SMART DIAGNOSIS THE STRUCTURAL DAMAGES OF BUILDINGS: FUZZY-GENETIC APPROACH

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Summary. A hybrid fuzzy logic- and genetic algorithms- based approach for smart diagnosis the structural damages of buildings is proposed. The approach is illustrated by a fuzzy expert system, finding the cause of stone construction crack of buildings. The proposed fuzzy-genetic approach seems to be prospective to creation of decision making support systems for detecting and diagnosis of damages in various mechanical and building constructions.

PRINCEPLES OF FUZZY-GENETIC DIAGNOSIS THE STRUCTURAL DAMAGES OF BUILDING

Diagnosis (or determination of cause) of structural damages of building is an important task in civil engineering. Instant and correct diagnosis of the damages makes further investigations, design, and reconstruction of buildings successful. Our approach to smart diagnosis of structural damages is hybrid. The one is based on such soft-computing techniques as: fuzzy logic [1] and genetic algorithms [2]. This allows to combine the advantages of linguistic expert diagnostic knowledge with power of genetic algorithms in searching the optima. The similar approach is widely used in medicine – a lot of fuzzy-genetic diagnostic systems were created for various medical tasks [3]. The proposed approach is constituted on the following principles:

- *description of the diagnostic model structure by hierarchical tree of fuzzy logical inference*. Such hierarchical knowledge organisation allows to reduce the diagnostic model complexity: a large rule base with many inputs is changing into several small chained rule bases with fewer inputs;
- *presentation of state parameters in linguistic variable form.* According to this principle, linguistic terms assess the state parameter values. For example, state parameter “crack direction” may be represented as a linguistic variable with term-set {Vertical, Oblique, Horizontal}.
- *formalisation of linguistic terms by fuzzy sets*. The formalisation is carried out via parametrical membership functions with bell-, triangular-, or trapezoidal- shapes.
- *formalisation of expert nature language judgements about relationship «state parameters - diagnosis» by fuzzy knowledge bases.* Each expert judgement is represented as a fuzzy if-then rule in the following form: **If** antecedent proposition, **then** consequent proposition. The fuzzy proposition is statement likes “x is oblique”, where “oblique” is a fuzzy set.
- *tuning the parameters of fuzzy knowledge bases by genetic algorithms.* The tuning is searching the weights of fuzzy if-then rules and parameters of the membership functions, that minimise the difference between actual and inferred decisions. It is supposed that a set of correct experimental data “state parameters - cause of structural damage” is available. We propose to employ a genetic algorithm, which finds next to global optimal solution quickly. Principal distinction of the genetic algorithm from classical optimisation methods is in the fact that it does not use the notion of a gradient while choosing search direction and it is based on crossover, mutation and selection operations.

FUZZY DIAGNOSTICAL SYSTEM OF STONE BUILDING STRUCTURAL CRACKS

An usage of above described principles is illustrated below by a fuzzy expert system [4] providing smart decision making support about cause of stone construction crack of buildings.

Different causes of stone construction cracks is classified by the following six diagnoses: d_1 - static overload; d_2 - dynamic overload; d_3 - especial overload (expositions and earthquakes); d_4 - defects of basis and foundation; d_5 - temperature changes; d_6 - breach of building technological process. Suggested classification accords to maximal depth of diagnosis, which can be got on the visual view.

Source information for decision making are values of the following factors (object state parameters): x_1 - construction type; x_2 - work condition; x_3 - thickness of horizontal junctures; x_4 - defects of junctures filling; x_5 - defects of bandaging system; x_6 - unforeseen holes; x_7 - defects of reinforcing; x_8 - curve of construction; x_9 - deflection from vertical line; x_{10} - moistening of brickwork; x_{11} - peeling of brickwork; x_{12} - weathering of brickwork; x_{13} - leaching of brickwork; x_{14} - crumbling of brickwork; x_{15} - crack location; x_{16} - crack direction; x_{17} – crack expansion; x_{18} - crack width; x_{19} - crack length; x_{20} – fair after-effect; x_{21} - information about earthquakes, explosions; x_{22} - presence of dynamic load; x_{23} - splitting under straight; x_{24} - crack depth; x_{25} - displacement of breast-wall; x_{26} - damage of water-supply system; x_{27} - quality of drains; x_{28} - presence of loose soils; x_{29} - presence of water in cellar; x_{30} - presence of tank in vicinity; x_{31} - presence of new adjacent buildings; x_{32} - displacement of straight, beam; x_{33} - necessity of sedimentary juncture; x_{34} - presence of sedimentary juncture; x_{35} - presence of additional loads; x_{36} - presence of

mechanical damages; x_{37} - quality of cushions under beams; x_{38} - insufficient size of beans bearing place; x_{39} - necessity of temperature juncture; x_{40} - presence of temperature juncture; x_{41} - execution of works on winter; x_{42} - usage of heterogeneous materials.
The diagnostic task $X = \{x_1,...,x_{42}\} \to D \in \{d_1,...,d_6\}$ is represented as the following hierarchical system of relations:

