SUPPLEMENT TO KYBERNETIKA VOLUME 28 (1992), PAGES 90-93

FUZZY SITUATIONAL INFERENCE FOR EXPERT SYSTEMS WITH FUZZY LOGIC

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The fuzzy logic inference method for decision making in expert systems of special class called situational is proposed. Decision inference in such systems is based on fuzzy classification of fuzzy input situation by comparison of its representation which describes the present (current) state of a controlled system. This situation is compared with the descriptions of standard fuzzy situations characterizing all possible states of a controlled system. Fuzzy situation inference of decision is enough simple for realization and in the same time has several advantages in comparison with the well known compositional inference rule.

For fuzzy situation inference the architecture of coprocessor for IBM-compatible computers was developed which essentially uses natural parallelism of operations implemented over fuzzy sets. Due to this an acceptance of decisions making is possible in real time.

Instrumental system for constructing expert systems on the base of fuzzy logic and fuzzy algorithms using fuzzy situational inferences is developed and a demonstration version of such expert system for IBM-compatible computers is created.

The fuzzy situational inference is the two-stage fuzzy recognition of the input fuzzy situation which describes the current state of the controlled system (the object of decision making).

Let us define the fuzzy situation [1]. The fuzzy situation is the second-level fuzzy set on the signs set.

If $\mathbb{Y} = \{y_1, y_2, \dots, y_p\}$ is a set of signs which characterize the state of the controlled system (e. g. "speed", "pressure", "temperature" etc.) and each sign corresponds to a linguistic variable $\langle y_i, \mathbb{T}_i, \mathbb{D}_i \rangle$, where y_i is the name of variable which coincides with the sign's name, $\mathbb{T}_i = \{T_1^i, T_2^i, \dots, T_{m_i}^i\}$ is a term-set of the variable y_i, $\mathbb{D}_i$ is an ordinary subject set, then the fuzzy situation $\tilde{s}_j$ is defined by the fuzzy set:

$$\tilde{s}_j = \{ \langle \mu_{s_j}(y_i) \,/\, y_i \rangle \}, \qquad y_i \in \mathbb{Y},$$

where

$$\mu_{s_j}(y_i) = \left\{ \left\langle \mu_{\mu_{s_j}(y_i)}(T_\ell^i) \,/\, T_\ell^i \right\rangle \right\}, \qquad T_\ell^i \in \mathbb{T}_i.$$

The fuzzy situations are formed on the basis of expert information.

Example 1. Let the object of the decision making (controlled system) be characterized by the signs set $\mathbb{Y} = \{y_1, y_2, y_3\}$, where y_1 is "speed", y_2 is "pressure" and y_3

is "temperature". Each sign $y_i \in \mathbb{Y}$ is described by a linguistic variable $\langle y_i, \mathbb{T}_i, \mathbb{D}_i \rangle$, built on the basis of the expert information which is, for example, for sign y_1 as follows: $\langle$"speed", $\mathbb{T}_1$, $\mathbb{D}_1\rangle$, where $\mathbb{T}_1 = \{$"small", "middle", "large"$\}$, $\mathbb{D}_1 = \{0, 10, 20, 30, \ldots, 100\}$.

The linguistic variables describing other signs are as follows: $\langle$"pressure", $\mathbb{T}_2$, $\mathbb{D}_2\rangle$, $\langle$"temperature", $\mathbb{T}_3, \mathbb{D}_3\rangle$. Here

$$\begin{aligned}\mathbb{T}_2 &= \{\text{"small", "large enough", "high", "very large"}\},\\ \mathbb{T}_3 &= \{\text{"small", "middle", "large", "top"}\},\\ \mathbb{D}_2 &= \{0, 5, 10, 15, \ldots, 50\}, \quad \mathbb{D}_3 = \{10, 30, 50, \ldots, 170\}.\end{aligned}$$

Then the fuzzy situation $\tilde{s}$ which characterizes the state of the controlled system (object of decision making) may be as follows:

$$\tilde{s} = \{\langle \mu_s(y_1) / y_1 \rangle, \langle \mu_s(y_2) / y_2 \rangle, \langle \mu_s(y_3) / y_3 \rangle\},$$

where

$$\begin{aligned}\mu_s(y_1) &= \{\langle 0.1 / \text{"small"}\rangle, \langle 0.5 / \text{"middle"}\rangle, \langle 0.9 / \text{"large"}\rangle\},\\ \mu_s(y_2) &= \{\langle 0.4 / \text{"small"}\rangle, \langle 0.8 / \text{"high enough"}\rangle, \langle 0.6 / \text{"high"}\rangle, \langle 0.2 / \text{"very high"}\rangle\},\\ \mu_s(y_3) &= \{\langle 1 / \text{"small"}\rangle, \langle 0.3 / \text{"middle"}\rangle, \langle 0.1 / \text{"high"}\rangle\}.\end{aligned}$$

