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Applying a New Method of Soft-computing for System Reliability

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Abstract: This study present a new method of soft computing for the reliability of a system. This is an application of Atanassov's intuitionistic fuzzy set theory in reliability engineering. The proposed method reduces to a method of fuzzy computing of system reliability as a special case and it is different from the existing methods of fuzzy system reliability. The application of IF-logic in our soft-computing method widens the scope to the reliability engineers to analyse the reliability of a large system even if the fractional data be not crisp in nature.

Key words: Intuitionistic, IFQ, IFR, (α, β) triangular representation, IFuzzification, De-IFuzzification

INTRODUCTION

Fuzzy-reliability is a novel concept (Bowles and Pelaez, 1995; Kaufmann and Gupta, 1988) in systems engineering as fuzzy sets can capture subjective, uncertain and ambiguous information. Implementation of the earlier crisp models is in terms of precise data only. Various concepts such as probist, profust and fuzzy event based method, fuzzy fault tree analysis methods, transformations and hybrid approaches are in the recent literature (Bertolini *et al*., 2004; Bowles and Pelaez, 1995; Cai, 1996a, b; Chen, 1994, 1996, 1997; Dong *et al*., 2004; Kaufmann and Gupta, 1988; Mon and Cheng, 1994; Singer, 1990; Utkin and Gurov, 1996).

Systems (Cai *et al*., 1991; Kai-Yuan *et al*., 1991) whose performance degrades as they experience component failures typically have many degrees of working between their fully working and fully not-working states. Fuzzy sets provide a natural way of describing such systems since we can associate the system's degree of working with an element's degree of membership in a set. Chen and Jong (1996) presented a new method for fuzzy system reliability analysis based on fuzzy time series and the alpha-cuts arithmetic operations of fuzzy numbers, where the reliabilities of the components of a system at different times t (t = ..., 0, 1, 2, ...) are to be represented by different membership functions. His method allows the reliabilities of the components of a system at different times t to have different membership functions and consequently it is more flexible than the ones presented by Chen (1994), Cheng and Mon (1993) and Singer (1990). In this study we present a soft-computing method for system reliability using the intuitionistic fuzzy theory of Atanassov. The method reduces to a fuzzy method as a special case. But our fuzzy method is different from that proposed by Chen (1994, 1996), Cheng and Mon (1993), Cai (1996a), Mon and Cheng (1994) and Singer (1975) specially in the simplicity in computations. First of all we visit in brief the intuitionistic fuzzy theory of Atanassov (1999).

PRELIMINARIES OF IFS THEORY

Several types of higher order fuzzy sets (Atanassov, 1986, 1989; Dubois and Prade, 1990; Kaufmann and Gupta, 1988; Zadeh, 1975; Zimmermann, 1991) were suggested by different authors time to time for various new operations and more specialized applications. Out of them, the one introduced by Atanassov (1999) is interesting for us and carries a significant potential for applications. Application of higher order fuzzy sets makes the solution-procedure more complex, but if the complexity on computation-time, computation-volume or memory-space are not the matter of concern then a better results could be achieved.

The key improvement of intuitionistic fuzzy set theory over fuzzy set theory is that while in the latter the membership value of an object also defines the non-membership value of it by means of a mathematical relation, in the former the membership value and non-membership value of an object are not, in general, related by a mathematical equation. Rather, the decision-maker (or the problem analyst or the intelligent agent) independently decides both, up to his best intellectual capability, subject to a mathematical constraint. While deciding the degree of membership of an object by a decision-maker, there may be some hesitation as a part of human factor. A fuzzy set could be viewed as a special case of intuitionistic fuzzy set, provided that at the processing stage for evaluation of membership value,

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there is no indeterministic situation with respect to any object of the universe of discourse. We present here the concept of intuitionistic fuzzy set theory of Atanassov, in brief.

Definition: Let E be a set called a universe of discourse. An Intuitionistic Fuzzy Set (IFS), A in E is an object of the form:

$$A = \{\langle x, \mu_A(x), u_A(x)\rangle \mid x \in E\}$$

where, μ_A and u_A are functions given by:

$$\mu_A: E\to[0, 1], u_A: E\to[0, 1]$$

satisfying the constraint $0 \le \mu_A(x) + u_A(x) \le 1 \ \forall\ x \in E$. The quantities $\mu_A(x)$ and $u_A(x)$ are called, respectively, the degree of membership and the degree of non-membership of the element x, to the set A. The amount $\Pi_A(x) = 1-\mu_A(x) - u_A(x)$ is the indeterministic part of the evaluation for membership or non-membership status of the element x in A. This part remains indeterministic due to the hesitation of the decision-maker. Hesitation is a part and parcel of the human decision-making process. It varies from man to man, agent to agent. Even for a fixed agent, hesitation varies in different situations. In fact, hesitation is almost unavoidable in all human-centered systems. In fuzzy set theory, this hesitation is assumed to be nil. As a result, if the membership value of an element is decided, its non-membership value is also, by definition, determined. If an element of hesitation exists in the mind of the decision-maker, fuzzy set theory is not appropriate. In such a case IFS theory plays a dominant role to the decision-makers or problem analysts.

