ROBUST MATCHING OF IMAGES BY AN ALGORITHM BASED ON VOTING FOR TREATMENT ACCURACY ASSESSMENT IN RADIOTHERAPY

Leszek Chmielewski[1], Piotr Gut[1], Paweł Kukołowicz[2], Andrzej Dąbrowski[2]

[1] **Institute of Fundamental Technological Research, PAS**
Świętokrzyska 21 00-049 Warsaw www.ippt.gov.pl
[2] **Holycross Cancer Centre**
Artwińskiego 3 25-734 Kielce www.onkol.kielce.pl

ABSTRACT

To find if the radiotherapy treatment of cancer is performed precisely it is necessary to register a pair of images: one made during therapy planning and the second one made during the therapy itself. To do this it is proposed to match the edges of the anatomical structures and the irradiation field found in both images and to use the Hausdorff distance modified by using a voting scheme. This makes it possible to perform the matching between those fragments of the edges which actually have their counterparts in the other image, and to omit hose which do not, in an automatic way.

INTRODUCTION

The pattern recognition problem dealt with in this paper is matching a pair of images coming from two different imaging modalities. Image matching, with the aim of precisely overlaying the corresponding regions of both images, is called *image registration*. Our problem will be discussed in close relation to a specific medical application it appears in. This application is the assessment of the accuracy of radiotherapy of cancer.

The use of ionising radiation in cancer teleradiotherapy imposes high requirements in terms of accuracy, in its medical as well as technical aspects. Close adherence to the geometrical parameters found in therapy planning is vital. Change of the applied dose by one per cent can lead to a change in time to local recurrence of the disease by as much as several percents [1]. Imprecise realisation of the geometry can imply the loss of chance for permanent remission of the disease or to severe post-irradiation effects. In an ideal treatment the position of the irradiation field with respect to the anatomical structures of the patient conforms to the planned one and is constant in all the radiotherapy courses.

The location of the irradiation field and anatomical structures in a specified therapeutical session can be recorded in the *portal image*. The planned geometry is recorded in the *reference image*, routinely made during therapy planning in a *simulator*. Assessment of the treatment accuracy consists in comparing the layout of anatomical structures and

Proc. 2nd Polish. Conf. Computer Pattern Recognition Systems KOSYR 2001, May 28-31, 2001, Miłków, Poland, pp. 211-216. http://www.zssk.pwr.wroc.pl/zssk/kosyr/kosyr.html

the irradiation field in a series of portal images taken during subsequent therapy sessions, in comparison to the reference image. This requires the registration of each of the portal images with the reference one. The natural loci of interest, or *landmarks*, in the anatomical structures as well as in the irradiation field, are their edges.

The reference image is an X-ray of high quality. The reference image is produced by the therapeutical beam, and is inherently of low contrast due to that different tissues, like bones and muscles, attenuate the therapeutical radiation very similarly. Edges of the compared features are difficult to find in the portal image. Not all the edges present in the reference image can be found in the portal one. In consequence, the comparison of geometries in these images is difficult and time-consuming. There exists a need for a tool that could support and objectify this process.

STATE OF THE ART

At present the radiotherapy accuracy assessment is done manually by an experienced physician, with the use of portal and reference images in the form of typical X-ray films. This tedious procedure is rarely applied and, as a rule, it is not performed routinely. The literature on image registration refers mainly to portal images made with beams generated in accelerators rather than with the cobalt apparata. In Poland more than a half of patients are treated with cobalt. There are numerous references to image registration methods tailored for finding the fitting and non-fitting fragments of the compared edges. Although full automation of the method has been attempted, as for example in [2, 3, 4, 5], the majority of algorithms lack generality. In [2] the rectilinearity of edges of the irradiation field is used. In [4] mutual rotation of images is not taken into account. Satisfactory results were received only in the case of pelvis [5], where edges of thick bones are clearly visible. Algorithms in which landmarks to be matched should be shown manually are still in use [6, 7]. A comparison and classification of the methods can be found in [8, 9].

