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Using Fuzzy Logic for Automatic Control: Case Study of a Problem of Cereals Samples Classification

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Abstract: The aim of this paper is to present the use of fuzzy logic for automatic control of industrial systems particularly the way to approach a problem of classification. We present a case study of a grading system of cereals that allows us to determine the price of transactions of cereals in Tunisia. Our contribution in this work consists in proposing not only an application of the fuzzy logic on the grading system of cereals but also a methodology enabling the proposing of a new grading system based on the concept of "Grade" while using the fuzzy logic techniques.

Keywords: Fuzzy logic, Automatic control, Classification, Quality of cereals.

1 Introduction

The traditional approach to solve industrial problems has often adopted an analytic tendency. In spite of the computing advances that pushed calculations to unimaginable boundaries, analytic approach has been believed to have arrived to a dead end in several complex problems. The idea to simulate human performance started with examining the abilities of man to make models of things surrounding him and to create strategies with which he can manage to control his environment. The theory of the fuzzy logic, one of the rare theories that have fixed such a goal, is certainly one of the most adopted approaches in industry.

Unlike the classical logic of Boole, the fuzzy logic is a tool that allows us to manipulate variables considered as fuzzy [1-3]. This concept is characterized by giving values between 0 and 1. This idea would help computers simulate the vagueness in our thought process and language.

Fuzzy logic is a multivalued logic that allows intermediate values to be defined between conventional evaluations like true/false, yes/no, high/low, etc. Notions like rather tall or very fast can be formulated mathematically and

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processed by computers, in order to apply a more human-like way of thinking in the programming of computers [4-6]. Fuzzy systems are an alternative to traditional notions of set membership and logic.

We can introduce basic operations on fuzzy sets. Similar to the operations on crisp sets we also want to intersect, unify and negate fuzzy sets. In his first paper about fuzzy sets, L. A. Zadeh suggested the minimum operator for the intersection and the maximum operator for the union of two fuzzy sets [6-10]. It can be shown that these operators coincide with the crisp unification and intersection if we only consider the membership degrees 0 and 1.

The importance of the fuzzy logic lies in its capacity to simplify the realization and the utilization of computer applications. It enables us to replace some mathematical models by others based on simple verbal descriptions.

Fuzzy classifiers are one application of fuzzy theory. Expert knowledge is used and can be expressed in a very natural way using linguistic variables, which are described by fuzzy sets.

Linguistic rules describing the control system consist of two parts; an antecedent block (between the IF and THEN) and a consequent block (following THEN). Depending on the system, it may not be necessary to evaluate every possible input combination, since some may rarely or never occur. By making this type of evaluation, usually done by an experienced operator, fewer rules can be evaluated, thus simplifying the processing logic and perhaps even improving the fuzzy logic system performance [11,12].

The inputs are combined logically using the AND operator to produce output response values for all expected inputs. The active conclusions are then combined into a logical sum for each membership function. A firing strength for each output membership function is computed. All that remains is to combine these logical sums in a defuzzification process to produce the crisp output.

The case of inference with one rule appears when we must compare many concurrent (objects or persons) in a certain situation and choose the optimum. We find this problematic mainly in domains not technical, where we must take a decision.

In this paper, we are interested in the application of the fuzzy logic particularly in decision making. Indeed, the human decision rests on knowledge of an expert of the concerned domain. For example, a qualified operator controls the quality of a product under manufacture in factory, whether it is a cake or a piece of foundry. The same thing in medicine, for example, a physician decides to operate, it is only after an objective diagnosis of the state of a patient, but also after a certain sign of interpretation from his experience.

This paper can be loosely divided into five parts: first, we summarize the complexity to introduce the fuzzy logic to industrial systems and second focus on what the system should do rather than try to model how it works. Subsequently, we present the issues involved in the application of the fuzzy logic, particularly the way to approach a control or classification problem. In order to deal with these issues, we present a case study of a grading system of cereals that we analyze and simplify. The last section concludes the article, likely presenting the interest of the fuzzy logic as an alternative to traditional notions of set membership and logic.

