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Application of Genetic Algorithms to Texture Analysis

Application of genetic algorithms to texture analysis is presented in this paper. The genetic algorithm technique was applied to the calculation of the orientation distribution function from a set of pole figures. The results are very satisfying. The same algorithm may be also applied to other problems of texture analysis, e.g., to find an optimal texture for a given application.

Keywords: genetic algorithm, crystallographic texture, orientation distribution function, pole figure, texture analysis, numerical algorithm

1. Introduction

The method of genetic algorithms (GA) is a modern computer technique based on some ideas taken from biological evolution theory (see, e.g., HOLLAND). GA is especially useful for a study of problems being not completely determined. They are, e.g., problems having a few but not very different solutions or problems without a strict (exact) solution. The last situation may occur if it is enough to find a good solution but not necessarily the best one. In GA approach it is not necessary to know a priori a general scheme of problem solution; however, it is important to have a procedure estimating the quality of a solution. This procedure is necessary to eliminate some solutions and to accept another. In last years the GA method was applied with success in different areas of science, e.g., in: sociology, construction engineering, artificial intelligence and many others.

The present work reports the first result (to the authors' knowledge) of GA application in texture analysis: the orientation distribution function (ODF) is calculated from a set of (measured) pole figures (PFs). The authors consider it as the first step before other future applications of GA in the field of crystallographic textures (one of possibilities is the "synthesis" of an optimal ODF for a given application).

2. Genetic Algorithms

The basic elements of GA will be recalled below. In the first step a numerical representation of any possible solution has to be defined (*coding procedure*). A typical procedure is to represent a solution as a string of n coefficients: S $(a_1, a_2, \ldots, a_n)$, where *n* and interpretation of a_i depend on a problem. Each solution S is called an *individual*. In the next step the *accommodation function* is defined: it defines the *accommodation factor* characterising the quality of solution. In the following step a set of random solutions is created: $S_1, S_2, \ldots S_k$; k is usually a big number depending on particular problem and on the length *n* of individuals. The set of solutions is called *population*. Having these basic elements, the GA program can be constructed.

In the GA program many iterations are done. At the beginning of each iteration the quality (expressed by accommodation factors) of all solutions $S_1 ... S_k$ from the population P_i is determined (*i* - is the number of iteration). The principal event in each iteration is the *reproduction*: each solution from P_i gets some number of copies. The number of copies of any solution is proportional to its accommodation factor. The solutions with accommodation factor below the mean value for the population are deleted from P_i (and of course are not copied). The next step is the *crossover* process: for some (randomly chosen) pairs of solutions their strings of coefficients are cut (in random point) and interchanged. The following example makes clear this procedure:

Before crossover: $S_2(a_{2,1}, \dots, a_{2,r}, a_{2,r+1}, \dots, a_{2,n})$, $S_6(a_{6,1}, \dots, a_{6,r}, a_{6,r+1}, \dots, a_{6,n})$
After crossover: $S_2(a_{2,1}, \dots, a_{2,r}, a_{6,r+1}, \dots, a_{6,n})$, $S_6(a_{6,1}, \dots, a_{6,r}, a_{2,r+1}, \dots, a_{2,n})$

The last event in each iteration is the *mutation*. Mutation is a simple procedure in which some coefficients in some solutions are randomly changed. After these three steps: reproduction, crossover and mutation the population P_i becomes the P_{i+1} one (i.e., the new generation). The new generation is the starting population for the next iteration. In any iteration the best solutions are not worse and usually better than those from the previous one. It means that each population has some solution(s) being better than the best one from the previous population. The presented scheme is the simplest one. It is possible to make many extensions and improvements; some of them are described by GOLDBERG.

3. Texture Analysis

A typical goal of texture analysis is to calculate the ODF from a set of PFs. There exist a number of methods for this calculation: the series expansion method (e.g., BUNGE), the series expansion method using Gauss-type model functions (LÜCKE, POSPIECH, JURA), the maximum entropy principle based method (SCHAEBEN) and the direct methods, e.g.: the vector method (RUER, BARO), the WIMV method (MATTHIES, 1979), ADC method (PAWLIK) or recently developped one (TARASIUK, WIERZBANOWSKI, BACZMANSKI).

