<KIV> KATEDRA INFORMATIKY A VÝPOČETNÍ TECHNIKY

Bc. Jan Hereš

Reconstruction of a patient specific surface model of the humerus bone

Master's Thesis

Software and Information Systems
2023/2024

Thesis supervisor:
Eva C. Herbst, B.A., Ph.D.
ETH Zürich

Abstract

This paper takes the reader into the field of reconstructing a missing distal region of a 3D humerus model reconstructed from CT scans using a statistical shape model. As clinicians utilize modern medical imaging methods, some of them utilize X-rays, which are deemed to be harmful for the patient. On the other hand, the clinicians need to gather as much imaging data as possible to enable exploring new possibilities, for instance biomechanical analysis, personalized implant designs and others. The goal of this thesis is to propose a new approach to reconstructing the full 3D surface model of a patient-specific humerus bone based on its partial basis rendered from a limited set of CT scans. Achieving this goal will enable clinicians to significantly limit the amount of necessary patient screening while preserving as much information about the humerus as possible.

Intro

This thesis dives into the field of surface model reconstruction of a physical template using a statistical model as a source of general shape information for the reconstruction. By utilizing the statistical model, a new pipeline for the process of reconstruction was presented with bearing existing knowledge from past research. The solution was implemented as a module into the 3D Slicer application to test the concepts on real use cases.

Theoretical background

For the task of surface model reconstruction, various different methods were already presented. However, in order to reconstruct an incomplete model of the humerus, a template serving as a source of general shape properties of the humerus needs to be created. After gathering this statistical shape model (SSM), we can proceed to the reconstruction process. This process consists of two main stages:

- SSM and target model pre-alignment,
- Target model reconstruction.

Before reconstructing the target (impartial) model, the SSM and the target models are pre-aligned in order to maximize the probability of reaching the best reconstruction results. This pre-alignment stage utilizes the Random Sample Consensus (RANSAC) algorithm for "raw" alignment and the Iterative Closest Points (ICP) algorithm for the alignment enhancement. For the target reconstruction, the Bayesian Coherent Point Drift (BCPD) algorithm was utilized.

Realization

The reconstruction pipeline was implemented as an open-source module to the 3D Slicer application. The module is written in the Python language with use of the Slicer's embedded API combined with the help of the Open3D Python package. The implemented module offers a wide range of parameter adjustment in order to reach the most optimal results in a specific use case scenario. Even though the module was implemented and tested only on humerus models, the use case is not limited.

Results

The results of the reconstruction process are, on a first sight, very promising. However, the example shown in Figure 1 is in ideal conditions, i.e. both the statistical model and the partial model are of high quality. In other cases, the reconstructed models do not resemble the anatomical properties of a humerus quite as well. One common aspect shared throughout all of the results is an issue with length preservation, however this unfortunate aspect can be quite easily mitigated in further releases of the module.

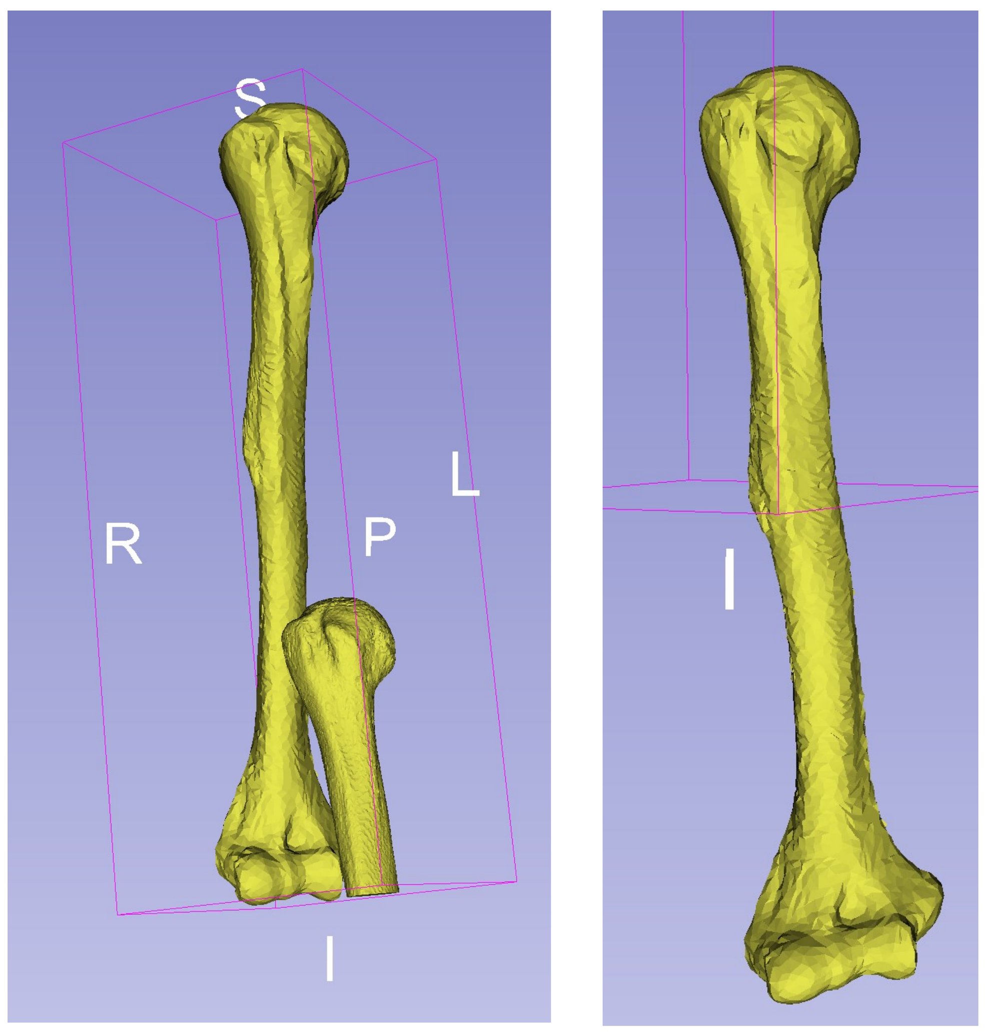

Fig. 1: Example of a fully reconstructed humerus model (right) based on a mean model of the humerus (left) with a partial model of the target humerus (left).

Conclusion

The proposed reconstruction pipeline was successfully implemented into the 3D Slicer application and tested on a dataset of humerus models reconstructed from their CT scans. The results in ideal conditions resemble the overall structure of a humerus quite well, however further enhancements and research are needed since usually these conditions are not met in a day to day scenario. One of the possible enhancement could be in form hyperparameter search, i.e. test many different parameter settings of the module and empirically choose the best one. Next, for the rigid alignment could be calculated by utilizing important anatomical landmarks rather the an automatic inference of fitness. In terms of length preservation, one of the approaches could be to compare the partial model to the SSM, compute a scaling factor of such and apply it to the reconstructed model.

FAKULTA APLIKOVANÝCH VĚD ZÁPADOČESKÉ UNIVERZITY V PLZNI