Proc. 1st Aachen Conf. on Neuropsychology in Neurosurgery, Psychiatry, and Neurology,
Dec. 12-14, 1997, Aachen/Germany, B.O. Hütter and J.M. Gilsbach (Eds.),
Verlag der Augustinus Buchhandlung 1997, 9-12

Characterization and Localization of Anatomical Landmarks in Medical Images

Karl Rohr **H. Siegfried Stiehl**

Universität Hamburg, Fachbereich Informatik, Arbeitsbereich Kognitive Systeme
Vogt-Kölln-Str. 30, D-22527 Hamburg, Germany

Background

Image registration is fundamental to computer-assisted neurosugery. Examples are the registration of MR and CT images, the registration of images with the patient coordinate system, and the registration of images with a digital atlas. In either case, the central aim is to increase the accuracy of localizing anatomical structures in 3D space. To this end, often corresponding prominent points, also denoted as landmarks, are identified and used as features to compute the transformation between different coordinate systems (e.g., [2],[3],[4],[6]). In comparison to fiducial markers placed outside the human head, anatomical landmarks have the advantage that they can be located within the relevant inner brain parts – thus the registration accuracy is generally increased. Usually, however, anatomical landmarks are localized manually which is time-consuming and often lacks accuracy. Instead, semi-automatic or automatic procedures open the possibility to improve this situation.

A methodic framework for the development of computational approaches to landmark localization

To develop computational procedures for landmark localization we find it imperative to work along a methodic framework (see Fig. 1) aiming at algorithms of predictable performance which thus can really be used in practice. Starting out from the selection and definition of prominent points we first characterize these landmarks verbally. This characterization primarily concerns geometry (e.g., characterization as a tip or a center of region) but may also include a characterization of the intensities as well as the definition of additional attributes. The (verbal) characterization then has to be transferred to a sound mathematical description, e.g., in terms of differential geometry. Based on this description, we can now design operators for detecting and localizing the landmarks. To end up with applicable operators, where one constraint may be computational complexity, it is often necessary to introduce well-motivated and mathematically-founded approximations. The last step of the framework is to validate and evaluate the operators using synthetic as well as real image data.

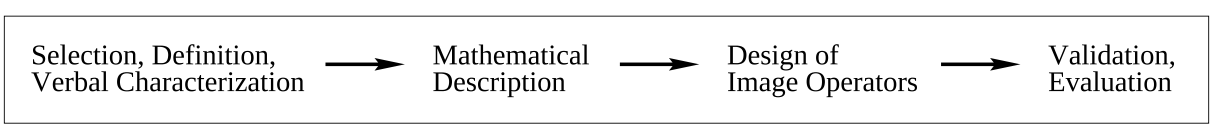

Figure 1: A framework for the development of approaches to landmark localization

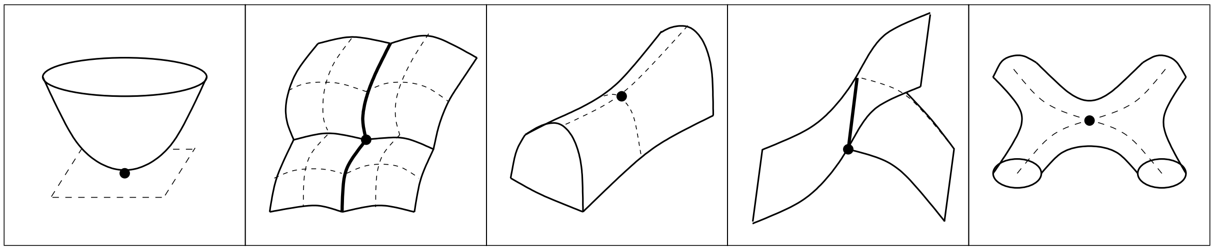

Figure 2: Different types of 3D point landmarks

Characterization of anatomical landmarks of the human head

In our investigation of anatomical landmarks of the human head it soon became clear that already the selection and definition of 3D point landmarks is a very hard problem (see also [3],[4]). This is due to the complexity of the anatomical structures, the variability between different persons and also between the two hemispheres, as well as because only sparse quantitative knowledge exists about structures of the human head. Moreover, in the case of multimodality image registration we have to deal with the visibility of landmarks in images from different modalities. Additionally, the localizability depends, for example, on the scale of the landmarks, the degree of contrast, the image resolution and blur, as well as on other imaging parameters (e.g., T1 vs. T2-weighted MR images). In our case, we mainly consider landmarks on the ventricular system and on the skull base since these structures are both visible in MR and CT images and exhibit a larger number of prominent points. Examples are the tip of the external protuberance, the saddle point on the zygomatic bone, as well as the tips of both the frontal and occipital ventricular horns. It appears that many point landmarks can be classified as either tips or saddle points (see Fig. 2). Other types of landmarks are, for example, surface-surface and line-surface intersections (e.g., junctions of sulci) or center points of cylinder crossings (e.g., optic chiasm).