The set of possible states of the controlled system is defined by a set $\mathbb{S}$ of standard fuzzy situations. Every fuzzy situation $\tilde{s}_i \in \mathbb{S}$ with the help of expert information is put to conformity to the control decision $\tilde{r}_i \in \mathbb{R}$, where $\mathbb{R}$ is a set of control decisions used for controlled system. So the decision making is reduced to the recognition of the fuzzy input situation $\tilde{s}_0$, which describes the current state of the controlled system, and to the output of the corresponding control decision from the set $\mathbb{R}$. The fuzzy situation recognition is realized according to the principle of 'nearest neighbour' in the field of signs. Some fuzzy measure of similarity of fuzzy situation $\tilde{s}_0$ and the fuzzy situations from the set $\mathbb{S}$. The controlled system is considered to be at the standard situation $\tilde{s} \in \mathbb{S}$, which has the maximum grade of similarity with the fuzzy situation $\tilde{s}_0$, and the control decision $\tilde{r} \in \mathbb{R}$, corresponding to the fuzzy situation $\tilde{s}$, must be fulfilled.

The most preferable fuzzy situations similarity measures are the grades of fuzzy situations inclusion and equality [2]. Both of these measures are realized by the calculation of the similarity grade in the interval $[0, 1]$. The maximum similarity grade is 1, and the minimum one is 0. The similarity grade equal to 0.5 means absolute uncertainty. The grade of fuzzy inclusion of the fuzzy situation $\tilde{s}_i$ into the fuzzy situation $\tilde{s}_j$ is described by the expression:

$$\nu(\tilde{s}_i, \tilde{s}_j) = \mathop{\&}_{y_\ell \in Y} B\left(\mu_{s_i}(y_\ell), \mu_{s_j}(y_\ell)\right),$$

where

$$B\left(\mu_{s_i}(y_\ell), \mu_{s_j}(y_\ell)\right) = \mathop{\&}_{y_\ell \in \mathbb{T}_\ell} \left(\mu_{\mu_{s_i}(y_\ell)}(T_k^\ell) \longrightarrow \mu_{\mu_{s_j}(y_\ell)}(T_k^\ell)\right).$$

The grade of the fuzzy equality of the fuzzy situations $\tilde{s}_i$ and $\tilde{s}_j$ is defined by the expression:

$$\mu(\tilde{s}_i, \tilde{s}_j) = \nu(\tilde{s}_i, \tilde{s}_j) \ \& \ \nu(\tilde{s}_j, \tilde{s}_i).$$

The fuzzy logic operations in the minimax basis are used while the grades of the fuzzy situations inclusion and equality are defined.

As the fuzzy situation is the second level fuzzy set on the sign set, the recognition of the fuzzy input situation $\tilde{s}_0$ consists of two stages:

– *identification*; the fuzzy sets $\mu_{s_0}(y)$, $y \in \mathbb{Y}$, which describe the grade of membership of fuzzy situation $\tilde{s}_0$ signs, are defined;

– the fuzzy situation $\tilde{s}_0$ *recognition* itself. This stage follows the fuzzy situation $\tilde{s}_0$ recognition stage and is the definition of the standard fuzzy situation, which has the maximum similarity grade (grade of fuzzy equality or inclusion).

The subject scale of values of every sign $y \in \mathbb{Y}$ must be defined for input fuzzy situation $\tilde{s}_0$ recognition. The subject scale of the sign $y_i \in \mathbb{Y}$ is a number of fuzzy sets describing the set values (terms) of the sign y_i.