$D = f_D(x_1,x_2,y_1,x_{15},x_{16},x_{17},x_{18},x_{19},y_3)$; $y_1 = f_{y_1}(x_3,x_4,x_5,x_6,y_2,x_7,x_8,x_9,x_{10})$;

$y_2 = f_{y_2}(x_{11},x_{12},x_{13},x_{14})$; $y_3 = f_{y_3}(y_1,y_5,x_{20},x_{21},x_{22},x_{23},x_{24},y_6,y_7)$;

$y_4 = f_{y_4}(x_{25},x_{26},y_8,x_{27},x_{28},x_{29},x_{30},x_{31},x_{32})$; $y_5 = f_{y_5}(x_{35},x_{36},x_{37},x_{38})$;

$y_6 = f_{y_6}(x_{39},x_{40})$; $y_7 = f_{y_7}(x_{41},x_{42})$; $y_8 = f_{y_8}(x_{33},x_{34})$,

where enlarged state parameters are: y_1 - state of construction; y_2 - destruction of brickwork; y_3 - additional inferred information; y_4 - possibility of basis and foundation defects; y_5 - possibility of static overload; y_6 - demand to temperature juncture; y_7 - possibility of crack connected with breach of technological processes; y_8 - demand to sedimentary juncture.
Inputs-output ties in the relations are represented by natural language expert judgements in fuzzy knowledge base form. There are 9 fuzzy knowledge bases with 151 rules in total: 102 rules assess fuzzy values of the enlarged state parameters and 49 rules infer the diagnostic decision. Table 1 shows a fragment of fuzzy knowledge base on top level. All the linguistic terms of state parameters x_1 - x_{42} are represented by fuzzy sets with bell-shape membership functions. There are 118 such membership functions in total.
A genetic algorithm was employed for tuning the fuzzy knowledge bases. Total number of the tuning parameters equals 387: 151 are rule weights and 2x118=236 are parameters of membership functions. After tuning, system outputs demonstrated a good match with actual causes of structural cracks, with an error rate of less than 5% (Table 2). For misclassification cases the second rank model decision equals actual cause of the crack.

Table 1. A fragment of fuzzy knowledge base about diagnoses

x_1	x_2	y_1	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}	y_3	D
any	holding	any	at supports	any	up	any	any	static overload	d_1
wall with pilaster	holding	weak	across whole wall	oblique	slanting	hair	very long	dynamic overload	d_2
deaf partition	holding	any	between walls	oblique	up	any	any	especial overload	d_3
wall with aperture	holding	any	across whole wall	vertical	up	large	very long	absence	d_4
any	self- holding	weak	between walls	vertical	up	hair	any	absence	d_4
deaf wall	holding	any	bottom of construction	vertical	down	large	any	defects of basis and foundations	d_4
any	self- holding	normal	top of construction	oblique	up	small	long	temperature influence	d_5
pier	holding	any	from monolithic inclusion	oblique	up	hair	average	breach of building process	d_6

Table 2. Experimental assessment of diagnostic errors

Type of decision	Number of objects	Number of error decisions	Percent of error decisions
d_1	9	2	22%
d_2	5	0	0%
d_3	8	0	0%
d_4	54	1	1.9%
d_5	9	1	11%
d_6	4	0	0%
All the decisions	**89**	**4**	**4.5%**

CONCLUSIONS

We have proposed a hybrid approach for smart diagnosis the structural damages of buildings. The approach is based on combination of fuzzy logic and genetic algorithms. An application of the approach is illustrated by the fuzzy expert system, finding the cause of stone construction crack of buildings with high diagnostic accuracy. An usage of hierarchically connected fuzzy rule bases provides transparent and compact diagnostic model. Tuning the fuzzy model by a genetic algorithm provides low misclassification level. The proposed fuzzy-genetic approach seems to be prospective to creation of decision making support systems for smart detecting and diagnosis of damages in various mechanical and building constructions.

References

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