The aim of this work is to apply the GA method for the same purpose, i.e., for the ODF calculation from a set of PFs.

4. Genetic Algorithm in Texture Analysis

The series expansion representation of the ODF defines the coding procedure in the present calculations. Consequently, an ODF is expressed as:

$$f(g) = \sum_{l=0}^{\infty} \sum_{\mu=1}^{M(l)} \sum_{\nu=1}^{N(l)} C_l^{\mu\nu} T_l^{\mu\nu}(g) \quad (1)$$

where $T_l^{\mu\nu}(g)$ are symmetric generalised spherical harmonics (cf., BUNGE). It is practical for the present method that an ODF may be represented by a set of $C_l^{\mu\nu}$ coefficients (the series is cut at $l_{max}=22$ in a typical case; odd and even terms are taken into account). Consequently, in the GA program each solution (ODF) is a string of numbers:

$$S(C_0^{11}, C_1^{11}, C_1^{21}, C_2^{12}, C_2^{13}, C_2^{21}, \dots \quad (2)$$

In such a way the coding procedure is simple and intuitive. The next stage is the definition of the accommodation function. First, the PFs are recalculated from the ODF corresponding to the solution S (using the well known "fundamental equation" - cf., BUNGE):

$$S(C_0^{11},...) \Rightarrow f(g) \Rightarrow p_S(\alpha,\beta) \tag{3}$$

Next the experimental PFs, $p_e(\alpha,\beta)$, are compared with the recalculated ones corresponding to the solution S. The correlation factor f_c according to the method developed by TARASIUK and WIERZBANOWSKI, was used as the accommodation factor (f_a) in the present work; hence $f_a=f_c$. The accommodation factor defined in such a way is very sensitive on the peak positions. In general, the accommodation factor characterises the quality of our solution, i.e., it estimates how close are recalculated PFs to the experimental ones. The schematic diagram of the GA program is depicted in Fig.1.

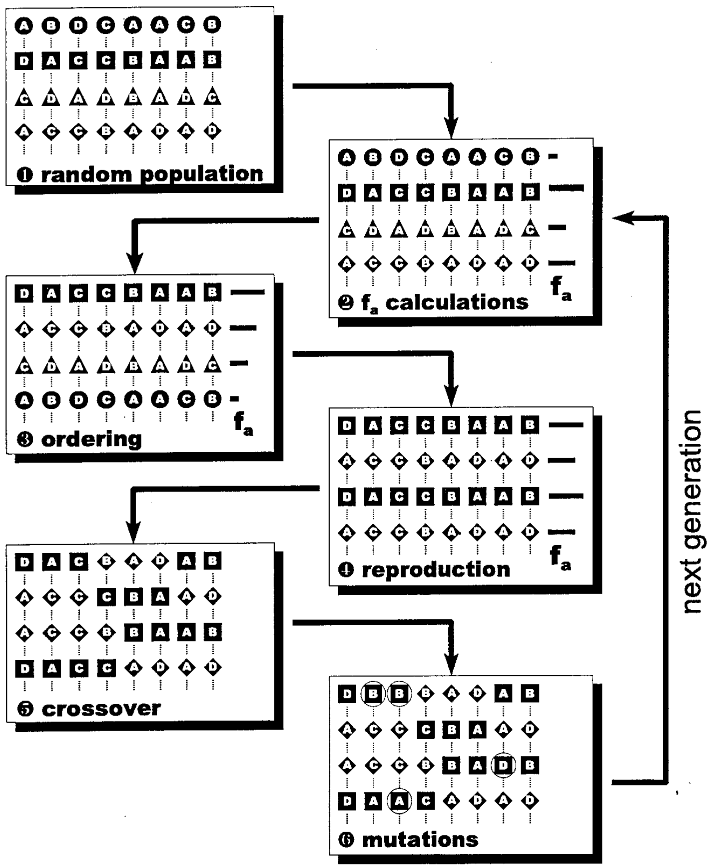

Fig. 1: Scheme of genetic algorithms program; note the horizontal bars: they represent values of accommodation factor f_a.

