FUZZY DECISION-MAKING IN THE PLANNING OF ASSEMBLY HEADS FOR INDUSTRIAL ROBOTS

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Abstract

The possibility of the application of the methods of fuzzy decision-making in the process of automated planning of robotic assembly systems based on algebraic vector-fuzzy sets is discussed. The application is demonstrated on the procedure of selecting assembly heads for industrial robots. Starting from predefined initial conditions, the planning procedure may be performed by a computer by means of the developed programming outfit.

1. The application of fuzzy decision-making in the planning of robotic assembly systems

The planning process allows an extremely extensive variety of possible solutions. Therefore the application of the principles of *situational modelling* appears very appropriate in the process of solution of the problems of planning. The situational modelling presumes the existence of a set of defined planning situations, as well as of a set of alternative solutions (plans).

A system of classification of all possible planning situations is built up and one or several *typical solutions* are assigned to any class of situations. Thus, the problem of optimization of the decission process arises, consisting of the identification (classification) of the actual planning situations, followed by the selection of the best suited typical solution.

The method of fuzzy decision-making [3], [5] may be applied advantageously in the search of the optimal solution. This method is based on the idea of *I-fuzzy algebra* [4] with vectorial membership grades.

In the course of the optimalization *similarity indices* of the given actual situation are calculated in relation to all typical solutions and the typical solution with the largest similarity index value is taken as the optimal one. The effectivity of the procedure can be substantially increased by the introduction of vector-valued fuzzy sets.

To define a *fuzzy set* A over an arbitrary set (universe) X, a *membership function* μ_A is chosen, performing the mapping

$$\mu_A : X \quad \mathcal{P} \tag{1}$$

where in most applications the closed interval [0,1] of real numbers is used as the space of the values of $\mathcal{P}$. Then, the ordered couple $A = \langle X, q_A \rangle$ is called a *fuzzy set* over the universe of discourse X.

If the universe of discourse consists of n elements $x_1, x_2, \ldots, x_n$ (it is finite), and the fuzzy set may be described in the form of two vectors:

$$X = (x_1, x_2, \ \ldots \ , x_i, \ \ldots \ , x_n)$$
$$P = (p_1, p_2, \ \ldots \ , p_i, \ \ldots \ , p_n) \tag{2}$$

where the components of vector X are necessarily mutually different but, of course, this need not be the case for the components of P which contains the membership degrees attached to x_i.

Moreover, the elements of the universe of discourse may be vectors with c components:

$$\mathbf{x}_i = (x_{i1}, x_{i2}, \ldots, x_{ic}), \quad (i=1,\ldots,n),$$

these vectors differing for unequal values of i by the value of at least one component. X is then expressed by an (n x c)-dimensional matrix

$$X=[x_{ij}], \quad (i=1,\ldots,n;\ j=1,\ldots,c) \tag{3}$$

of necessarily mutually different rows. The *vector-valued fuzzy set* in the way of establishing the corresponding (n x c)-dimensional matrix of the values p_{ij} is:

$$P = [p_{ij}], \quad (i=1,\ldots,n\ ;\ j=1,\ldots,c) \tag{4}$$

Of course, again, the rows of the matrix **P** can be arbitrary combinations of the numbers in [0,1].

The *planning situation*, such as obtained in the course of solving the planning problem, is the manifestation of the actual state of decision in relation to the system's enviroment. It is a fuzzy category, because of the following.

Linquistic fuzzy estimations, such as "very small", "small", "medium", "large", "very large" risk, are used in the description of planning situations, where the fuzziness is the expression of the existing uncertainty resulting from the inaccurate and incomplete knowledge or estimation of the parameters, even because of the nonexact definition of the described notions.

The fuzzy mapping (2) or the relation of the fuzzy sets described by matrices (3), (4) are an appropriate form for the formulation of the planning situations.

The similarity of two fuzzy sets *A*, *B* is expressed in the form of a matrix (see [3]):

$$S_{AB} = [s_{ij}] = M_{A \equiv B} = [p_{i,jA} \equiv p_{i,jB}] \tag{5}$$

where

$$(A \equiv B) = (A \wedge B) \vee (\bar{A} \wedge \bar{B}),$$

and $\wedge$, $\vee$ are represented by the algebraic t- and s-norms:

$$\mu(A \wedge B) = \mu(A) \cdot \mu(B)$$

$$\mu(A \vee B) = \mu(A) + \mu(B) - \mu(A) \cdot \mu(B)$$

Negation is as usual:

$$\mu(\bar{A}) = 1 - \mu(A)$$

So the axiomatic system of I-fuzzy algebra is satisfied.

