METHODES AUTOMATIQUES DE RECALAGE D'IMAGES NON SIMILAIRES -

AUTOMATED METHODS FOR THE REGISTRATION OF DISSIMILAR IMAGES -

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RESUME

La comparaison automatique d'images à l'aide d'un ordinateur, nécessite une étape de recalage qui peut être menée à bien en optimisant un critère de similitude entre images par rapport aux paramètres de recalage. Cet article traite du recalage automatique d'images non similaires. D'abord une nouvelle classe de critères de similitude entre images est présentée; un cas stochastique, un cas déterministe et un cas mixte sont distingués mais dans tous les cas ces critères reposent sur le calcul d'un nombre de changements de signe dans une image de soustraction balayée ligne par ligne ou colonne par colonne. L'utilisation de ces critères pour le recalage d'images non similaires conduit à des algorithmes de recalage qui sont démontrés être beaucoup plus robustes que les méthodes classiques les plus utilisées. Ensuite sont présentées diverses méthodes d'optimisation pour l'estimation des paramètres de recalage. Deux approches sont distinguées : La première repose sur une association de l'étude systématique de toutes les valeurs possibles des paramètres des transformations géométriques à une méthode d'optimisation monodimensionnelle destinée, elle, à l'estimation d'un paramètre d'une transformation de l'échelle de gris. La seconde est l'application d'une méthode d'optimisation globale par recherche aléatoire à la détermination simultanée de tous les paramètres de recalage. Cette méthodologie est appliquée à certaines techniques d'imagerie médicale : images scintigraphiques en rayons Gamma et images d'angiographie numérisée en rayons X.

SUMMARY

The computer comparison of two images requires a registration step which can be performed by optimizing a similarity measure with respect to the registration parameters. This paper deals with the automated registration of dissimilar images. First a new class of similarity measures is presented including a stochastic, a deterministic and a mixed case. Each case involves the calculation of the number of sign changes in the pixels of a subtraction image scanned line by line or column by column. Using these integer similarity measures for the registration of dissimilar images leads to registration algorithms which are demonstrated to be far more robust than the methods currently in use. Second we present an application of optimization methods to the estimation of registration parameters. Two approaches are developped : The first one consists in coupling a systematic study of geometric transformation parameter values to a unidimensional optimization method for the estimation of one parameter of a gray scale transformation. The second one is the application of a random search optimization method for the simultaneous determination of all registration parameters. Applications are given in the field of the medical imagery : Gamma ray scintigraphic and X ray digital subtraction angiographic images.

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1- INTRODUCTION

The use of digitized images is actually growing in various domains of applications such as the earth observation by satellites or the medical imagery. Therefore the computer comparison of images acquired at different times or with different sensors becomes a common problem. It necessitates first a registration step and second a point by point comparison of the registered images. The registration step can be performed by optimizing a similarity measure with respect to the registration parameters. Three particular similarity measures are representative of those used in the algorithms of interest (1,2) : The correlation coefficient (CC), the correlation function (CF) and the sum of the absolute values of the differences (SAVD). These algorithms work correctly when the images to compare are very similar but they frequently lead to a misregistration when dissimilarities are present in the images. This is due to the fact that these similarity criteria directly take into account the pixel values of the images. We have developped a new class of similarity measures which are well suited for the robust registration of dissimilar images (3). They involve calculations on signs and not on values of the pixels of the subtraction image ; they are issued from non parametric statistical considerations (4) which are sometimes used for the statistical test of a model in system theory.

The first part of this paper presents this new class of similarity measures and their main properties and in the second part two algorithms are developped for their optimization. Finally demonstrative examples of applications are given in the field of Gamma and X ray imaging techniques.

2- THE SIGN CHANGE CRITERIA

2-1 Definition of the sign change criteria

2-1-1 The SSC criterion

Consider two images $F_1(i,j)$ and $F_2(i,j)$ of the same object. $F_1(i,j)$ and $F_2(i,j)$ differ only because of the noise measurement which is assumed to be additive, zero mean, with a symmetric density function. Let $D(i,j)=F_1(i,j)-F_2(i,j)$ be the subtraction image. The new similarity measure between $F_1(i,j)$ and $F_2(i,j)$ introduced in (3) is defined as the number of sign changes in the sequence of the values of $D(i,j)$ scanned line by line or column by column. This stochastic sign change criterion is called the SSC criterion. It was theoretically and experimentally proven to be a similarity measure between images with demonstrative examples in the field of the Gamma ray imagery (3).