2 Presentation of the Grading System of Cereals in Tunisia

A grading system of cereals determines the transactions price at the purchase and the sale of cereals according to their quality; it governs the technical and juridical relations between suppliers of cereals (agriculturists, producers, importers, and stockers for delivery) and customers (agriculturists for seed, stockers for conservation, millers, industry of transformation, etc.).

The survey of assessment system of the quality of cereals in some producing countries (USA, Canada, Argentina, Australia, France, etc.) enables us to identify two types of systems: the first one is based on the concept of "*barème d'agréage*" characterized by an important number of slices but presenting many insufficiencies and the second one, is based on the concept of "*Grade*" [13].

Indeed, these producing countries sell their wheat according to Grades and commercial classes having a standard quality: a minimum specific weight and a maximal percentage of impurity assign wheat to a definite grade.

The **Tables 1** and **2** illustrate a comparison between many grading systems in some countries relative to the parameters specific weight and impurities for the case of Durum wheat.

Table 1
Parameters specific weight [kg/hl] *and Impurities* [%].

	Specific weight [kg/hl]			**Impurities** [%]		
Grade	Argentina	Canada	USA	Argentina	Canada	USA
1	78	79	58	0.50	0.50	0.50
2	76	77	57	1	1.50	1
3	74	74	55	2	2	2
4	72	71	53	4	3	3
5	70	-	50	7	10	5

In Tunisia, there are two grading systems based on the concept of Grade proposed: The first one is composed by three Grades [14] and the second one is composed by four Grades [15]. These two grading systems have not been exploited yet and no analyses have been done.

Actually, the evaluation of the quality of cereals is controlled by the "barème d'agréage" [16] exploited by the diverse entities of storage in transactions of cereals (Durum wheat, Soft wheat, Barley, etc.). This "barème d'agréage", defined since 1936, is used at the beginning of each cereal campaign through a decree (décret de campagne). Many attempts have been done recently in order to simplify the "barème d'agréage" used [17-20].

After taking the sample, we proceed to the analysis: we measure the specific weight, assess visually the impurities and the humidity of cereals and determine the price using the "barème d'agréage" (Fig. 1).

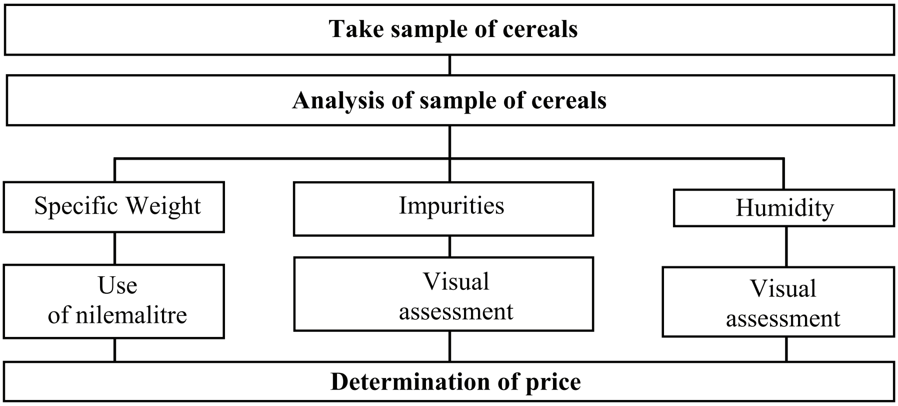

Fig. 1 – *Grading system of cereals.*

The determination of the price of cereals at the time of transactions is based essentially on the grading process particularly for the bonus and the reduction. We present an illustration of bonus and reduction applied at sale of Durum wheat in Tunisia (**Table 2**).

Table 2

Illustration of bonus and reduction applied.

