IMAGE REGISTRATION

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ABSTRACT

The existence of numerous imaging modalities makes it possible to present different data present in different modalities together, thus forming multimodal images. Component images forming multimodal image should be aligned, or co-registered, so that all the data, coming from the different modalities, are displayed in proper locations. The term *image registration* is the most commonly used to denote the process of alignment of images, that is, of transforming them to the common coordinate system. In the paper the classification of the image registration methods is presented and the selected methods are described.

INTRODUCTION

The technological development gave rise to numerous methods of visualising the objects – the ones which surround us, and also our own body. Those methods which make it possible to see the inside of the human body are of special interest. The ageing society, subjected to more and more harmful influences, and having more and more elevated needs related to health, needs more advanced and more reliable methods of medical diagnosis, therapy planning, and biological and medical research. Images coming from different sources, called *modalities*, must be viewed and analysed together. These multiple images, arranged in the organised manner so that the viewed objects are properly positioned in all of the particular images to form a coherent composition, are called *multimodal images*. Data present in component images forming a *multimodal image* can be different and can form a new quality. This is the case, for example, if an EEG (Electroencephalography) image is composed with an MRI (Magnetic Resonance Imaging) image. In the former, some specific information about functioning the human brain is displayed, while the anatomical information is absent. In the latter, only the anatomical information is present. Both images can provide information on how the different parts of the brain are functioning (Fig. 1). Their mutual complementarity should not be hindered by the fact that the resolutions of both images is different, and that each of them has different distortions. The distortions can be of geometrical or other nature, for example non-uniform contrast or non-linear scaling between the visualised phenomenon and the image brightness or colour.

The process of overlaying one image over the other, to obtain a multimodal image, is called *image registration*. Other terms used are *coregistration*, *alignment* or *matching*. Probably the term *coregistration* is the most suitable, as it evokes no confusion with such terms as *im-*

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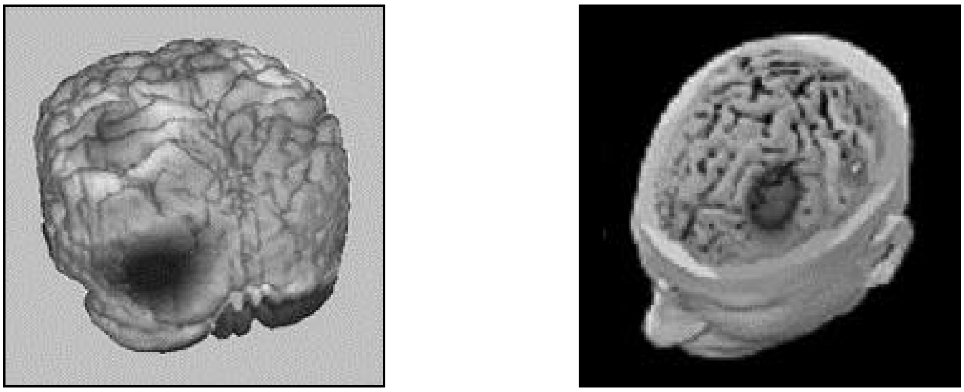
age recording and *feature matching*, but *image registration* is most commonly used. The registration is the process of transforming the component images to a common coordinate system. Then, the so registered images are *integrated* or *fused*, that is, presented together [25].

From the image processing point of view, the most interesting, and probably the most difficult process is that of finding the transformation which converts the component images into the common coordinates. The main question is, where from the information for finding such a system can be extracted, and how to derive it from the available data. In any case, the elements of the images which should be overlaid on one another are sought. These are frequently called the *corresponding features*. They can be either such image features like the edges of objects or the loci of corresponding grey levels, or the elements added to the imaged objects, like extrinsic markers or frames.



a b

Fig. 1. a: EEG data registered with the MRI image. b: SEP data (Sensory Evoked Potentials) registered with the MRI image. In the original colour image the hue was proportional to the electric potential (courtesy: authors of [17]).

CLASSIFICATION OF THE METHODS

A number of classifications of the image registration methods have been proposed. These can be found in the papers by Van der Elsen et al. [12], Gottesfeld-Brown [8], Mauer and Fitzpatrick [22] and Lester and Arrige [19]. Here we shall attempt to merge all these classifications into one. Below the used classification criteria will be described.

