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Design and Evaluation of a Fuzzy Logic Based Decision Support System for Grading of Golden Delicious Apples

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ABSTRACT

In this study, fuzzy logic was applied as a decision support system to grade Golden Delicious apples. Features such as color and size were measured through a data acquisition system consisted of apple's sorter, webcam and a PC. A total of 250 apples were investigated. The selected apples were of five different sets or grades ranging from very bad to very good. In order to find the performance of proposed fuzzy inference system (FIS) the same sets were graded by human expert, too. For input and output fuzzy linguistic variables of the FIS, triangular and trapezoidal membership functions were selected. Totally, 125 rules with logical and operator, Mamdani implication, and Centroid method for defuzzification were employed to develop an efficient fuzzy expert system for decision making about apple grades. The algorithm was implemented in visual basic environment. The developed VB program can automatically capture image of each apple and extracts its RGB color and size features. The software generated all the 125 rules by comparing these features with the reference input. The rules were then exported to Matlab's for further investigation. Grading results obtained from our developed FIS scheme showed 90.8% agreement with the results from the human expert.

Key Words: Golden delicious apple; Grading; Sorter; Fuzzy logic; Fuzzy inference system; Fuzzy algorithm

INTRODUCTION

Fruits are delicate materials, and as such should be graded via non-destructive techniques. Classification is vital for the evaluation of agricultural produce. However, the high costs, subjectivity, tediousness and inconsistency associated with manual sorting have been forcing the post harvest industry to apply automation in sorting operations. Apple is one of the important and valuable exported products of our country. Iran has exported more than 17000 tones of Golden Delicious apples in 1999 (Ministry of Agriculture, 2000). But due to its poor classification or sorting based on color, size, spot etc. has decreased marketing. Hence the first necessary step for manufacturing apple sorter is the design of an automatic electronic intelligent system such as fuzzy logic based decision support system for its quality evaluation and sorting.

Umeda (1977) developed a photo-sensing method to detect the diameter, height and color of fruits. The sensing elements were composed of several photo-transistors with vertical spaces 5 mm apart. Hahn *et al.* (1998) declared that apple sizing efficiency could be increased by using fuzzy logic. The use of automatic apple sizing and color sorting has become a reality with the decline of computing and imaging hardware prices (Umeda, 1977; Hahn *et al*., 1998). Graf (1981) tried different image algorithms in order to detect apple bruises and used a multivariable linear statistical analysis of each pixel to classify bruised apples as well as a human inspector (Graf, 1981; Hahn *et al*., 1998). Rule-based expert systems are successfully applied for classification purposes in various application fields such as fault detection, biology and medicine. Fuzzy logic can improve such classifications and decision support systems by using fuzzy sets to define over-lapping class definitions. The application of fuzzy if-then's rules also improves the interpretability of the results and provides more insight into the classifier structure and decision making process (Johannes *et al*., 2003).

The objective of this study was to design an algorithm for grading of Golden Delicious apples based on their color and size using fuzzy logic.

MATERIALS AND METHODS

The inputs for fuzzy system of apple grading were apple's RGB colors and size. Crisp input data are obtained from a camera. Initially, fuzzy system fuzzifies the crisp data and then with Mamdani inference system (Mamdani *et al*., 1975) applies the fuzzy rules. Finally, after defuzzification the grade of each apple is determined. Schematic of our proposed FIS is shown in Fig. 1.

Fuzzy logic starts with the concept of fuzzy sets. The fuzzy set is the set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership (Zadeh, 1965). A fuzzy set is defined by the following expression:

$$D = \left\{ \left(x, \mu_D(x) \right) \middle| \, x \in X \right\} \quad (1)$$

Where $\mu_D(x) \in [0,1]$ is the membership function (MF) of fuzzy set D, X is the universal set, x is an element in X, D is a fuzzy subset in X. Degree of membership (DoM) for any set ranges from 0 to 1. A value of 1 represents 100% membership, while a value of 0 means 0% membership. If there are 5 subgroups of size, then 5 membership functions are required to express the size values in fuzzy rules (Kavdir *et al*., 2003).

A MF is a curve that defines how each point in the input space is mapped to a membership value (or DoM) between 0 and 1. The input space is sometimes referred to as the universe of discourse (UoD). The MFs are usually defined for inputs and output in terms of linguistic variables. There are many forms of MFs such as triangular, trapezoidal, Gaussian etc. In this study, triangular and trapezoidal MFs were selected for input and output variables as they can represent our linguistic variables more effectively.