2. Application of fuzzy decision-making in the selection of assembly heads for industrial robots

The algorithm used for classifying actual planning tasks into typical solutions was developed in the scope of the experimental verification of an automated planning system of robotic production systems. The algorithm was applied to the selection of the sort and type of assembly heads for industrial robots.

An informational stack of typical solutions, containing their basic data (Table 1) and an informational stack of factors, influencing the basic assembly operations, (Table 2) were elaborated in support of the experimental verification of the choice of assembly heads for industrial robots. The basic data of the assembly heads were arranged into an (n x m)-dimensional fuzzy matrix, containing numeric elements from the interval [0,1]. The elements of the fuzzy matrices, corresponding to singular typical solutions of the assembly heads, may be established in two ways [5]:

1. In the way of analysis and evalution of actual planning solutions by means of an off-line computation.

2. In the way of incorporation of experts into the process of estimation of the values of the elements of the membership matrix.

The fuzzy matrices, compiled in this way and applied in the course of the following verification, were arranged as follows:

$$M_A = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ p_{41} & p_{42} & p_{43} & p_{44} \end{bmatrix}$$

where the physical meaning of the elements is:

p_{11} form of the assembled objects
p_{12} edge arrangement of the assemled objects
p_{13} size of the assembled objects
p_{14} mass of the objects
p_{21} position of the objects
p_{22} form of the objects
p_{24} total angular deviation
p_{31} total linear deviation
p_{32} force applied in the asembly process
p_{33} velocity used during the assembly process
p_{34} number of freedom degrees
P_{41} type of joining of the head to the arm and to the grip of the robot or of the manipulator
p_{42} direction of the movement during the assembly
p_{43} roughness of the surface of the assemled objects
p_{44} functional reliability of the head

A numeric value from the interval [0,1] expressing the degree of having a given typical property was attached to every element, using the procedures mentioned above, and the elements were arranged into a (4x4) matrix.

The values were adapted before actual application, thus, the factors influencing the conditions of the concrete assembly operation were taken into account.

The values of the adapted matrix were compared with those of the typical solutions by means of the developed classifying algorithm (Fig. 1). The actual solution was then designated by the typical solution of which the similarity index mostly approached the value 1.

3. Conclusions

The rationalization of the planning procedures of robotic assembly systems and of their technical equipments requires to an ever increasing degree the application of cybernetic and mathematical methods, thus making possible an exact formulation of the planning procedures and of their solutions in the way of computation. Our experience, obtained in this sphere, confirms the need of the development of such procedures and indicated their high effectivity. The method applied was originally developped for classification of textures but the same mathematical modell proved to be applicable also for our present problem.

References

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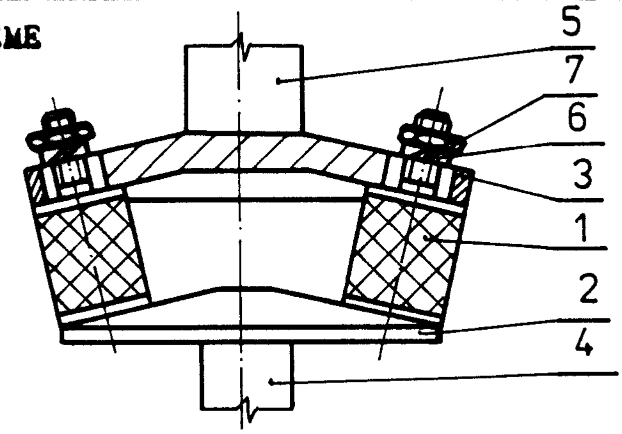
EXAMPLE OF A CATALOGUE LEAF OF AN ASSEMBLY HEAD TABLE 1

NAME	ASSEMBLY HEAD WITH A RUBBER ELASTIC MEMBER AND AN ADJUSTABLE ELASTICITY CENTRE

SCHEME



1. RUBBER ELASTIC ELEMENTS FIXED BY MEANS OF ADHESIVE BETWEEN STEEL PLATES WITH SCREWS
2. ADJUSTABLE BODY
3. FIXED BODY
4. LOWER PART OF THE HEAD
5. UPPER PART OF THE HEAD
6. WASHER
7. NUT