2-1-2 The DSC criterion

The images $F_1 i,j)$ and $F_2(i,j)$ are now supposed without noise. A third image $F_3(i,j)$ is calculated according to the following way :

$$F_3(i,j)=F_2(i,j)+q \text{ if } i+j \text{ is even}$$

$$F_3(i,j)=F_2(i,j)-q \text{ if } i+j \text{ is odd}$$

(q is a small real or integer value whose choice will be discussed later.

$D(i,j)$ is now defined as $F_1(i,j)-F_3(i,j)$. The deterministic sign change criterion (DSC criterion) is defined as the number of sign changes in $D(i,j)$ scanned line by line or column by column.

2-1-3 The mixed case

The SSC criterion is well suited for the registration of images where the entire noise is coded (Gamma ray images with count statistical fluctuations) (3,5). The DSC criterion is well suited to images with a high signal to noise ratio leading to images which are nearly without noise (after truncation by coding). When the noise level remains low but sufficient to be coded in part, the SSC values are low (too low to be used as a similarity measure) and the DSC value depends on the value of q. The following calculations permit to derive the DSC expectation values when q is expressed as a function of σ^2, the variance of the noise (assumed to remain constant in the whole image).

Consider two neighboring pixels 1 and 2 of the subtraction image $F_1(i,j)-F_3(i,j)$. If there were no noise, their values would be for example +q and -q. Suppose these pixels are affected by a noise which is assumed to be uncorrelated, zero mean, gaussian with a variance σ^2. Suppose ε_1 and ε_2 are respectively the noise samples on pixel 1 and 2. The probability P(SC) that a sign change remains present between pixel 1 and 2 is :

$$\begin{aligned} P(SC)=&P(\varepsilon_1>0).P(\varepsilon_2<0)\\ &+P(\varepsilon_1>0).P(q>\varepsilon_2>0)\\ &+P(0>\varepsilon_1>-q).P(0>\varepsilon_2)\\ &+P(0>\varepsilon_1>-q).P(q>\varepsilon_2>0)\\ &+P(-q>\varepsilon_1).P(\varepsilon_2>q)\end{aligned}$$

Define P_1 as : $P_1=P(\varepsilon>q)=P(\varepsilon<-q)$; we have : $P(\varepsilon>0)=0.5$ and $P(\varepsilon<0)=0.5$ so that :

$$P(0>\varepsilon>-q)=P(q>\varepsilon>0)=0.5-P_1$$

Hence :

$$\begin{aligned} P(SC)=&0.25\\ &+0.5(0.5-P_1)\\ &+(0.5-P_1)0.5\\ &+(0.5-P_1)(0.5-P_1)\\ &+P_1.P_1\end{aligned}$$

$$P(SC)=1-2.P_1+2.P_1^2$$

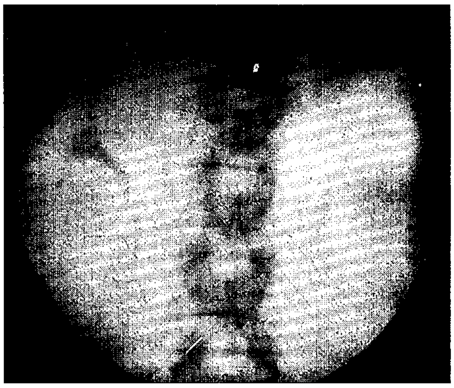
This expression permits to recover the probability of a sign change corresponding to the SSC and DSC criteria: The SSC case corresponds to $q<<\sigma$ so that $P_1 \rightarrow 0.5$ and $P(SC)=0.5$

The DSC case corresponds to $q>>\sigma$ so that $P_1 \rightarrow 0.$ and $P(SC)=1$.

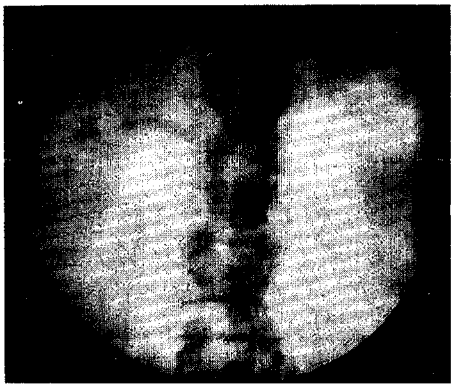
The P_1 values can be found in tables of a reduced normal law so that the P(SC) values can be numerically calculated when q is expressed as a function of σ values. For the values $q=\sigma/8$, $\sigma/4$, $\sigma/2$, σ, 2σ the respective values of P_1 are 0.45, 0.40, 0.30, 0.16, 0.02 and the P(SC) values are respectively equal to 0.50, 0.52, 0.58, 0.73, 0.96. These calculations demonstrate that when the value of σ is known, there is no advantage to select values of q greater than 2σ because in this case the corresponding value of P_1 is 0.96 and is very near 1, the maximum value of P_1.