The triangular MF is a function that depends on three scalar parameters a, b and c (see Fig. 2) and is given by (Zimmermann, 1996):

$$f(x;a,b,c)=\begin{cases} 0, & x<a \\ \dfrac{x-a}{b-a}, & a\le x<b \\ \dfrac{c-x}{c-b}, & b\le x<c \\ 0, & c\le x \end{cases} \quad (2)$$

Or, more compactly, by the following expression:

$$f(x;a,b,c)=max(\,min(\frac{x-a}{b-a},\frac{c-x}{c-b}),0\,) \quad (3)$$

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. The If-Then rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy If-Then rule assumes the form:

IF x is A THEN y is B (4)

Where A and B are linguistic values defined by fuzzy sets on the ranges (UoD) X and Y, respectively. The If-Then part of the rule "x is A" is called the antecedent or premise, while the then-part of the rule "y is B" is called the consequent or conclusion.

More generally, rules have more than one premise, that is:

R_i: IF x_i is A_i AND y_i is B_i THEN z_i is C_i (5)

Where i = 1, 2, n (n is the number of the rules). A_i, B_i and C_i are the fuzzy sets for the inputs (x_i & y_i) and the output z_i, respectively in the i-th rule, R_i. The values of C_i are the linguistic terms such as Good, Normal, Bad, etc. (Xu *et al*., 2002).

For grading of Golden Delicious apples, two conditions were used in the if-part or antecedent of the rules, one for color and one for size. We used the logical operator of "AND" defined by:

$$\mu_{A\cap B}=min(\mu_A,\mu_B) \quad (6)$$

Where $\mu_{A\cap B}$ is the MF of intersection of fuzzy sets A and B. μ_A and μ_B are the MFs of the fuzzy sets of A and B, respectively. The AND operator is used here because the color and size features must be captured simultaneously and applied in decision making by fuzzy logic for grading.

In fuzzy rules, five MFs: Very Low (0 - 25), Low (15 - 50), Normal (25 - 75), High (50 - 90) and Very High (75 - 100) in % for color and five MFs: Very Small (0 - 45), Small (30 - 55), Normal (40 - 65), Large (55 - 80) and Very Large (70 - 160) in mm for sizes (length & width) were selected. In totally, 125 (= 5^3) if-then rules with logical operator of "AND" were used. Five MFs: Very Bad (60 - 140), Bad (100 - 180), Normal (140 - 220), Good (180 - 260) and Very Good (220 - 290) (data are unit less), for output variable were selected to express grades of apples. The input and output MFs are shown in Fig. 3. These rules have a general agreement with that human expert. For example, the 11 rules that define the "Very Good" grade of apples are:

R1: If Color is Very High and Height is Very Large and Width is Very Large then Grade is Very Good

R2: If Color is Very High and Height is Very Large and Width is Large then Grade is Very Good

R3: If Color is Very High and Height is Very Large and Width is Normal then Grade is Very Good

R4: If Color is Very High and Height is Large and Width is Very Large then Grade is Very Good

R5: If Color is Very High and Height is Large and Width is Large then Grade is Very Good

R6: If Color is Very High and Height is Normal and Width is Very Large then Grade is Very Good

R7: If Color is High and Height is Very Large and Width is Very Large then Grade is Very Good

R8: If Color is High and Height is Very Large and Width is Large then Grade is Very Good

R9: If Color is High and Height is Very Large and Width is Normal then Grade is Very Good

R10: If Color is High and Height is Large and Width is Very Large then Grade is Very Good

R11: If Color is High and Height is Normal and Width is Very Large then Grade is Very Good

Where "High", "Very High", "Normal", "Large", etc. are the linguistic variables (MFs) in the universal set. "Grade" is the apple grade (or output variable). Height and Width in the above rules are the major and minor diameters (sizes) of each apple, respectively. Finally, Color is an indication of the overall RGB content of each apple. It is calculated from the following equation:

$$Color=\frac{R}{R+G+B}\times 100 \quad (7)$$

Where R, G and B are the red, green and blue content of each pixel in RGB color space. Spectral components of these primary colors combine additively to produce a resultant color. The overall color of each apple is then determined by averaging over all pixels.

Since decisions are based on the testing of all of the rules in the FIS, rules must be combined in some manner in order to make decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification (See Fig. 1). The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable.