SORT	PASSIVE	DEVELOPED BY :	KAaR a KMaR VŠT Košice

CHARACTERISTICS OF THE SPHERE OF APPLICATION OF THE HEAD

INSERTION OF OBJECTS		SPHERE OF FUNCTIONAL APPLICABILITY			
FORM	SIZE	DEVIATIONS		FORCE	FREEDOM DEGREES
		LINEAR	ANGULAR		
ROTATIVE SYMMETRICAL	ø 10-100 mm	2 mm	$1,5^{o}$	750 N	6

DETAILED SPHERE OF APPLICABILITY EXAMPLE OF ACTUAL APPLICATION		SENSOR EQUIPMENT
		NONE

ELASTIC ELEMENTS			BASIC SIZE	ø 56-45
SORT	NUMBER	ELASTIC CHARACTER		
RUBBER	4	PASSIVE	MASS	0,35 kg

KIND OF THE JOINT OF THE ARM OF THE INDUSTRIAL ROBOT	BY SCREWS

REMARK :

ANNEX : - TABLE OF MEASURED VALUES WITH EVALUATION
- MAX. ASSEMBLY FORCES AS FUNCTION OF ANGULAR AND AXIAL DEVIATIONS

Tab. 2: Factors influencing the assembly operation of pairing and insertion

Basic indices (factors) influencing the success of the assembly operation of the roller and sleeve	Estimated degrees of the effects of singular factors				
Form of the object	Rotative symmetrical 1	Rotative symmetrical, oriented with a groove 0,9	Rotative asymmetrical oriented 0,7	Rotative asymmetrical oriented with a groove 0,6	Rotative asymmetrical, non-oriented 0,2
Edge adjustement of the object	Edges rounded in the points of contact 0,7	$z_1 + z_2 > \Delta$ 0,5	$z_1 + z_2 = \Delta$ 0,3	$z_1 + z_2 < \Delta$ 0,2	Wishout edge adjustment in the spot of contact 0,1
Size of the objects	ø 5-10 mm $1 < 1_{max}$ 0,9	ø 10-15 mm $1 = 1_{max}$ 0,8	ø 15-20 mm $1 < 1_{max}$ 0,7	ø 20-25 mm $1 > 1_{max}$ 0,3	Diameter larger than 25mm $1 > 1_{max}$ 0,2
Mass of the object, including the assembly head	Very small as compared with the loading capacity of the robot 1	About 1/3 of the loading capacity of the robot (manipulator) 0,9	About 1/2 of the loading capacity of the robot (manipulator) 0,5	About 3/4 of the loading capacity of the robot (manipulator) 0,4	Equal to the loading capacity of the robot (manipulator) 0,4
Mutual fitting of the objects	Free 0,7	Loose 0,5	Sliding 0,3	Equal 0,2	Pressed 0
Geometric accuracy of the object	Very high 0,8	Equal to the minimum value of the allowance 0,7	In the limits of the allowance 0,5	Equal to the maximum value of the allowance 0,1	Exceeding the maximum value of the allowance 0,0
Material of the objects	Elastic, wear-resistant, high mechanical strength 1	Elastic, low mechanical strength 0,9	High mechanical strength, relatively brittle 0,6	Low wear resistancy, soft 0,3	Brittle, low mechanical resistance 0,1
Angular inaccuracy	$\varphi = 0^o$ 1	$\varphi = 0,3^o$ 0,6	$\varphi = 0,7^o$ 0,5	$\varphi = 1^o$ 0,2	$\varphi = 1,5^o$ 0,1

Basic indices (factors) influencing the success of the assembly operation of the roller and sleeve	Estimated degrees of the effects of singular factors				
Linear inaccuracy	$\Delta_x = 0$ mm 1	$\Delta_x = 0,5$ mm 0,7	$\Delta_x = 1$ mm 0,5	$\Delta_x = 1,5$ mm 0,3	$\Delta_x = 2$ mm 0,2
Assembling force	Very low as compared with the max. axial force of the robot (manipulator) 1	About 1/3 of the max. axial force of the robot (manipulator) 0,9	About 1/2 of the max. axial force of the robot (manipulator) 0,7	The force does not damage either the assembly head, or the assembled component 0,6	Maximum force of the robot (manipulator), without damaging the assembled component 0,5
Velocity of the assembling operation	Uniform during the whole assembling procedure 1	Uniform at the start and before finishing of the assembly operation 0,9	Uniform at the start of the process 0,8	Uniform before and after finishing the assembly process 0,5	Non-uniform during the whole assembly process 0,3
Number of freedom degrees	6 1	5 ½ 1	5 1	4 ½ 1	4 0
Kind of joining of the head to the robot (manipulator)	Occurrence of clearance, easy replacement (Morse cone) 0,9	Limited occurrence of clearance, easy replacement (screwing) 0,8	Without clearance, relatively easy replacement (gripping) 0,8	Limited occurrence of clearance, complicated replacement (wedge) 0,7	Without clearance, no possibility of replacement (pressing) 0,3
Direction of the assembly operation	Vertical, from above downwards 1	From above under the angle of 45° 0,8	From below under the angle of 45° 0,5	Under arbitrary angle, from above or from below 0,4	Horizontal 0,3
Roughness of the active surface	$R_a = 0,2$ 0,9	$R_a = 0,8$ 0,6	$R_a = 3,2$ 0,4	$R_a = 12,5$ 0,3	Undefined 0,2
Reliability of the operation of the assembly head	Time interval before failure: more than 50 hours 0,8	Time interval before failure: up to 50 hours 0,6	Time interval before failure: 30 up to 50 hours 0,4	Time interval before failure: 15 up to 30 hours 0,2	Time interval before failure: less than 15 hours 0,1