3D operators for localizing point landmark

We have developed 3D differential operators to localize the above-mentioned landmarks within a semi-automatic procedure ([6],[5],[1]). Semi-automatic means that (i) a region-of-interest is specified by the physician, (ii) an image operator is applied yielding landmark candidates, and then (iii) these candidates can be either approved or discarded. Our 3D differential operators can be classified into three groups: Ridge-line based operators, operators based on the mean or Gaussian curvature of isocontours, and operators which are 3D extensions of existing 2D corner detectors. The complexity ranges from operators based on partial derivatives of the image of only first order to those with derivatives up to the third order (in Fig. 3 the result of an operator based on only first order derivatives is shown). For first comparative results concerning the validation of the different operators on MR and CT images see [5],[1]. The localized landmarks are used as features for a 3D elastic registration scheme which is based on approximating thin-plate splines ([6],[7]).

Despite the progress we achieved by now, the indicated fundamental problems require that the here described framework should further be pursued within an interdisciplinary

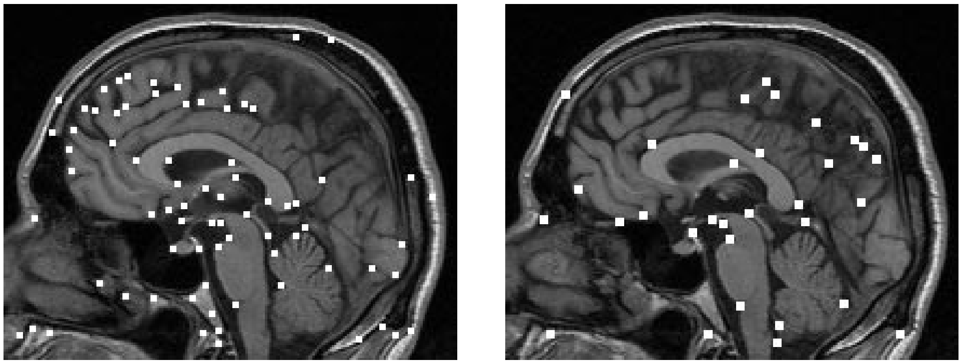

Figure 3: Landmark candidates: Application of a 2D 'corner' detector (left) vs. a 3D extension (right) on a 2D and 3D MR image, resp.

cooperation between experts from anatomy, neurosurgery/radiology, and computer vision/informatics.

Acknowledgement

Support of Philips Research Hamburg, project IMAGINE (IMage- and Atlas-Guided Interventions in NEurosurgery), is gratefully acknowledged.

References

[1] W. Beil, K. Rohr, and H.S. Stiehl, "Investigation of Approaches for the Localization of Anatomical Landmarks in 3D Medical Images", *Proc. Computer Assisted Radiology and Surgery (CAR'97),* Berlin, Germany, June 25-28, 1997, H.U. Lemke, M.W. Vannier, and K. Inamura (Eds.), Elsevier Amsterdam Lausanne 1997, 265-270

[2] F.L. Bookstein, "Thin-Plate Splines and the Atlas Problem for Biomedical Images", *Proc. 12th Internat. Conf. Information Processing in Medical Imaging,* July 1991, Wye/UK, *Lecture Notes in Computer Sciene 511,* A.C.F. Colchester, D.J. Hawkes (Eds.), Springer-Verlag Berlin Heidelberg 1991, 326-342

[3] A.C. Evans, W. Dai, L. Collins, P. Neelin, and S. Marrett, "Warping of a computerized 3-D atlas to match brain image volumes for quantitative neuroanatomical and functional analysis", *Medical Imaging V: Image Processing,* 1991, San Jose, CA, Proc. SPIE 1445, M.H. Loew (Ed.), 236-246

[4] D.L.G. Hill, D.J. Hawkes, J.E. Crossman, M.J. Gleeson, T.C.S. Cox, E.E.C.M. Bracey, A.J. Strong, and P. Graves, "Registration of MR and CT images for skull base surgery using point-like anatomical features", *The British J. of Radiology* 64:767 (1991) 1030-1035

[5] K. Rohr, "On 3D Differential Operators for Detecting Point Landmarks", *Image and Vision Computing* 15:3 (1997) 219-233

[6] K. Rohr, H.S. Stiehl, R. Sprengel, W. Beil, T.M. Buzug, J. Weese, and M.H. Kuhn, "Point-Based Elastic Registration of Medical Image Data Using Approximating Thin-Plate Splines", *Proc. 4th Internat. Conf. Visualization in Biomedical Computing (VBC'96),* Hamburg, Germany, Sept. 22-25, 1996, *Lecture Notes in Computer Science* 1131, K.H. Höhne and R. Kikinis (Eds.), Springer Berlin Heidelberg 1996, 297-306

[7] K. Rohr, R. Sprengel, and H.S. Stiehl, "Incorporation of Landmark Error Ellipsoids for Image Registration based on Approximating Thin-Plate Splines", *Proc. Computer Assisted Radiology and Surgery (CAR'97),* Berlin, Germany, June 25-28, 1997, H.U. Lemke, M.W. Vannier, and K. Inamura (Eds.), Elsevier Amsterdam Lausanne 1997, 234-239