Definition: If A and B are two intuitionistic fuzzy subsets of the set E, then:

$A\subset B$ iff $\forall\ x\in E, [\mu_A(x) \le \mu_B(x)$ and $u_A(x)\ge u_b(x)]$

$A\subset B$ iff $B\supset A$

$A = B$ iff $\forall\ x\in E, [\mu_A(x) = \mu_B(x)$ and $u_A(x) = u_B(x)]$

$\bar{A} = \{\langle x, u_A(x), \mu_A(x)\rangle \mid x \in E\}$

$A\cap B = \{\langle x, \min(\mu_A(x), \mu_B(x)), \max(u_A(x), u_b(x))\rangle \mid x\in E\}$

$A\cup B = \{\langle x, \max(\mu_A(x), \mu_B(x)), \min(u_A(x), u_B(x))\rangle \mid x\in E\}$

$A + B = \{\langle x, \mu_A(x)+\mu_B(x)-\mu_B(x)\mu_A(x), u_A(x)u_B(x)\rangle \mid x\in E\}$

$A.B = \{\langle x, \mu_A(x)\mu_B(x), u_A(x)+u_B(x)-u_A(x)u_B(x)\rangle \mid x\in E\}$

$\Box A = \{\langle x, 1-\mu_A(x), \mu_A(x)\rangle \mid x\in E\}$

$\Diamond A = \{\langle x, 1-u_A(x), u_A(x)\rangle \mid x\in E\}$

$C(A) = \{\langle x, K, L\rangle \mid x\in E\}$

$I(A) = \{\langle x, k, l\rangle \mid x\in E\}$

where, $K = \sup_{x\in E}\mu_A(x)$, $L = \inf_{x\in E} u_A(x)$, $k = \inf_{x\in E}\mu_A(x)$ and $l = \sup_{x\in E} u_A(x)$.

IFUZZIFICATION AND DE-IFUZZIFICATION

Here, we present few definitions and examples to explain our notion of IFuzzification and De-IFuzzification of linguistic data (imprecise data) which are intuitionistic fuzzy by nature.

Definition intuitionistic fuzzy quantity (IFQ): The linguistic data of type approximately 9, little more than 7, very close to 12, more or less 25, or not less than 18, etc. are not well defined quantities. Consequently, any computations involving such type of data can not be done with crisp mathematics as it is a kind of soft-computing because of flexibility (non-rigid nature) in computation. These data are not real numbers in crisp sense. But they are very frequently used in many real life problems like management problems in industries/factories, in administration, in statistical analysis, in weather forecasting, in traffic management, in routing techniques (in networks), in intelligent searching (like Branch and Bound search with a suitable underestimates), etc. to list a few only. These type quantities are fuzzy or rather intuitionistic fuzzy by nature. We will call them to be a kind of intuitionistic fuzzy quantity or IFQ (in short).

Definition (α, β) representation of an IFQ q: We define it by an example. Consider an IFQ q = approximately 9. Suppose that an intelligent agent proposes this IFQ q in the form of an IFS Q of the universe U = R (the set of real numbers). Our assumption here is that in this IFS Q the maximum membership value (minimum non-membership value) is attained by a unique element (unique element). Choose $\alpha, \beta \in (0, 1)$ as choice parameters (also to be called as decision parameters).

Suppose that:

$l = \sup\{x: x \in R, x \ge m$ and 'either $\mu_Q(x) = \alpha$ or $u_Q(x) = 1-\alpha$'$\}$,

$m = \max\{x : x \in R$ and 'either $\mu_Q(x) = \sup \mu$ or $u_Q(x) = \inf u$'$\}$

$n = \inf\{x : x \in R, x\ge m$ and 'either $\mu_Q(x) = \beta$ or $u_Q(x) = 1-\beta$'$\}$

Then the (α, β) representation of the IFQ q is defined by a tuple given by:

$$<(l, m, n), \mu_Q(m), u_Q(m)>$$

or, may also be denoted by the tuple:

$$<(l, m, n), \mu_q(m), u_q(m)>$$

The pair (α, β) where 0≤α, β ≤1 is called the decision-pair, as this will be pre-choosen by the intelligent agent and could be renewed time to time if necessity arises. By an intelligent agent, we mean an intelligent company-manager, or a decision-maker in administration or an intelligent robot, or an intelligent router in a communications network, or an intelligent software, etc.