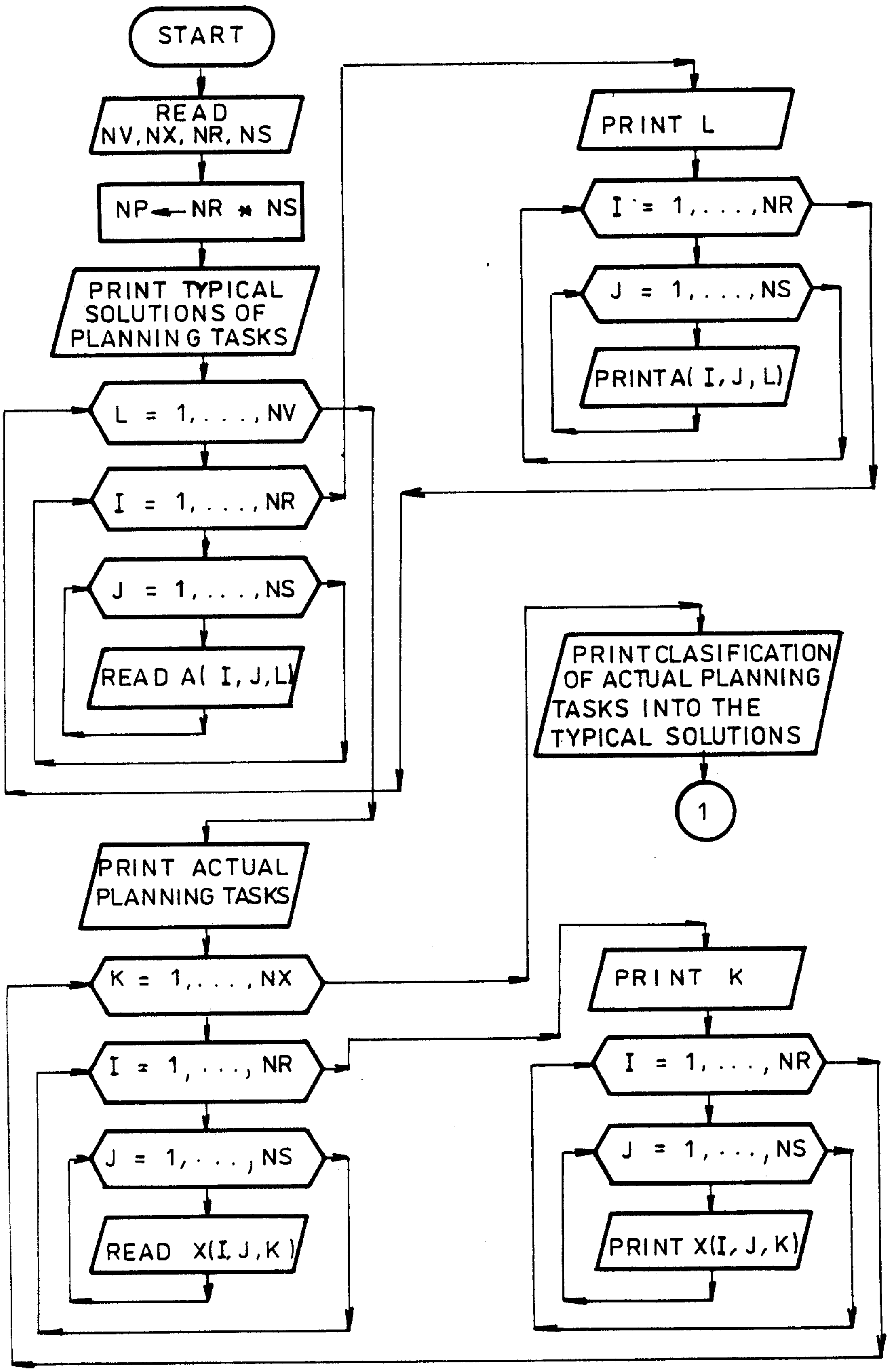


FIG. 1 ALGORITHM OF CLASSIFICATION