Dimensionality *Two-dimensional* (2D) methods are used for 2D images, and *three-dimensional* (3D) methods for 3D images. Also 2D images can be registered with layers in 3D ones. The special case is when surface data are registered with the surface of an object in 3D. Time can be the fourth dimension.

Domain of the transformation The registering transformation can be *global* or *local*, according to whether it operates on the whole image or its part.

Type of the transformation The transformation can be *rigid*, *affine*, *projective*, or *nonlinear*. The last group of transformations is infinite in itself, while the second one is probably the most frequently used. This feature can be otherwise defined, as the **order** of the transformation (*1st order*, *2nd order* etc.).

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Tightness of feature coupling The transformation can be either *interpolating* or *approximating*. In the first case, the features of objects in one image are exactly transformed into features in the other one. In the second case, a non-zero fitting error appears, spread over the overlaid features, for example, as a result of least square fitting.

Measure of the registration quality Various measures are applied, using either the features derived from the data, or the data themselves. The most frequently used measures are the quadratic mean distance and the maximum distance, in the Euclidean or city block metric. Also, measures robust against errors are used, like the measure with the limit of distance, and the quantiles, including the median, which is the quantile of order 0.5.

Method of parameter determination In the *direct* methods, the parameters of the transformation are directly calculated from the data; in the *search-orientated* methods they are found by searching the space of possible values in the process of optimizing the quality measure.

Subject of registration The registration is *intrasubject*, if different images contain data on the same subject (for example, the same patient). The registration is *intersubject*, if the subjects are different.

Type of data The data which control the registration process can be the *raw data* – in the case if images, these will be the raw pixels or voxels; further, these can be the calculated *features of data* – in the case of images, for example edges or blobs; and further, these can be *markers on data*, that is, data introduced to the original data, for example manually marked pixels.

Source of features Registration algorithms can use the *intrinsic* or *extrinsic* features. Intrinsic features are those present in the data, either explicitly (image grey levels) or implicitly (edges, geometrical features of imaged objects, characteristic anatomical points, surfaces or landmarks, like points on bones, skin, cerebral cortex, ventricles). Extrinsic features are those added to the data from outside, like frames mounted to the patient's head, marks on the skin, measuring points on masks.

The last two criteria are relatively similar, but they underline different aspects of the way the data are treated.

Additionally, another criterion can be distinguished, which is not related to the nature of the methods, but rather to their range of applicability:

Automatisation level Scope of user intervention can be small or null, then the method is *automatic*. If the user intervention is necessary for some reasons, the method is *semi-automatic*.

EXAMPLES OF METHODS

From the above criteria, the most important one seems to be that of the *type of data*, because the distinctions in respect of this criterion are the most closely related to the clinical problems analysed with the use of the image registration methods. Therefore, a number of methods classified according to this criterion will be briefly listed here.

Methods using the markers Markers, or *corresponding points*, can be intrinsic (characteristic anatomical points, edges of bones, etc.) or extrinsic (introduced marks, measuring points on masks, or frames). In most of the methods the pairs of corresponding points are registered *directly*, in an *interpolating* manner, usually *globally* [5, 6]. Usually the correspondence of points should be known, that is, the corresponding points should be assembled into pairs. A large group of methods uses the least square fitting – these are the approximating methods [16, 25]. The methods in which a *stereotactic frame* is attached to the patient's head with screws, mounted into shallow holes drilled in the skull, are commonly used [26]. The characteristic points on the frame are very accurate reference points, but the discomfort resulting from the invasiveness of the method is large.

Methods using geometrical features Such *intrinsic geometric features* like surfaces [3], volumes [1, 13], edges or dispersed points [2, 4, 20] are used. The commonly used *direct* and *interpolating* technique is the use of the centroid (centre of gravity) for finding the translation and the geometrical moments for finding the rotation angle of the *rigid transformation*. The strategic direction of development of the considered methods seems to be the use of the registration quality measures based on the distance measures [4, 20], using the distance transforms [7], and variants of the chamfer matching techniques (e.g. [15]), equipped with the robustness offered by advanced statistical approaches [9, 10, 14, 23, 24]. The important property of such approaches is the possibility to cope with data which are partly missing and have some errors (Fig. 2).