APPLIED METHODOLOGY

In our application, the images are transformed to a digital form by precision scanning. The applied method will be described using the classification of main elements of image registration algorithms according to [8].

Landmarks to be matched Edges of selected anatomical structures and of the irradiation field[1]. Using artificial landmarks is excluded due to practical reasons

Geometrical transformation Affine transformation (2 translations, rotation, 2 scalings – along two coordinate axes). These transformations, used in nearly whole literature, are sufficient to model the mutual differences between the considered images, and have a mathematical form suitable for easy computations. In practice, a long series of transformations is performed. This does not imply cumulation of errors in the transformed images, as the subsequent transformations are aggregated in a single transformation matrix, which is always applied to a source edge portal image. Transformation of this sparse image is not time consuming.

Measure of image registration accuracy Modified Hausdorff distance measure [10, 11, 12]. This is a robust method based on voting. Distance is calculated and

---

[1] It is planned to use the classical zero-second-derivative edge detector, with scale fitted to the scale of edges, but this part of the algorithm is still under development.

Proc. 2nd Polish. Conf. Computer Pattern Recognition Systems KOSYR 2001, May 28-31, 2001, Miłków, Poland, pp. 211-216. http://www.zssk.pwr.wroc.pl/zssk/kosyr/kosyr.html

parts of the contours that do not fit the general tendency are rejected. In this way, the edges in one image which have no counterparts in the other image are rejected from the matching process in an automatic way.

The classical Hausdorff distance is defined on two finite sets of points A and B

$$H(A,B) = \max\left[\max_{a\in A}\min_{b\in B} d(a,b), \max_{b\in B}\min_{a\in A} d(b,a)\right] \tag{1}$$

where $d(a,b)$ is the distance between the points a and b in the chosen metric, for example, the Euclidean distance. The modification of the distance function (1) is as follows [10, 12]

$$h^f(A,B) = Q^f_{a\in A} \min_{b\in B} d(a,b) \tag{2}$$

where $Q^f_{x\in X} g(x)$ is the quantile of rank f of $g(x)$ over the set X, and $f \in (0,1]$. The function (2) is not symmetrical, so it is not a distance in a strict sense. It is a robust measure due to that the maximum is replaced with a quantile. In our application, A is the set of edge pixels in the portal images, and B the set of edge pixels in the reference image. In the practical realisation of the quantile, frequency is used instead of the probability, so it is necessary to build a histogram of minimum distances of all the pixels a of the portal image edges to the set B of reference image edge pixels. These calculations are speeded up by using the distance transform [13] of the reference edge image, calculated only once. From this transform, a minimum distance of a pixel in the portal image to its corresponding pixel in the reference edge image can be read out directly [12].

Optimisation method for finding the best transformation Maximum gradient in the space of transformations. Together with the use of the distance transform this resolves to the *chamfer matching* method. Optimisation is started with a moment-based minimum. In the beginning the quantile rank 1 is used, which resolves to the maximum measure like in Eq. (1) inside the outer ellipses, and it is reduced by 0.01 each time a local minimum is reached. Optimisation is terminated at the minimum when the rank reaches a specified value. Practice shows that very satisfactory location of the matched images is reached with the value of 0.8.

In the presented methodology the main original element is the application of the modified Hausdorff distance to the problem of registration of the portal images. Also our aim to make it possible to process portal images made with cobalt apparata can not be found elsewhere.

The idea of starting with the quantile of rank 1 and going down to a specified value is not a typical practice. Another novel idea is used in the optimisation. Normally, in each optimisation step, 10 possible transformations of the *portal* edge image are calculated (2 translations, rotation, 2 scalings, each in 2 directions) and the one which yields a largest improvement in the registration accuracy is chosen. Instead, it is possible to use the pre-calculated distance transforms for 10 virtual transformations of the *reference* edge image, to find from them the 10 measures of accuracy without calculating the respective transformations of the *portal* edge image. Only that transformation of the *portal* image is calculated, which yields the best improvement. The opposite sign of the transformation is taken. The technique saves computations of transformations at the expense of calculating multiple distance transforms, which are more expensive. Hence, it is profitable only if multiple optimisation steps are made. The assumption is that the centre of rotation and scaling is fixed with respect to the reference image. This assumption does not hold in the initial part of the optimisation process. The use of the described technique needs more investigations.