The input fuzzy situation $\tilde{s}_0$ is to be identified in each of the following input information types:

a) The value of the sign y_i is the subject state element k. The grades of the membership of the element $k \in \mathbb{D}_i$ to the fuzzy sets $\tilde{\mathbb{C}}^i_j$ are to be calculated for $\mu_{s_0}(y_i)$ definition. $\mu_{C^i_j}(k)$ are considered to be the membership grade of terms T^i_j to the fuzzy set $\mu_{s_0}(y_i)$, i. e. $\mu_{s_0}(y_i) = \left\{ \langle \mu_{c^i_j}(k) \,/\, T^i_j \rangle \right\}$, $T^i_j \in \mathbb{T}_i$.

b) The value of the sign y_i is the fuzzy set $\tilde{\mathbb{C}}$ in the subject set $\tilde{\mathbb{D}}_i$. In this case it is necessary to calculate the grade of similarity of the input fuzzy set to all fuzzy sets $\tilde{\mathbb{C}}^i_j$, which describe the terms of the linguistic variable $\langle y_i, \mathbb{T}_i, \mathbb{D}_i \rangle$. Then in analogy with previous case the grades of membership of terms $T^i_j \in \mathbb{T}_i$ to the fuzzy set $\mu_{s_0}(y_i)$ are considered to be equal to grades of similarity of fuzzy set $\tilde{\mathbb{C}}$ to the corresponding fuzzy sets $\tilde{\mathbb{C}}^i_j$. For example, if the fuzzy sets equality grade is used as a similarity measure the fuzzy set $\mu_{s_0}(y_i)$ is as follows:

$$\mu_{s_0}(y_i) = \left\{ \langle \mu(\tilde{\mathbb{C}}, \tilde{\mathbb{C}}^i_j) \,/\, T^i_j \rangle \right\}, \qquad T^i_j \in \mathbb{T}_i.$$

Note that the grade of fuzzy equality of fuzzy sets $\tilde{\mathbb{B}} = \{\langle \mu_B(a) \,/\, (a) \rangle\}$ and $\tilde{\mathbb{C}} = \{\langle \mu_C(a) \,/\, a \rangle\}$, $a \in \mathbb{A}$, is calculated in analogy to the fuzzy situation equality grade:

$$\mu(\tilde{\mathbb{B}}, \tilde{\mathbb{C}}) = \nu(\tilde{\mathbb{B}}, \tilde{\mathbb{C}}) \ \& \ \nu(\tilde{\mathbb{C}}, \tilde{\mathbb{B}}).$$

In turn, $\nu(\tilde{\mathbb{B}}, \tilde{\mathbb{C}}) = \underset{y_i \in \mathbb{A}}{\&} \ (\mu_B(a) \longrightarrow \mu_C(a))$.

c) The value of the sign y_i is the term T^i_ℓ from the term-set $\mathbb{T}_i$. In this case the result of the identification will be the following fuzzy set:

$$\mu_{s_0}(y_i) = \left\{ \langle \mu_{\mu_{s_0}(y_i)}(T^i_j) \,/\, T^i_j \rangle \right\}, \qquad T^i_j \in \mathbb{T}_i,$$

where

$$\mu_{\mu_{s_0}}(y_i)(T_j^i) = \begin{cases} 1, & \text{if } T_j^i = T_\ell^i; \\ 0, & \text{elsewhere.} \end{cases}$$

The second stage of input fuzzy situation $\tilde{s}_0$ recognition is made by the appeal to the verbal scales of the values of signs $y_i \in \mathbb{Y}$. The verbal scale of sign $y_i \in \mathbb{Y}$ is described by a totality of fuzzy sets on the sign y_i linguistic values (terms) set.

The verbal scale introduction is approved by the necessity of more 'careful' attitude to the expert information. An expert does not prescribe obviously standard fuzzy situations in the form of the second level fuzzy sets because of a big volume of such situations and monotonicity of the work. We must take into account that it is much more suitable for him to give the standard fuzzy situation description in the following way: ⟨*small* / "speed"⟩, ⟨*high* / "pressure"⟩, ⟨*middle* / "temperature"⟩}. However due to the fact that it is impossible to account the whole totality of the facts influencing the controlled system (so-called 'shady' sign set) [3], the terms used by the expert are not the elements of term-set of linguistic variables which describe the corresponding signs. Really they represent more complex constructions called fuzzy terms which are fuzzy sets on sign term-sets. That is why standard fuzzy situations are stored and processed in the following form ⟨*small* / "speed"⟩, ⟨*high* / "pressure"⟩, ⟨*middle* / "temperature"⟩}, where for example small is an element of verbal scale of sign "speed". The verbal scale of any sign y_i receives information only after its processing by subject scale of the same sign and hence only in the form of fuzzy sets on the term-set $\mathbb{T}_i$.

In dependence of chosen similarity measure of fuzzy situations the grade of fuzzy inclusion or fuzzy equality of input fuzzy set and elements of verbal scale are computed. Maximum similarity grade defines the element of verbal scale corresponding to the input fuzzy set. The totality of such elements along all signs determines the standard fuzzy situation $\tilde{s}$ corresponding to the fuzzy input situation $\tilde{s}_0$.

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