Note that, if q = approximately 9, it is not necessary that in its (α, β)-representation the value of m will be 9.

Example: Consider an IFQ q = little more than 28. Suppose that a manager propose the following IFS Q for the IFQ q (without any hesitation or indeterministic-value in Q) Fig. 1.

In this case, the (0.98, 0.96) representation of the IFQ q will be denoted by the notation <(□, 29, □), 0.9, 0.1>, where □ is the don't-care symbol. But, in our work in the subsequent sections we will not consider such type of situations (involving □), because an intelligent-agent is expected to choose the decision-parameters (α, β) in such a way that the constraint α, $\beta \le \mu_x$ (m) holds. (In this example, it is the constraint α, $\beta \le \mu_x$ (29)).

In our work in this paper, we will present a method of soft-computing for large-system reliability. As a reliability engineer, we frequently say, for instance, that a system is 90% reliable during the time period (t_1, t_2). Consequently, in our intuitionistic fuzzy computing, we choose the universe of discourse U to be the unit interval (0, 1), instead of the set R of real numbers. Our basic assumptions in our technique of reliability-computation are that:

- The membership-function and non-membership function are triangular in diagrams. The (α, β) representation in this case will be called to be (α, β) triangular representation
- There exists a point x ϵ (0,1) on the left-side of the triangles at which μ(x) = 0 and u(x) = 1. (If there are more than one such points, we take sup of them)
- There exists a point y ϵ (0, 1) on the right-side of the triangle, at which μ(y) = 0 and u(y) = 1. (If there are more than one such points, we take inf of them)

Definition fuzzification and De-IFuzzification: Consider a component P of a large complex system S, whose reliability is not known but could be imprecisely estimated as an IFQ r. Such type of imprecise estimate of reliability is called intuitionistic fuzzy reliability or IFR (in short).

Let an intelligent agent propose the IFS R for the IFR r. Suppose that the (0, 0) triangular representation of the IFR r is $<(a, b, c), \mu_r(b), u_r(b)>$. Then this representation of the reliability r in a (0, 0) triangular fashion is called to be the IFuzzification of the IFR.

The concept of De-IFuzzification is explained below by an example.

Example: Let a component P of a system S has the reliability r = approximately 7. Suppose that an intelligent decision-maker proposes an IFS R for this IFQ r given by Fig. 2:

If it is de-IFuzzified, it signifies the following results:

- Reliability of the component is 0.7 with minimum membership value 0.8 and maximum membership value 0.9
- Reliability of this component can not be 0.4 or less, in any case
- Reliability of this component can not be 0.9 or more, in any case

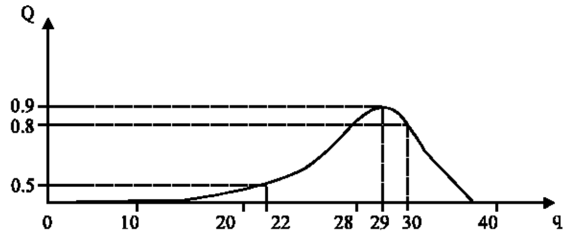

Fig. 1: IFSQ for the IFQq. For the decision-pair (0.5, 0.8), the (0.5, 0.8). Representation of the IFQ q is <(22, 29, 30), 0.9, 0.1>

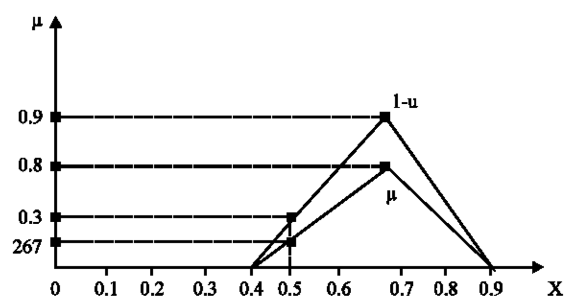

Fig. 2: IFSR for this IFQr. Here we see that the IFuzzification of the reliability approximately 7 is the tuple <(0.4, 0.7, 0.9), 0.8, 0.1>

