Implant-Tolerant Orthopaedic Measurements for Post-Operative Radiographs of the Lower Limbs

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Abstract. In this work we present a method for automated orthopaedic measurements for patients that have undergone a partial or full joint replacement in the lower limbs. In contrast to previously published approaches for partially occluded objects, we deal with objects were the major part of the contour is missing, namely the epiphyses of the long bones in the lower limbs, that have been replaced in large parts by artificial joint implants of varying appearance. We present an approach based on the automatic detection and segmentation of implants and a robust adaptation of a segmentation technique based on deformable models. We evaluated our method on a set of clinical images and achieve an accuracy of 0.6° for angles and 1.3mm for lengths measurements while significantly reducing assessment time and eliminating user interaction.

1 Introduction

Joint replacement surgery has become a standard procedure in orthopaedics. In Germany, according to the German Federal Association of Medical Technology, more than 400,000 artificial hip and knee joints are implanted each year [1]. To rate the success of a replacement surgery it is necessary to measure several quantities on a pre- as well as a post-operative radiograph of the lower limbs.

There exist various methods for segmentation of the bone structure in digital radiographs. In a recent publication, Gooßen et al. [2] achieve an average accuracy of 0.5mm when segmenting the joints of the lower limbs. However, as with any of the previously published method, their approach does not incorporate post-operative segmentation after joint replacement.

Dong et al. [3] evaluated their hybrid approach, based on geometric models and shape priors, occluding small fractions of the bone contour. But an implant typically replaces major parts of the bone and does therefore not match their presumption. Though there exists a model-based approach for the segmentation of total hip joints replacements (THR) by Kotcheff et al. [4], it only works up to a certain degree of similarity between the trained and actual prostheses. The German Federal Association of Medical Technology, however, reports more than 200 different types of prostheses for the hip joint alone [1], each available in different sizes, ruling out any model-based technique.
2 Materials and Methods

In order to tolerate implants when measuring orthopaedic quantities within the lower limbs, we developed an approach consisting of two complementing stages. The first one robustly detects the presence of implants and segments them with pixel accuracy. Subsequently, a second step adapts the deformable templates used for segmentation in order to avoid the implant structure and precisely delineate the remaining bone contours.

2.1 Automatic Implant Segmentation

Implants in radiographs showcase a distinct sharpness of edges and homogeneous brightness due to the high absorption of its materials. We exploit these features by creating binary images $B_{↔}, B_{↕}$, containing pixels enclosed by strong horizontal and vertical edges, respectively. Another binary image, $B_{\text{hist}}$, is created via histogram-adaptive thresholding of the input image. Intersecting these binary images and morphologically eroding with structure element $v$ for leakage avoidance yields the candidate image $B_{\text{seed}} = (B_{↔} \cap B_{↕} \cap B_{\text{hist}}) \ominus v$.

To identify connected areas in $B_{\text{seed}}$ we combine Region Growing with the Level-Set cost function of Malladi et al. [5]

$$g = \frac{1}{1 + |\nabla (G_{\sigma} * I)|} \quad (1)$$

as the stopping criteria to benefit from the former speed and the latter accuracy.

To save processing time, preliminary processing up to this point utilizes a lower level of a Gaussian pyramid, hence the implant segmentation result lacks precision. To maximize accuracy, the now known location of the implant borders are utilized in a further local adaptive thresholding procedure. Herein Otsu’s algorithm [6] is applied to a small window which is shifted along the implant outline in $I$ to produce refined implant edges in image $B_{\text{Otsu}}$. Since local image content can display several general brightness classes (implant, dense bone tissue, soft tissue, and direct radiation) we found that it is advantageous to perform the thresholding with three classes. Fig. 1 displays the intermediate images resulting in the implant delineation $\gamma$ overlayed onto the original image $I$.

![Fig. 1. Implant segmentation from (a) original image to (h) overlayed implant.](image-url)