A typical number of solutions (on which the algorithm was working) in each population was 600, the probability of mutation of each coefficient was 0.004 and the probability of crossover was 0.7. Obviously, all these parameters may be modified if needed.

5. Simple Test of Method

Before application of GA method to texture analysis, i.e., to the ODF calculation from a set of PFs, a simple test of the method was done. A model ODF was generated and a file with its numerical values was created (original programs for the standard distribution functions were used - Matthies, Vinel and Helming, 1987). The arguments of the ODF are three Euler angles: $\varphi_1, \phi, \varphi_2$ - cf., BUNGE. The numerical values of the ODF were given in a regular set of points of the Euler angles space: $\varphi_1 = i * 5^0, \phi = j * 5^0, \varphi_2 = k * 5^0$ (i,j,k – being integers). For cubic crystal and sample orthorhombic symmetries it is enough to consider: $0 \le \varphi_1, \phi, \varphi_2 \le 90^0$. Taking this numerical data and using GA method the coefficients of development into series of harmonic spherical functions were found (for the problem of such the development see, e.g., BUNGE). The comparison of model input ODF and recalculated one (using development coefficients) is shown for the case of Goss type texture in Fig.2: a good agreement is obtained. This test shows that the GA method is correctly adapted to deal with texture analysis.

Type of texture	Component position: $\varphi_1, \phi, \varphi_2$ (degs)	FWHM (degs)	Function (Gauss or Lorentz)	Component Intensity (%)
Goss Texture (011)[100]	(0, 45, 0)	22	Lorentz	60
Cubic (001)[100]	(0, 0, 0)	25	Lorentz	80
Brass type rolling texture	(35.3, 45, 0)	20	Lorentz	60
'Santa Fe'	(63.4, 48.2, 63.4)	20	Gauss	27

Table 1: Parameters of the model textures. Isotropic background ("phon") completes the volume concentration of texture components to 100 %.

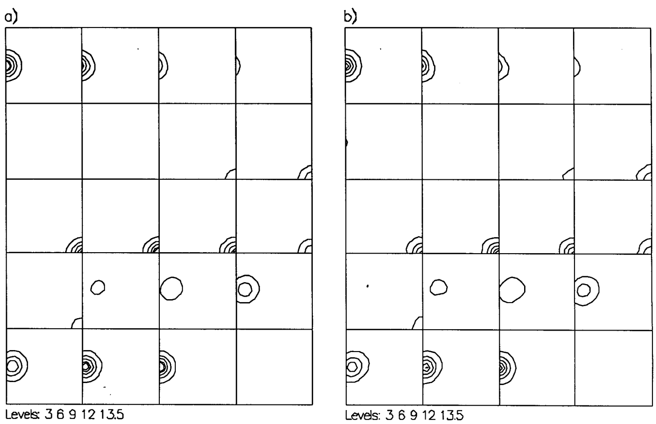

Fig. 2: (a) Model and (b) recalculated ODFs for the Goss type texture; the recalculated ODF was reproduced with series development coefficients found by GA method on the basis of numerical values of the model ODF

6. Results of ODF calculation from PFs

Finally the GA method was applied to the calculation of an ODF from a set of PFs. Also in this case model input data sets were used to test the method. Model ODFs as well as corresponding sets of model PFs were generated using the programs for the standard distribution functions (MATTHIES, VINEL, HELMING). The parameters of model textures used in the present work are listed in Table 1. In each case model PFs were the input data and next the calculated ODF was compared with the corresponding model ODF. The results for the Goss, cubic and rolled brass type textures are shown in Figs. 3- 5. These results are very satisfying. Also the famous 'Santa Fe' texture was examined (Fig.6). This texture was often used as a sensitive test of the "ghost phenomenon" occurrence in ODF calculation (cf., MATTHIES, 1988). The result is satisfying: the "ghost" maximum (cubic orientation in this case) is practically absent; however, the quality of reproduction is lower than in the previous examples.

The convergence of the method is shown in Fig.7 (variation of f_a for the best solution against the number of populations). After about 100 populations the algorithm starts to give reasonable solutions.