If the time of calculations is too long with the processors available at the time of delivery of the final version of the tool, then a hierarchical approach consisting in processing a pyramid of images with increasing resolution can be applied, with the result from a given level used as the starting point for the next level.

VERIFICATION

The proposed methodology and the developed software tool will be verified, first with the human-like phantoms, then in the typical radiotherapy practice at the Holycross Cancer Centre in Kielce. The result of the analysis will make it possible to correct the therapeutic system geometry or the location of the patient.

EXAMPLE

Examples of calculations performed up till now confirm the appropriateness of the proposed methodology. We shall present the results received for a pair of images shown in Fig. 1 a and b. These are the images of a pelvis region with resolution of $809 * 1006$ pixels. For presentation, the irrelevant parts of the images were removed and the scales were changed. Edges were marked manually by an experienced person[2]. The results of matching the edges are shown in Fig. 1 c. Matching is good in spite of that some corresponding edges are missing in one or the other image, typically in the portal one. Moreover, there are erroneous fragments in both images.

The final transformation was found in 144 steps: translation along $x:-7$, $y:-58$, scaling along $x:1.1139$, $y:1.1139$, rotation -0.41^0. Time of calculation with a Pentium III 800 MHz was around 1.5 minutes.

CONCLUSION

The presented methodology supporting the quality assessment of radiotherapy is operational in the scope of registering the images made during the therapy planning and realisation. In matching the edges in the reference and the portal images the main problem is that in both images the sets of visible edges are different, and their common part, which should be matched, is not known before the matching is performed. This problem can be overcome by using as the measure of matching quality the Hausdorff distance modified by using a quantile instead of the maximum in its definition. This measure, successfully used in other applications presented in the literature, performs very well in the case of reference and portal images. The affine geometrical transformation which realises the registering is found in the way of a maximum gradient optimisation. Pre-calculation of some multiply used data and hierarchisation of the algorithm can be used to speed up its operation.

---

[2] A software tool for automated marking and editing the edges is being prepared.