Parameter	**Slice**	**Bonus** [%]	**Reduction** [%]
Specific weight [Kg/hl]	77.500 to 77.749	0.33	-
	77.750 to 77.999	0.66	-
	74.000 to 74.249	-	8
	74.250 to 74.499	-	7
Impurity [%]	0.00 to 0.50	1.40	-
	0.51 to 0.75	0.75	-
	0.76 to 1.00	0.5	-

For a quality parameter P_{qj}, a slice T_{ri} is defined by low threshold and a high threshold. A bonus or a reduction is reported to a slice and it is expressed by the basic price *PB*. Thus for T_{ri}, and for a parameter P_{qj}, the bonus is bonus $(P_{qj}, \tau_{ri}) = \tau(P_{qj}, T_{ri}) * PB$.

For example, for the first parameter P_{q1} (*PS*) the first slice of reduction corresponds to the low and high thresholds respectively 76.250 Kg/hl and 76.499 Kg/hl; the rate of reduction for this slice is 0.005.

3 Methodology for the Integration of the Fuzzy Logic

Due to the fact of the diversity of the different categories of the bodies concerned with the assessment of the cereal quality, we adopt the TQM (Total Quality Management) methodology according to which we adopt the Customer-supplier gait. The “barème d’agréage” must take into account the various points of view of every intervening part according to its position in the circuit of cereals transaction (Fig. 2). This is how the first transformer (Miller) is called to take into account his customer's constraints (the second transformer: baker, confectioner, pastier, etc.) through the technological parameters while considering his own constraints (flour, semolina, conservation, etc.).

Following the dynamics of cereal parameters conditioning the grading system as well as the procedure and conditions of sampling on the one hand and the various points of view of the different bodies concerned by the transaction on the other hand, it is frequent to fall into contradictory situations. This is why the approach that we propose enables us to contribute to the appeasing of these situations and to the establishing of a consensual and more objective support.

Hence, it is necessary to proceed to a collection of every intervening tendencies of every part expressed in a natural language and to proceed to their analyses while adopting the fuzzy logic.

In order to institute a reflex of adoption of the method, we illustrate in a first time, a relative application to the “barème d’agréage” by using the fuzzy logic [21-23].

The methodology of integration of fuzzy logic techniques proposed consists in:

Step 1: Schematization of the transaction circuit of cereals and identification of the various operators.

Step 2: Listing the parameters of quality including those not exploited at present in the “barème d’agréage” and classifying hierarchically these parameters.

Step 3: Making an exhaustive bibliography of cereal quality assessment and constitution of a reference database representing various real situations of cereals.

Step 4: Collection of the various points of view of operators of the cereal path according to a qualitative evaluation.
Step 5: Organization of a workshop regrouping resources people representing the various operators in the cereals transactions.
Step 6: Clarification of a consensual criterion for the determination of the price and model these criteria according to a fuzzy algorithm.
Step 7: Making a simulation according to various situations exploiting the elaborated database.

According to the methodology of fuzzy logic integration presented and to the variety of cereals (Durum wheat, Soft wheat, Barley, etc.) and to the case of the grading process (production, sale to millers, Import, etc.), we identify many grading parameters. In this part, we exploited two techniques of fuzzy logic in order to simplify the “barème d’agréage”: formulation of assessment criteria based on only one rule of inference and realization of fuzzy controllers based on several rules of inference. We present the results of classification for the evaluation of the cereals samples.

4 Results of Samples Classification Using AND Operator

In order to assess the effect of parameters of the grading system of cereals, we define a membership function μ_{Vi} $(i = 1, 2, \ldots, n)$ indicating the bonus value or reduction according to a considered slice. This function is limited to a maximum value.

For example, according to the “barème d’agréage” of barley, we represent the different membership functions relatively to the four parameters of barley: Specific weight, inert materials, foreign grains and weevil grains. For the parameter Specific weight, we represent 36 membership functions with a rectangular shape corresponding to each slice (Figs. 2 and 3).

