anatomical landmark detection usually uses deep convolutional neural networks to detect the locations of anatomical landmarks on X-ray scans. The output of these networks are usually heatmaps.



The goal of this project is to investigate, how the heatmaps can be used during the intensity-based registration as well, by combining the similarity metric with a landmark-based loss to create novel loss functions for intensity-based X-ray to CT registration.

Please send the completed proposal to javier.esteban@tum.de, ardit.ramadani@tum.de, mf.azampour@tum.de and zl.jiang@tum.de. Please note that this proposal will be evaluated by the BMC coordinators and will be assigned to a student only in case of acceptance.

Student's Tasks Description

Students will start by writing their own intensity-based X-ray to CT registration algorithm. To this end, they will combine existing non-linear optimization libraries together with existing DRR generators (Note: If you insist, you can write everything from scratch, but I really do not recommend it).

Then they will start experimenting by changing the cost function and incorporating the landmark cost and investigating what the best way to do that is. An easy example could be a Euclidean distance between the projected landmark location and the maximum intensity pixel of the heatmap.

Students will NOT have to develop their own landmark detection. Instead they will only work with the output of a landmark detection which they get from me. (Note: again, if you insist, you can do it)

Technical Prerequisites

Scientific:

- Basic computer vision and projective geometry knowledge
- Basic knowledge about optimization
- Basic understanding of intensity-based registration

Programming:

Depending on their preferences, students can either work in C++ or Python. In general they need to be able to install and use multiple third party libraries, especially for optimization or DRR generation. Suggested libraries are (but others are fine, too):

- NLopt (C++ / Python) for optimization
- PyBOBYQA (Python) for optimization
- DeepDRR (Python) for DRR generation
- https://github.com/SeverineHabert/DRR-renderer (C++) for DRR generation

References

- Grupp, R. B., Unberath, M., Gao, C., Hegeman, R. A., Murphy, R. J., Alexander, C. P., ... & Taylor, R. H. (2020). Automatic annotation of hip anatomy in fluoroscopy for robust and efficient 2D/3D registration. *International Journal of Computer Assisted Radiology and Surgery*, 1-11.
- Esteban, J., Grimm, M., Unberath, M., Zahnd, G., & Navab, N. (2019, October). Towards fully automatic X-ray to CT registration. In *International Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 631-639). Springer, Cham.
- Unberath, M., Zaech, J. N., Lee, S. C., Bier, B., Fotouhi, J., Armand, M., & Navab, N. (2018, September). DeepDRR–a catalyst for machine learning in fluoroscopy-guided procedures. In *International Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 98-106). Springer, Cham.
- Bier, B., Unberath, M., Zaech, J. N., Fotouhi, J., Armand, M., Osgood, G., ... & Maier, A. (2018, September). X-ray-transform invariant anatomical landmark detection for pelvic trauma surgery. In *International Conference on Medical Image Computing and Computer-Assisted Intervention* (pp. 55-63). Springer, Cham.

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