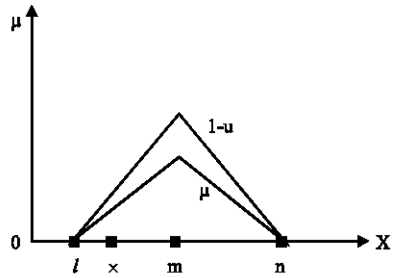

Fig. 3: A general case of IFuzzification

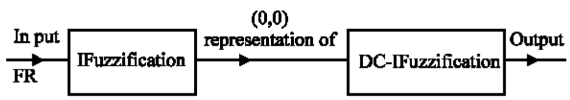

Fig. 4: IFuzzification of a reliability IFR r

- Reliability can only be in the open interval (0.4, 0.9); For instance, reliability could be 0.5 with minimum membership value = 0.267 and maximum membership value = 0.3

Now, consider a general case of IFuzzification as shown below Fig. 3:

Let, IFuzzification of a reliability IFR r be given by the tuple <(l, m, n), μ_r (m), u_r (m)>. De-IFuzzification of this tuple reveals the following results in Fig. 4:

- Reliability of the component is m with minimum membership value μ_r (m) and maximum membership value 1-u_r (m)
- Reliability of this component can not be l or less.
- Reliability of this component can not be more than n
- Reliability can only be in the open interval (l, n). If x ∈ (l, n), then reliability could be assumed with minimum membership value m_{min} (x) and maximum membership value m_{max} (x), where,

$$m_{min}(x) = \mu_r(m).(x-l)/(m-l), \text{ if } x \le m$$
$$= \mu_r(m).(x-n)/(m-n), \text{ otherwise.}$$

and

$$m_{max}(x) = (1-u_r(m)).(x-l)/(m-l), \text{ if } x \le m$$
$$= (1-u_r(m)).(x-n)/(m-n), \text{ otherwise}$$

SOME USEFUL OPERATIONS

In configuration of a complex hardware system, there may be a large number of components constituting its subsystems. These components in the subsystems may be:

- In serial
- In parallel
- In combination of serial and parallel

For the computation of the reliability of such a system under intuitionistic fuzzy environment, we need to define few operations over IFRs. In all of our definitions below, we consider the notion of IFuzzification of IFRs as defined earlier.

Consider two components P_1 and P_2 of a system having the IFRs A and B respectively, given by:

$$A = \langle(a_1, b_1, c_1), \mu_A(b_1), u_A(b_1)\rangle$$

and

$$B = \langle(a_2, b_2, c_2), \mu_B(b_2), u_B(b_2)\rangle$$

Addition of two IFRS: The addition of the IFRs A and B yields the IFR (A+B) given by:

$$(A+B) = \langle(l, m, n), \mu_{A+B}(m), u_{A+B}(m)\rangle$$

where, $l = a_1 \vee a_2$, $m = b_1 \vee b_2$, $n = c_1 \vee c_2$ and $\mu_{A+B}(m) = \mu_A(b_1) \wedge \mu_B(b_2)$, $u_{A+B}(m) = u_A(b_1) \vee u_B(b_2)$.

Complement of an IFR: The complement of an IFR A is the IFR A^c given by:

$$A^C = \langle(l, m, n), \mu_{AC}(m), u_{AC}(m)\rangle$$

where $l = 1-c_1$, $m = 1-b_1$, $n = 1-a_1$ and $\mu_{Ac}(m) = u_A(b_1)$, $u_{Ac}(m) = \mu_A(b_1)$.

Product of two IFRs: The product of two IFR A and B yields the IFR A*B given by:

$$A \times B = \langle(l, m, n), \mu_{A\times B}(m), u_{A\times B}(m)\rangle$$

where, $l = a_1 a_2$, $m = b_1 b_2$, $n = c_1 c_2$ and $\mu_{A*B}(m) = \mu_A(b_1) \wedge \mu_B(b_2)$, $u_{A*B}(m) = u_A(b_1) \vee u_B(b_2)$.

SOFT-COMPUTATION OF SYSTEM RELIABILITY

In this section, we will show how to compute the reliability of a system S with n components $P_1, P_2, ..., P_n$, all being:

- In serial
- In parallel

Serial system: As the number of components increases, the reliability of the system S decreases. The configurations are as shown in Fig. 5.