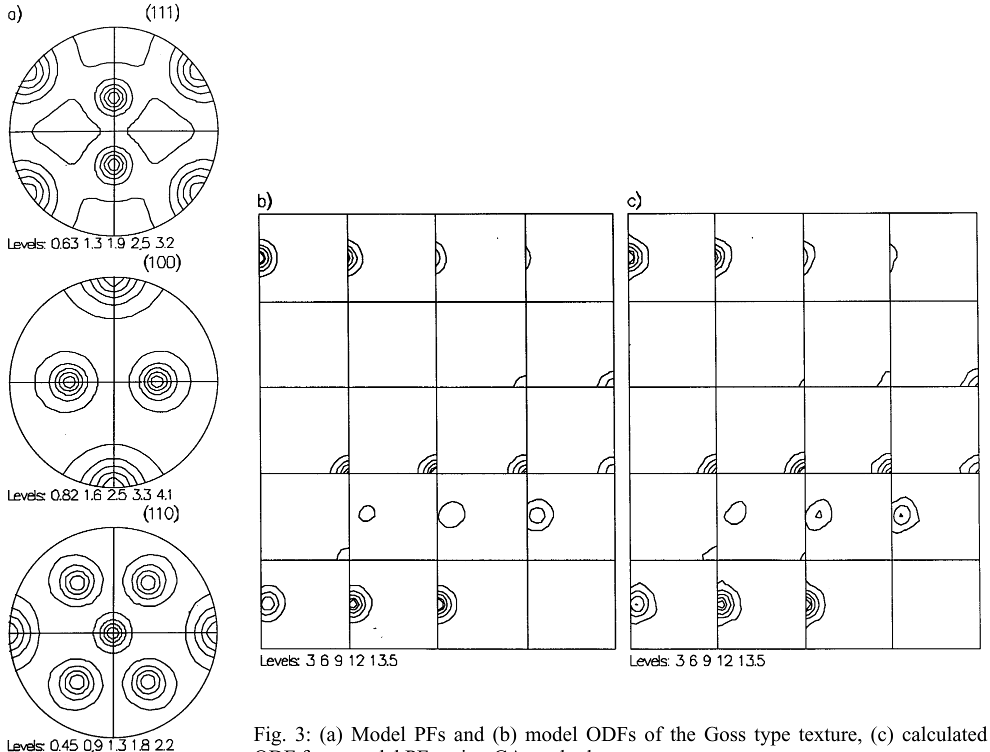

Fig. 3: (a) Model PFs and (b) model ODFs of the Goss type texture, (c) calculated ODF from model PFs using GA method

Conclusions

The present results of the ODF calculation show that the GA method can be successfully used in the field of texture analysis. Obviously, further improvements of the present approach can be done. These may be: modification of the accommodation factor (e.g., combination of f_c and χ^2 method), introduction of elite individuals or using variable size of populations.

It is evident that the precision of the ODF calculation by GA is lower than in other 'classical' methods: GA is a typical 'trials and errors' method. In this sense the GA method is not really an alternative method of texture analysis. It is possible, however, to apply GA to other important problems in the field of crystallographic textures. The example is finding of the best textures of materials for a given application (e.g., for deep drawing, for transformer sheets etc.).

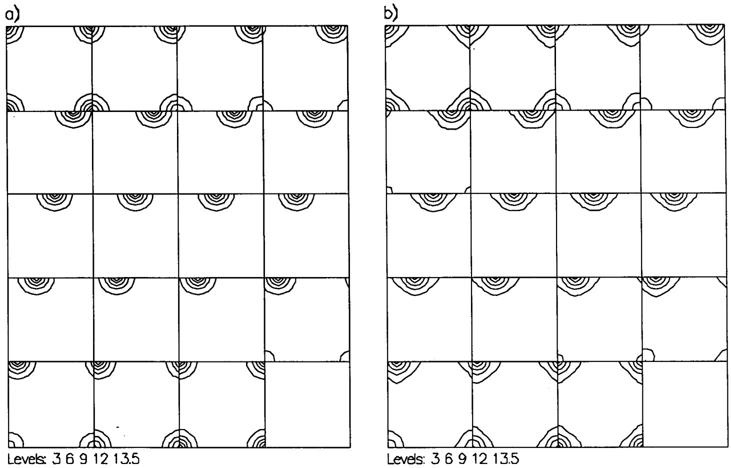

Fig. 4: (a) Model ODF of the cubic type texture, (b) calculated ODF from model PFs using GA method