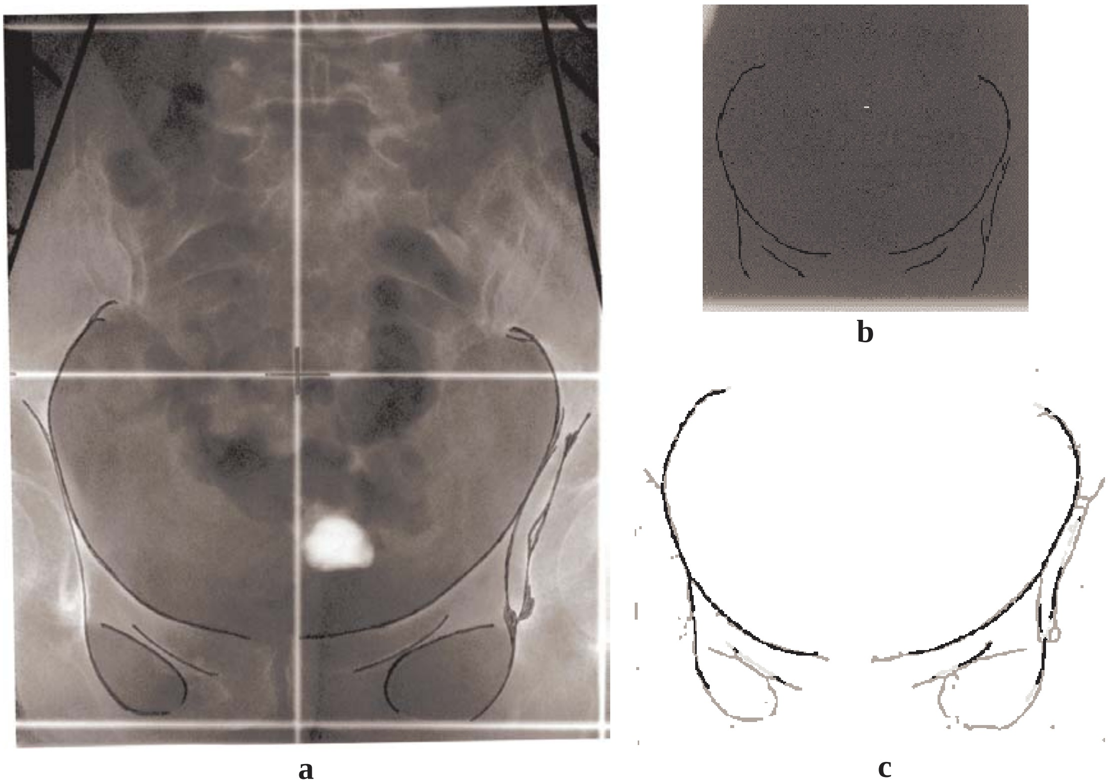

Fig. 1. Example of matching the edges. a: reference image – pelvis; b: portal image (significant fragment); c: result. In a and b: edges marked in black. In c: edges from portal image: black – matched, light grey – not matched; edges from reference image: dark grey. All edges thickened for presentation.

Acknowledgement The work was supported by the Committee for Scientific Research, Poland, within the grant no. KBN 4 P05B 064 18.

REFERENCES

[1] Aaltonen-Brahme P., Brahme A. *et al.*, Specification of dose delivery in radiation therapy. *Acta Oncologica*, 36, Supplementum 10, 1977.

[2] Eilertsen K., Skretting A., Tennvassas T. L., Methods for fully automated verification of patient set-up in external beam radiotherapy with polygon shaped fields. *Phys. Med. Biol.*, 39, 1994, 993-1012.

[3] Gilhuijs K. G. A., van Herk M., Automatic on-line inspection of patient setup in radiation therapy using digital portal images. *Med. Phys.*, 20, 3, 1993, 667-677.

[4] Giraud L. M., Pouliot J., Maldague X., Zaccarin A., Automatic setup deviation measurements with electronic portal images for pelvic fields. *Med. Phys.*, 25, 7, 1998, 1180-1185.

[5] Guilhuijs K. G. A., El-Gayed A. A. H., van Herk M., Vijlbrief R.E., An algorithm for automatic analysis of portal images: clinical evaluation for prostate treatments. *Rad. Oncol.*, 29, 1993, 261-268.

[6] Cai J., Zhou S-Q., Hopkinson J., Saxena V. A., Chu J., Alignment of multi-segmented anatomical features from radiation therapy images by using least squares fitting. *Med. Phys.*, 23, 12, 1996, 2069-2075.

[7] Cai J., Chu J. C. H., Saxena A., Lanzl L. H., A simple algorithm for planar image registration in radiation therapy. *Med. Phys.*, 25, 6, 1998, 824-829.

[8] Brown Gottesfeld L., A survey of image registration techniques. *ACM Computing Surveys*, 24, 4, 1992, 325-376.

[9] Lester H., Arrige S. R., A survey of hierarchical non-linear medical image registration. *Pattern Recognition*, 32, 1999, 129-149.

[10] Rucklidge W. J., Efficiently locating objects using the Hausdorff distance. *Int. J. Comput. Vision*, 24, 3, 1997, 251-270.

[11] Mount D. M., Netanyahu N. S., Le Moigne J., Efficient algorithms for robust feature matching. *Pattern Recognition*, 32, 1999, 17-38.

[12] Chetverikov D., Khenokh Y., Matching for Shape Defect Detection. *Lecture Notes in Computer Science*, vol. 1689, Springer Verlag, 1999, 367-374.

[13] Borgefors G., Distance transformations in digital images. *Comput. Vision, Graphics and Image Processing*, 34, 3, 1986, 344-371.