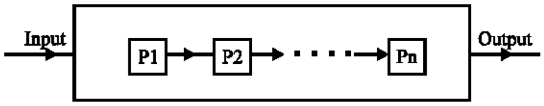

Fig. 5: Reliability of the system S decreases

Suppose that, for i = 1, 2, ..., n

r_i = IFR of the component
$P_i = <(a_i, b_i, e_i), \mu_{ri}(b_i), u_{ri}(b_i)>$
and r = IFR of the whole system S.

Since the components are in serial, we have:

$$r = r_1 * r_2 * ..... * r_n = <(l, m, n), \mu_r(m), u_r(m)>$$

where, $l = a_1a_2a_3 .... a_n$, $m = b_1b_2b_3 ..... b_n$, $n = c_1c_2c_3......c_n$ and $\mu_r(m) = \inf_i \{\mu_{ri}(b_i)\}$, $u_r(m) = \sup_i \{u_{ri}(b_i)\}$.

Parallel system: In this case, the configuration is as shown in Fig. 6:

The overall system reliability r can be computed as follows:

$$r = (r^c)^c = (r_1^c \times r_2^c * .... * r_n^c)^c$$

Now, for i = 1, 2, ..., n, we have:
$r_i^c = <(1-c_i, 1-b_i, 1-a_i), u_{ri}(bi), \mu_{ri}(bi)>$

Therefore:

$$r_1^c \times r_2^c \times . \times r_n^c = <(l_1,m_1,n_1),\mu_{rc}(m_1),u_{rc}(m_1)>$$

where, $l_1 = \prod_{i=1}^{n}(1-c_i)$, $m_1 = \prod_{i=1}^{n}(1-b_i)$, $n_1 = \prod_{i=1}^{n}(1-a_i)$

and $\mu_{rc}(m_1) = \inf_i \{u_{ri}(b_i)\}$, $u_{rc}(m_1) = \sup_i \{\mu_{ri}(b_i)\}$.

Thus, r = complement of:

$$< (l_1,m_1,n_1), \mu_{rc}(m_1), u_{rc}(m_1) >$$
$$= < (L,M,N), \mu_r(M), u_r(M) >$$

where, $L = 1 - n_1 = 1-\prod_{i=1}^{n}(1-a_i)$

$M = 1 - m_1 = 1-\prod_{i=1}^{n}(1-b_i)$

$N = 1 - l_1 = 1-\prod_{i=1}^{n}(1-c_i)$

and $\mu_r(M) = u_{rc}(m_1)$, $u_r(M) = \mu_{rc}(m_1)$.

Complex system and future work: A complex system is any system featuring a large number of interacting components (agents, processes, etc.) whose aggregate activity is nonlinear (not derivable from the summations of the activity of individual components) and typically exhibits hierarchical self-organization under selective pressures. This definition applies to systems from a wide array of scientific disciplines. Indeed, the sciences of complexity are necessarily based on interdisplinary research.

Since, it in a combination of serial and parallel, its reliability can be computed according to its configuration using the above two formulas and the calculations for it will be as future work.

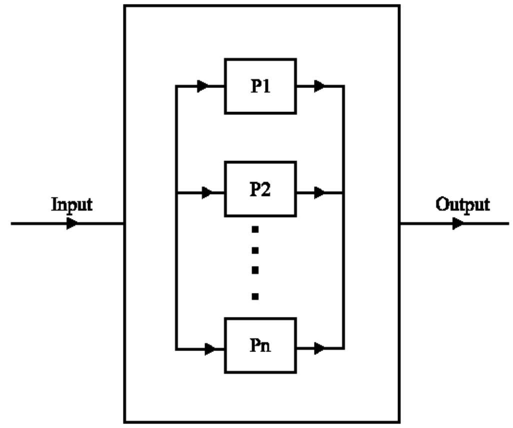

Fig. 6: Parallel system

CONCLUSION

In this study, we have reported a method of soft-computing of reliability of a complex system under intuitionistic fuzzy situation situation (2006-2007). Reliability has an inverse relation with real-time and also with the incorporation of more number of components in the configuration of the system. Our method will be useful if the data are of IF nature. In case all the indeterministic parts are nil although the computation, the method reduces to a fuzzy computing technique of system reliability. Our method of fuzzy-computing, so developed as a special case of IF-computing, is a simple for computation and is different from the fuzzy-computing of reliability suggested (Cai, 1996b; Chen, 1994, Cheng and Mon, 1993; Mon and Cheng, 1994; Singer, 1990). We have introduced the IFuzzification and De-IFuzzification of imprecise data for reliability-analysis and we have described our technique of soft-computing by using (0, 0) triangular representation of IFR. We have defined (α, β) representation of an IFQ, of which a special case is the (0, 0) triangular representation.

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