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Automatic detection of intra-articular implants for mobile cone-beam computed tomography

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With the development of novel intraoperative devices for computed tomography (CT) imaging, new opportunities for computer-aided image assessment have arisen. In particular, the introduction of mobile C-arm CT devices has allowed surgeons to assess their implant placements more precisely than with single X-ray fluoroscopy. This advantage is helpful at critical and complex intra-articular bone structures, where an improper implant placement can affect the healing process and increase the risk of arthritis. It is therefore highly important to detect and revise improper implant placements during surgery.

In this work, a software-based prototype for an intraoperative assistance system for orthopedic surgeons has been developed, which allows to automatically detect intra-articular implants in C-arm CT images. The presented approach is composed of an implant detection and a bone segmentation. A subsequent overlap detection of both outputs is used to determine intra-articular implants.

In order to detect surgical implants, a novel approach based on methods for cylinder detection is presented. It performs a cluster analysis of local cylindrical characteristics and addresses CT-related challenges regarding image artifacts due to metallic material. The bone segmentation approach combines independently learned shape models in order to create a fast and robust multi-object segmentation of adjacent bones. By incorporating the anatomical knowledge of the articular surface location into the model, joint spaces are identified. A subsequent solving of geometric equations, e.g. intersections, allows the detection of implants protruding into the joint space.

All developments were evaluated for the calcaneus bone, which is characterized by four articular surfaces and a high risk of intra-articular fracturing. A retrospective evaluation of the cylinder detection has shown a high implant detection performance of 96.1% true positive rate (TPR) at a 2.5% false positive rate (FPR) on 50 images from actual patient treatments of the calcaneus bone. For the same image set, the bone segmentation achieved an average surface distance error of 0.59 ± 0.29 mm at the lower ankle joint and 0.45 ± 0.14 mm at the calcaneocuboid joint.

In order to ethically create a representative set of CT images, a human cadaver study was conducted to create 102 realistic cases with intra-articular implants. The evaluation of the data from the human cadaver study has shown that a high detection performance of around 95% (TPR) at 5% (FPR) is possible in less than one minute computation time.

This thesis gives the concept, implementation and demonstration of an assistance system for intra-articular implant detection. It has been shown that the developed methods fulfill intraoperative requirements and work robustly despite limitations in mobile CT imaging. The assistance system is ready for clinical trials in order to measure the saved time during image assessment and to evaluate the impact on surgeon decisions that lead to intraoperative implant revision.