After defining the different membership functions of the grading parameters of cereals, we propose to use AND operator of the fuzzy logic.

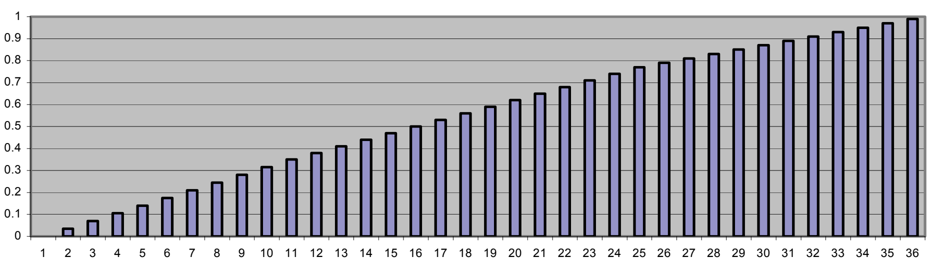

Fig. 2 – *Membership function of the parameter Specific weight.*

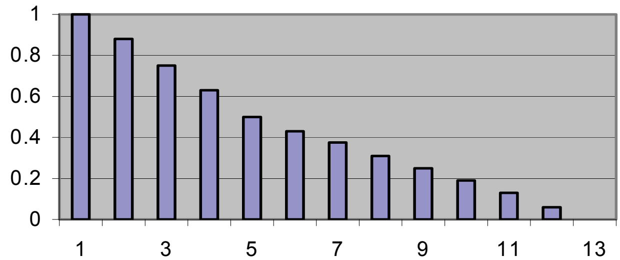

Fig. 3 – *Membership function of the parameter inert materials.*

The criterion used for the classification of the samples of barley is:

$$\mu_{cr} = \gamma \min[\mu_{v1}, \mu_{v2}, \mu_{v3}, \mu_{v4}] + (1-\gamma)[\mu_{v1} + \mu_{v2} + \mu_{v3} + \mu_{v4}]/4$$

and $\gamma \in [0,1]$.

Table 3 presents the image of the five samples of barley.We present the results of the classification using five values of γ.

Table 3
Results of classification for 5 samples of barley.

Parameter	Samples				
	1	2	3	4	5
v_1	0.18	0.95	0.7	0.38	0.45
v_2	0.13	0.37	0.75	0.25	0.06
v_3	0.13	0.25	0.5	0.75	0.37
v_4	0.7	0.78	0.88	0.91	0.67
$\gamma = 1$	0.13	0.25	**0.5**	0.25	0
$\gamma = 0.75$	0.17	0.33	**0.55**	0.33	0.14
$\gamma = 0.5$	0.21	0.42	**0.6**	0.41	0.22
$\gamma = 0.25$	0.25	0.5	**0.66**	0.49	0.31
$\gamma = 0$	0.29	0.59	**0.71**	0.57	0.39
Class	5	2	1	3	4

For durum wheat, we used the criterion:

$$\mu_{cr} = \gamma \min[\mu_{v1}, \mu_{v2}, \mu_{v3}, \dots, \mu_{v14}] + \\ + (1-\gamma)[\mu_{v1} + \mu_{v2} + \mu_{v3} + \dots + \mu_{v14}]/14$$

and $\gamma \in [0,1]$.

Table 4 presents the image of the five samples of durum wheat. We present the results of the classification using five values of γ.

Table. 4
Results of classification for 5 samples of durum wheat.