Methods using raw data Among the methods of this class, the method of *mutual information* is the most promising [11, 21, 27]. This information theoretical method is *search-orientated* and *fully automatic*. This last virtue, and the fact that no image features, either *intrinsic* or *extrinsic*, must be derived or introduced, makes this method particularly interesting. However, the fact that all the *raw image data* are used as input, without any data reduction, has an important drawback of the method as a result: the *search* for the solution is very calculation intensive. The method is founded on the following observation: the mutual information of the two sets of elements (pixels, voxels) is maximal when the sets are registered. No assumption is made on the nature of the relation between the intensities of the elements.

CONCLUSION

In the domain of image registration, the following two problems seem the most important at present.

- If features are used, how to find their correspondence in the presence of noise and errors.
- If raw data are used, how to perform the calculations in the effective way.

These problems, appearing in the complementary classes of the image registration methods, will probably drive the research in the nearest future.

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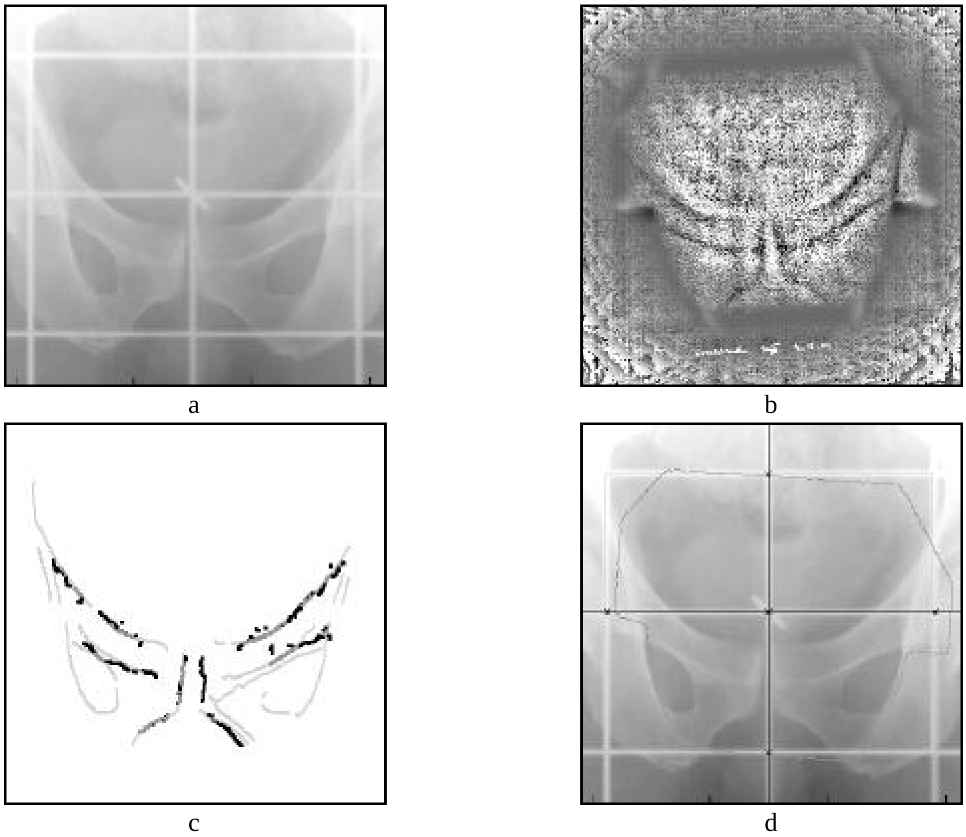

Fig. 2. Registration with the use of robust statistics. a: Therapy simulation image in oncological radiotherapy, with irradiation field and pelvis visible. b: Therapeutical session recorded in a portal image (enhanced with adaptive histogram equalization). c: Edges of bones found in both images registered: bright grey – simulation image, dark grey – portal image, *inliers*, black – portal image, *outliers*, that is, pixels (automatically) rejected from the analysis. d: After registering the bones, the error of alignment of the irradiation field between the plan and the actual therapy can be visualized and measured (courtesy: authors of [10]).

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