2-2 Experimental demonstration of the robustness of the registration procedures using the sign change criteria.

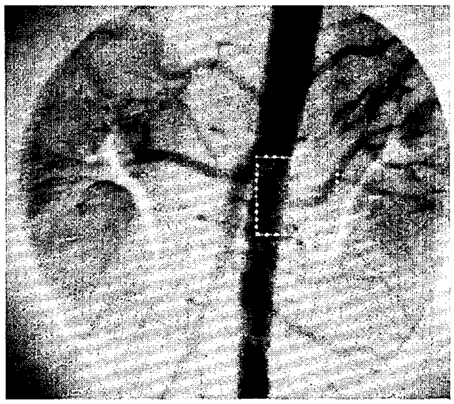
We have demonstrated in previous papers the robustness of the registration procedures using the SSC criteria either for performing gray scale transformations (normalization of Nuclear Medicine scintigraphic images (5)) or for carrying out geometric transformations such as translations (3,6), when compared to the CC, CF and SAVD criteria. This is due to the fact that the pixel values in the subtraction image never directly influence the SSC or DSC criteria. Suppose that one pixel value is multiplied by 10^6, the SSC or DSC value will differ by a value lower than or equal to 2 but the classical criterion values will be strongly modified. Fig. 1 gives a picturial illustration of this property studied on X ray angiographic images. Fig. 1-a and 1-b represent two images respectively without and with iodine contrast intravenously injected. Fig.1-c is the logarithmic subtraction image and shows the pure vascular structures. Fig.1-d demonstrates in a 3D view the DSC criterion surface when progressive translations of the figured window (70X70) of image 1-c are carried out along the horizontal and vertical axis of the image. Fig. 1-e shows same surface corresponding to the CC values. The maximum of the DSC criterion (calculated with q=2) is obtained for a null translational shift which is a good value since the subtraction image is a good quality one. CC is maximum for a wrong value of the translation (2 and -1 pixels). Maximizing CC value for registration purposes would lead to image 1-f which is evidently a very bad subtraction image.