Parameter	N°1	N°2	N°3	N°4	N°5
v_1	0.8	0.9	0.7	0.5	0.4
v_2	0.6	0.7	0.9	0.4	0.5
v_3	0.8	0.7	0.7	0.6	0.8
v_4	0.8	0.5	0.5	0.5	0.2
v_5	0.7	0.5	0.2	0.4	0.1
v_6	0.6	0.5	0.5	0.5	0.3
v_7	0.3	0.2	0.3	0.4	0.3
v_8	0.8	0.8	0.3	0.5	0.3
v_9	0.8	0.8	0.2	0.4	0.2
v_{10}	0.4	0.8	0.3	0.6	0.2
v_{11}	0.5	0.8	0.5	0.5	0.5
v_{12}	0.7	0.6	0.7	0.7	0.1
v_{13}	0.6	0.7	0.7	0.5	0.2
v_{14}	0.4	0.5	0.4	0.8	0.9
$\gamma = 1$	0.3	0.2	0.2	**0.4**	0.1
$\gamma = 0.75$	0.38	0.31	0.27	**0.42**	0.15
$\gamma = 0.5$	**0.47**	0.42	0.35	0.45	0.21
$\gamma = 0.25$	**0.56**	0.54	0.42	0.47	0.26
$\gamma = 0$	**0.65**	**0.65**	0.5	0.5	0.32
Class	**1**	**2**	4	3	5

5 Results of Sample Classification Using Different Operators of Fuzzy Logic

In this part, we propose to use the different operators of fuzzy logic (NOT, Product, Average, AND, OR, Fuzzy AND, Fuzzy OR, min-max and gamma).

The image *F* of a grading parameter *P* is borned in the interval [0,1] and it is calculated using the formula: $F = (P - \text{Min}) / (\text{Max} - \text{Min})$.

Table 5 presents the results of image determination of the grading parameters for five samples of barley. Indeed, we identify four parameters (*P*) in the case of barley: Specific weight, inert materials, foreign grains and weevil grains.

Table 5
Determination of the image of the grading parameters of barley.

N°	Parameter			Sample									
				1		2		3		4		5	
		Min	Max	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*
1	Specific weight [Kg/hl]	50	70	53	0.2	69	0.9	64	0.7	58	0.4	60	0.5
2	Inert materials [%]	10	0	8.7	0.1	6.3	0.3	2.5	0.7	7	0.3	9	0.1
3	Foreign grains [%]	10	0	8.7	0.1	7.5	0.2	5	0.5	2	0.8	6	0.4
4	Weevil grains [%]	10	0	3	0.7	2.2	0.7	1.2	0.8	1	0.9	3	0.7

Table 6
Results of evaluation using different criteria.

Criterion		Samples				
NOT		0.186	0.005	0.005	0.008	0.081
Product		0.002	0.069	0.231	0.086	0.014
Average		0.285	0.588	0.708	0.600	0.425
AND		0.130	0.250	0.500	0.300	0.100
OR		0.700	0.950	0.880	0.900	0.700
Fuzzy AND	1	0.130	0.250	0.500	0.300	0.100
	0.75	0.169	0.334	0.552	0.375	0.181
	0.5	0.208	0.419	0.604	0.450	0.263
	0.25	0.246	0.503	0.656	0.525	0.344
	0	0.285	0.588	0.708	0.600	0.425
Fuzzy OR	1	0.700	0.950	0.880	0.900	0.700
	0.75	0.596	0.859	0.837	0.825	0.631
	0.5	0.493	0.769	0.794	0.750	0.563
	0.25	0.389	0.678	0.751	0.675	0.494
	0	0.285	0.588	0.708	0.600	0.425
Min-Max	1	0.130	0.250	0.500	0.300	0.100
	0.75	0.273	0.425	0.595	0.450	0.250
	0.5	0.415	0.600	0.690	0.600	0.400
	0.25	0.558	0.775	0.785	0.750	0.550
	0	0.700	0.950	0.880	0.900	0.700
Gamma	1	0.814	0.995	0.996	0.992	0.919
	0.75	0.184	0.510	0.691	0.539	0.323
	0.5	0.042	0.261	0.480	0.293	0.113
	0.25	0.009	0.134	0.333	0.159	0.040
	0	0.002	0.069	0.231	0.086	0.014

The fuzzy logic allows influencing the evaluation criteria with certain operators. We notice that many human decisions are not rigidly objective. It is desirable in the case of inferences with one rule that lead to moderate decisions.