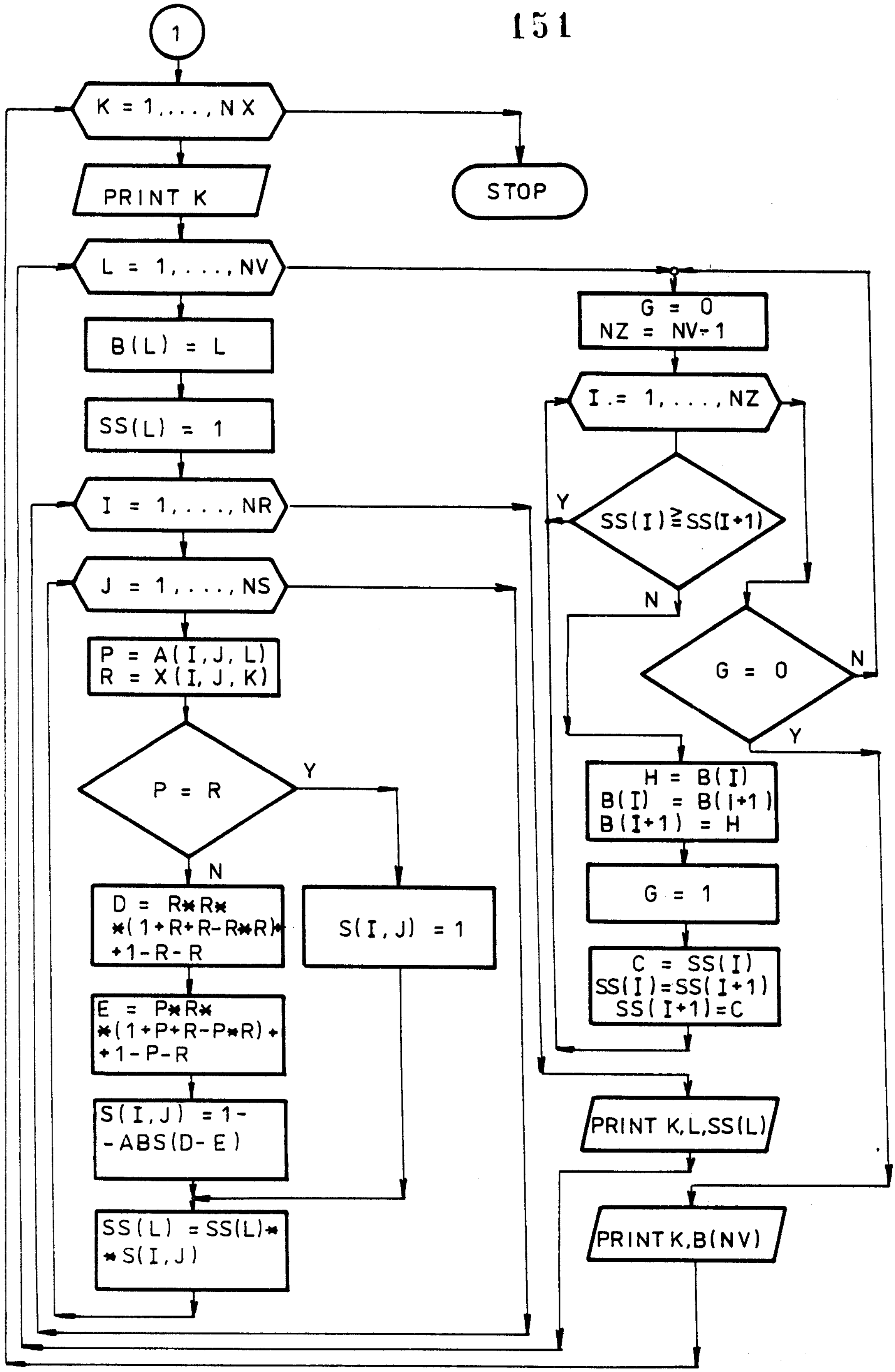


FIG.1 ALGORITHM OF CLASSIFICATION