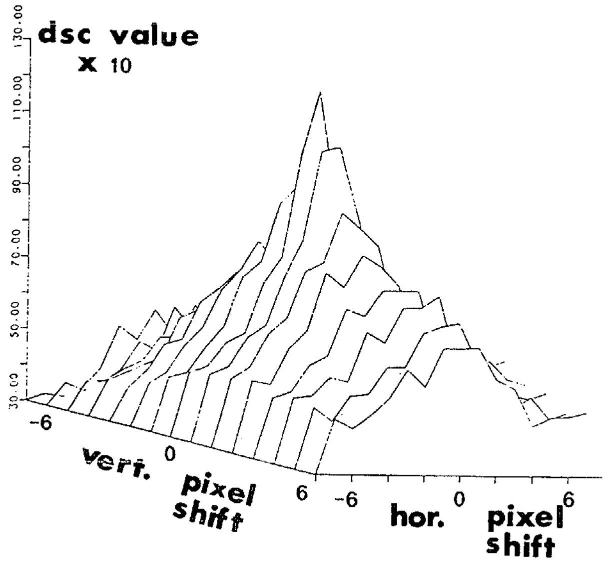
1-a



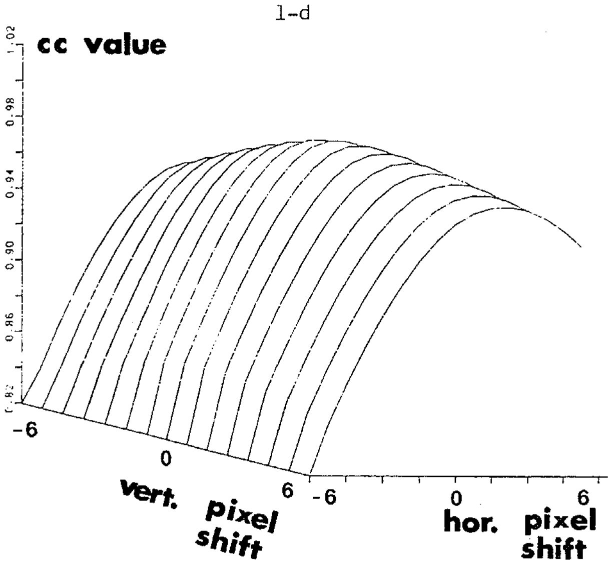
1-b



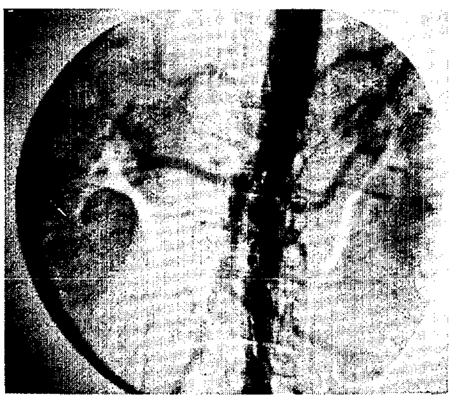
1-c



1-d



1-e



1-f

Figure 1. 1-a : Mask image, 1-b : Angiographic image, 1-c : Subtraction image for the maximum value of the DSC criterion, 1-d : DSC criterion surface for -7 to +7 pixel translations along the vertical and horizontal axis, 1-e : CC criterion surface for same translations, 1-f : Subtraction image for the maximum value of the CC criterion.

3- METHODS FOR OPTIMIZING THESE CRITERIA

3-1 General considerations

Once a similarity criterion and the registration transformations (gray scale, geometric) have been selected, the registration of images is reduced to an optimization problem. The similarity criterion has to be maximized with respect to the registration parameters. When using the sign change criterion, this problem has the following features: - The function to optimize (the DSC or SSC criteria) only has integer values. - The function is not differentiable with respect to the registration parameters. There is no analytic solution to the differentiation and even the numerical differentiation is delicate because of the integer value of geometric transformation parameters such as the translational shifts. - The function to optimize may not be unimodal. - The calculations of the similarity criteria at each step are time consuming.

In the following, we present two different approaches : The first one consists in the systematic exploration of the values of a geometric transformation coupled with a unidimensional optimization method for the estimation at each step of another registration parameter such as that of a gray scale transformation. The second one is a random search approach applied to the simultaneous estimation of all registration parameters.

3-2 Using a unidimensional method.

In a previous paper (5) we have demonstrated the interest of using a unidimensional method such as the Fibonacci or the golden section (7) for the determination of a gray scale transformation parameter value. This automatic research can be coupled with a systematic investigation of the similarity criterion values corresponding to every parameter integer value of a geometric transformation in a given interval (for example the $(2n+1)^2$ possible values of the parameters in a -n,+n interval of variation for translations along the vertical and horizontal axis). If m iterations are necessary for a correct estimation at each step of the gray scale transformation parameter, the search in the whole interval requires $m(2n+1)^2$ calculations of the criterion. In practical examples, m and n are respectively greater than or equal to 8 and 2. This leads to a minimum of 200 calculations of the criterion for a correct determination of 3 registration parameters. This number reaches 3288 for a -10,+10 search interval for the translational shifts, so that this approach must be reserved to problems with few registration parameters. Nevertheless when only a translation is considered, these calculations furnish a criterion surface (see Fig. 1) which can be easily interpolated for an infra pixel determination of the optimum of this surface, using 2D interpolation techniques. When the number of registration parameters or their search interval increases, one is naturally driven to another optimization approach which is developed in the following section.

3-3 Using a global optimization method

To avoid the difficulties which were emphasized in section 3-1, an adaptative random search strategy (ARS) has been developed and tested for the optimization of the SSC or DSC criteria with respect to several parameters (8).

If $\theta^k=(\theta_1^k, \theta_2^k, \ldots, \theta_n^k)^T$ is the parameter vector at iteration k and $J^k=J(\underline{\theta})$ is the corresponding value of the criterion, the basic structure including two phases of the implemented ARS algorithm can be summarized as follows:

-Specify the admissible range for each parameter θ_i $\theta_{imin}<\theta_i<\theta_{imax}$

-Choose the initial point as $\theta_i^o=\theta_{imax}+\theta_{imin}/2$ (i=1, 2, .., N)

(first phase) -Generate a random displacement vector $\underline{r}^k$ according to a normal distribution with a zero mean and a variance α_i.

-Determine the value of α_i (see (8)) which gives the most successful results.

(second phase) -Select this value of α_i^* and use it during the second phase of the algorithm for a fixed number of times.

-Go to the best point and resume a new variance selection phase (first phase).

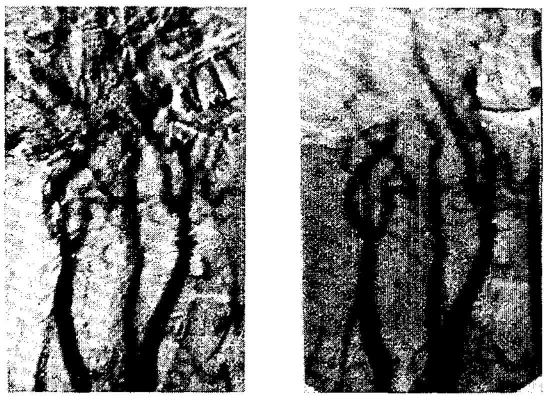
-Stop the algorithm when, after a certain number of trials, there is no increase in the criterion value.