Table 7
Different results of samples classification.

Criterion		**Samples**				
Product		**5**	**3**	**1**	**2**	**4**
Average		**5**	**3**	**1**	**2**	**4**
AND		**4**	**3**	**1**	**2**	**5**
OR		**4**	**1**	**3**	**2**	**4**
Fuzzy AND	1	4	3	1	2	5
	0.75	5	3	1	2	4
	0.5	5	3	1	2	4
	0.25	5	3	1	2	4
	0	5	3	1	2	4
		24	15	5	10	21
	class	**5**	**3**	**1**	**2**	**4**
Fuzzy OR	1	4	1	3	2	4
	0.75	5	1	2	3	4
	0.5	5	2	1	3	4
	0.25	5	2	1	3	4
	0	5	3	1	2	4
		24	9	8	13	20
	class	**5**	**2**	**1**	**3**	**4**
Min-Max	1	4	3	1	2	5
	0.75	4	3	1	2	5
	0.5	4	2	1	2	5
	0.25	4	2	1	3	5
	0	4	1	3	2	4
		20	11	7	11	24
	class	**4**	**2**	**1**	**2**	**5**
Gamma	1	5	2	1	3	4
	0.75	5	3	1	2	4
	0.5	5	3	1	2	4
	0.25	5	3	1	2	4
	0	5	3	1	2	4
		25	14	5	11	20
	class	**5**	**3**	**1**	**2**	**4**

We consider that the different grading parameters are linguistic variables for an evaluation of a sample of cereals. The **Tables 6** and **7** present the results of evaluation of different samples of barley using different criteria and the results of samples classification.

While variables in mathematics usually take numerical values, in fuzzy logic applications, the non-numeric linguistic variables are often used to facilitate the expression of rules. Thus, we have simplified the grading system of barley not only by defining the variation of grading parameter but also by reducing the number of slices used.

Fuzzy logic provides a different way to approach a control or classification problem. This method focuses on what the system should do rather than trying to model how it works. One can concentrate on solving the problem rather than trying to model the system mathematically. On the other hand the fuzzy approach requires a sufficient expert knowledge for the formulation of the rule base, the combination of the sets and the defuzzification. In general, the employment of fuzzy logic might be helpful, for very complex systems, when there is no simple mathematical model, for highly nonlinear processes or if the processing of expert knowledge is to be performed.

6 Conclusion

In this paper, we present our contribution in proposing a transition gait of the "barème d'agréage" used in Tunisia to determine the price of transactions of cereals toward a new grading system while using the fuzzy logic. The last one corresponds to a grading system based on the concept of "Grade". The fuzzy logic approach which was applied on the grading system enables not only to contribute to attenuate the contradictory situations but also to lead to a consensual and more objective support. Many experiments results are presented while using classification and control techniques.

The interest of the application of the fuzzy logic on this type of process resides in its contribution to offer a modern and applicable management tool for the calculation of the cereal price. This tentative can be generalized for all analogous processes of the agro alimentary sector where the transaction is strongly tributary of the quality product according to various classes of parameters.

7 References

[1] L.A. Zadeh: Fuzzy Logic = Computing with Words, IEEE Transactions on Fuzzy Systems, Vol. 4, No. 2, May 1996, pp. 103 – 111.

[2] H.J. Zimmermann: Fuzzy Sets Theory and its Applications, Kluwer Academic Publishers, Norwell, MA, USA, 1987.