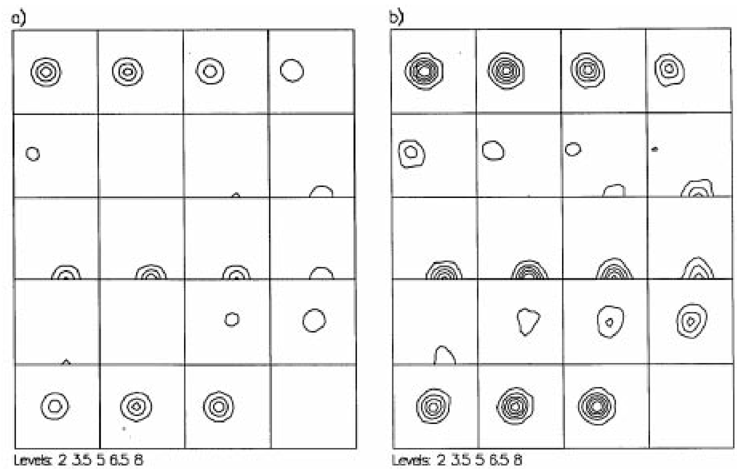

Fig. 5: (a) Model ODF of the rolled brass type texture, (b) calculated ODF from model PFs using GA method

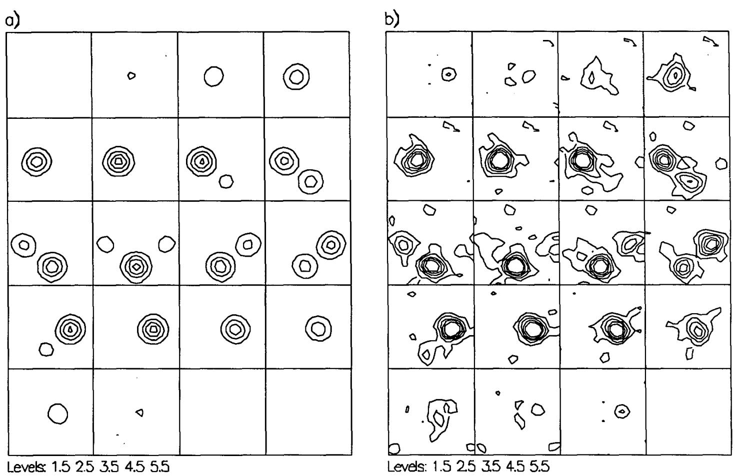

Fig. 6: (a) Model ODF of the 'Santa Fe' texture, (b) calculated ODF from model PFs using GA method

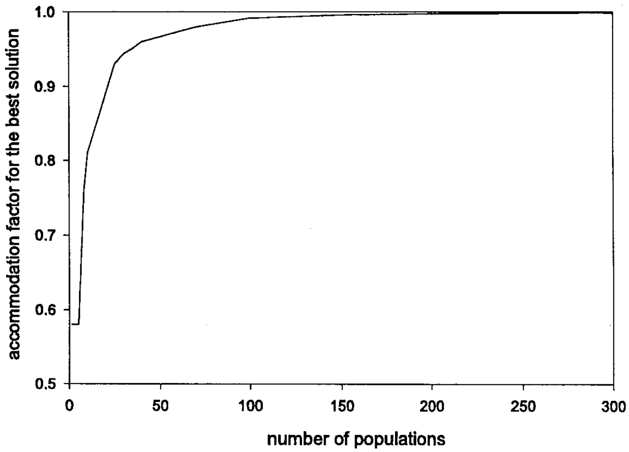

Fig. 7: Convergence of the method: accommodation factor for the best solution against the number of populations in the case of Goss type texture

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