This algorithm has been successfully used for the registration of 128X128 Nuclear Medicine images with respect to five parameters (two translational shifts, one rotation angle, the two parameters of a linear gray scale transformation). The admissible domain for the parameters was typically -30 to +30 pixels for the horizontal and vertical translations, -45 to +45 degrees for the rotation, 0.1 to 10. and -20 to 20 respectively for the multiplicative and additive factors of the linear gray scale transformation. The 128X128 images were typically correctly registered after 2000 computations of the SSC criterion. The algorithm was coded in FORTRAN on a mini computer connected with an array processor so that this procedure required approximatly two minutes.

4- EXAMPLES OF APPLICATION IN THE FIELD OF THE MEDICAL IMAGERY.

4-1 Correction of patient movement during digitized subtraction angiography.

Digitized subtraction angiography consists in visualizing the differences between two images obtained without and with iodine contrast intravenously injected. If the patient moves during this investigation, the subtraction procedure becomes inadequate and the second image must be registered prior to the subtraction. We present in Fig. 2 a picturial illustration of the registration of such image carried out by maximizing the DSC criterion with respect to two vertical and horizontal shifts and the additive parameter of a linear gray scale transformation according to the optimization procedure described in section 3-2. The original subtraction image is shown in Fig. 2-a. Significant improvements in the subtraction image are demonstrated by Fig. 2-b corresponding to the subtraction image after registration.

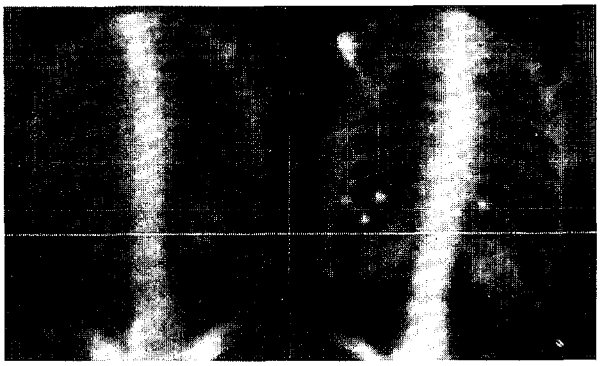


2-a 2-b

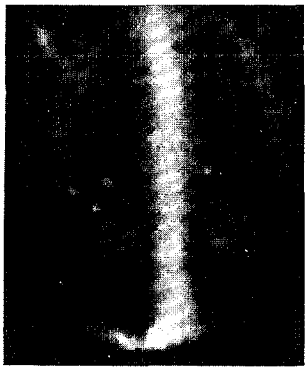
Figure 2.: Carotid angiography. 2-a : Original subtraction image, 2-b : Subtraction image after registration.

4-2 Registration of Nuclear Medicine scintigraphic images.

The comparison of two scintigraphic images of the same organ explored under varying conditions (acquisition at different times, with different tracers..) is a routine problem in Nuclear Medicine. If performed automatically, it first necessitates a proper registration of the images to compare (6). We present in Fig. 3 an example of application of the optimization method of section 3-3. Fig. 3-a is the scintigraphic posterior view of a thorax ; Fig. 3-b is a rotated, translated and modified version of image 3-a acquired with a different acquisition time. Image 3-c is the registered version of image 3-b (optimization of the SSC criterion with respect to five registration parameters).



3-a 3-b



3-c

Figure 3 : Registration of Gamma ray scintigraphic images. 3-a : Scintigraphic posterior view of a thorax, 3-b : Rotated, translated and modified version of image 3-a, 3-c : Registered image 3-b.

5- DISCUSSION AND CONCLUSION

The sign change criteria and their optimizations by an efficient optimization method yield completely automated registration methods which permit to correctly register dissimilar images. The proper use of these algorithms necessitates to simultaneously consider the gray scale and the geometric transformations necessary for the registration of images. They differ in this way from the correlation methods where the geometric parameter values can be computed independently from certain gray scale transformations. Accordingly, the number of registration parameters is high when the DSC or SSC criteria are used for registration purpose and the optimization of these criteria necessitates many calculations. The adjunction of an array processor to the minicomputer used for image processing is necessary to carry out these calculations in an admissible time. Some specific hardware devoted to these calculations could be another improvement for the implementation of these methods.

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