[3] A. Kaufmann, M.M. Gupta: Fuzzy Mathematical Models in Engineering and Management Science, Elsevier Science Inc. New York, NY, USA, 1988.
[4] L.A. Zadeh: Making Computers Think Like People, IEEE Spectrum, Vol. 21, No. 8, Aug. 1984, pp. 26 – 32.
[5] A. Kelman: Fuzzy Models for Data Aggregation and Decision Making, PhD Thesis, University of Paris, Dec. 1996.
[6] S. Bothorel, M.B. Bouchon, S. Muller: A Fuzzy Logic-based Approach for Semiological Analysis of Microcalcificationin Mammographic Images, International Journal of Intelligent Systems, Vol. 12, No. 11-12, Dec. 1998, pp. 819 – 848.
[7] B. Fustier: Evaluation, Prise de Décision et Logique Floue, Economie Appliquée, No. 1, 2000.
[8] N. Belacel: Approche du choix flou pour les problèmes de classification multicritère, Conférence LFA '2000, 18-20 October 2000, CEPADUS-Editions, pp. 37-44.
[9] H. Ishibuchi, T. Yamamoto: Comparison of Heuristic Criteria for Fuzzy Rule Selection in Classification Problems, Fuzzy Optimization and Decision Making, Vol. 3, No. 2, June 2004, pp. 119 – 139.
[10] K. Nozaki, H. Ishibuchi, H. Tanaka: Adaptive Fuzzy Rule-based Classification Systems, IEEE Transaction on Fuzzy Systems, Vol. 4, No. 3, Aug. 1996, pp.238 – 250.
[11] M. Souissi, M. Annabi: A Fuzzy Controller for Climate of Greenhouse, Entropy, Vol. 36, No. 229, 2000, pp. 24 – 30.
[12] R. Hartani: Fuzzy Systems Modeling: Theoretical Contributions and Applications, PhD Thesis, University of Paris, June 1995.
[13] Grain Research Laboratory, Quality of Western Canadian Wheat Exports, Canada, Cargo, Bulletin No. 277, April 1995.
[14] S. Nouaigui: Formulation Simplifiée d'un Barème d'agréage de Blé Dur et Blé Tender Tunisien, Revue de l'INAT, Vol. 7, No. 2, Déc. 1992.
[15] Décret No. 90-671, Prix et Modalités de Paiement, de Stockage et de Rétrocession des Céréales, J.O.R.T, 1990.
[16] Décret. No. 96-2549, Prix et Modalités de Paiement, de Stockage et de Rétrocession des Céréales, J.O.R.T, No. 4, 1996.
[17] M.N. Lakhoua, M. Annabi: Using Fuzzy Logic Techniques to Simplify a Grading System of Cereals, LFA'2005, IEEE, Barcelona, Spain, Sept.2005, pp. 345 – 350.
[18] M.N. Lakhoua, J. Zrida, M. Annabi: Application de la Logique Floue au Contrôle du Système d'agréage de Céréales, CIFA'02, IEEE, Nantes, France, 8-10 July 2002.
[19] A. Damak, M.N. Lakhoua, J. Zrida, M. Annabi: Classification des Lots de Céréales Mélangés par des Techniques de la Logique Floue, Revue Industries des Céréales, No. 140, 2004, pp. 15 – 18.
[20] A. Damak, M. Annabi: Barème d'agréage des Céréales en Tunisie: Approche pour la Simplification, SETIT'04, IEEE, Tunisie, 2004.
[21] H. Buhler: Réglage par Logique Floue, Presses Polytechniques et Universitaires Romandes, 1994.
[22] S. Maruthai, J. Gunna, R.H. Ranganathan: Integrated Fuzzy Logic Based Intelligent Control of Three Tank System, Serbian Journal of Electrical Engineering, Vol. 6, No. 1, May 2009, pp. 1 – 15.
[23] M. Sugeno: Introductory Survey of Fuzzy Control, Information Science, Vol. 36, No. 1-2, 1985, pp. 59 – 83.
[24] V. Peneve, I. Popchev: Fuzzy Logic Operators in Decision Making, Cybernetics and Systems, Vol. 30, No. 8, Dec. 1999, pp. 725 – 745.