We obtain output crisp data from our FIS upon defuzzification. A number of defuzzification methods such as center of gravity (CoG) also known as centroid, mean of maximum and first of maximum are available (Zimmermann, 1996). CoG is the most popular and the most precise method for defuzzification, hence it used here. CoG method is a grade weighted by the areas under the aggregated output functions. For example, the Very Good grade of apples with 11 rules is accessible. The truncated MFs of the output fuzzy sets are shown in Fig. 4, where w_1 and w_2 are the degrees of membership of the x to the Fuzzy set of D.

Let a_1, a_2, a_n be the areas of the truncated triangular under the aggregated function and C_1, C_2, C_n be the coordinates of their centers on the *x*-axis. The centroid of the aggregated area is given by (Xu *et al*., 2002):

$$G = \frac{\sum_{i=1}^{n} a_i C_i}{\sum_{i=1}^{n} a_i} \qquad (8)$$

Where, n is the number of the areas (e.g. 11 for Very Good grade) and G, is the location of the centroid of the total areas. The location of CoG determines the grade of the apple.

Data acquisiton system. For conducting experiments, a data acquisition system was introduced that acquired data of apples' color and size automatically. The main components of this system are apple sorter, personal computer and a webcam. The designed system is shown in Fig. 5.

Apple sorter is composed of belt conveyor, illumination chamber and an induction motor (See Table I for its characteristics). The belt conveyor has 150 cm length and 25 cm width. The belt is made from rubber and it has 23.5 cm width and 3 mm thickness. The induction motor is 0.37 kW (0.5 hp) and its output speed is 25 rpm from hollow shaft. The linear velocity of belt was 8.8 cm/s. The illumination chamber is rectangular (30 × 25 × 30 cm) and it is completely covered with black color. Four fluorescent bulbs (130 w each) were placed inside the chamber in order to produce a uniform light. For measuring color and size features a Mercury webcam with 2.1 Mpixels resolution was used. The webcam was inserted at fixed height on the hole at top of the chamber. Pictures of apples were sent to the PC via USB port. The processing unit of our data acquisition system was a PC (A 2.80 GHz Pentium 4 with 768 MB of

Fig. 1. Fuzzy Inference system for grading of Golden Delicious Apples

Fig. 2. Schematic of triangular membership function

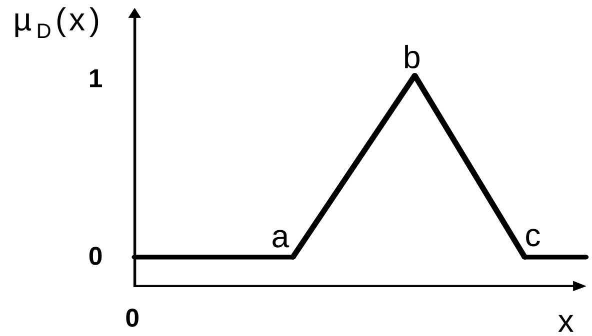


Fig. 3. Membership functions of input and output fuzzy sets

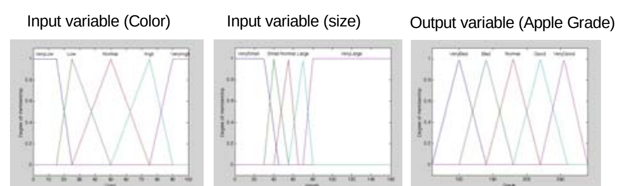


Fig. 4. The truncated output membership functions for a special grade

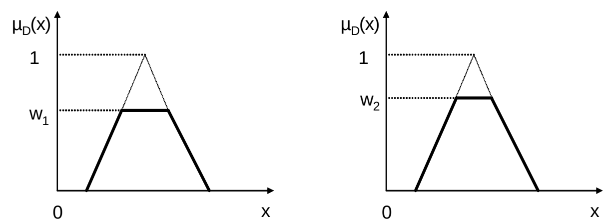


Fig. 5. Automatic data acquisition system used for apple grading

RAM). For the determination of the linguistic variables, the experiments were conducted off-line. Altogether 250 apples (50 samples from each grade) were chosen. First, apples were put under the illumination chamber and then the webcam captured images from them. In this way the main features of apple i.e., its RGB color and two perpendicular diameters of apple were saved in PC. The collected data were then used in developing fuzzy expert system for apple grading.

In order to generate the rules for our FIS model a program in VB environment was designed and implemented. The program is capable of capturing the image of an apple from the webcam, analyzing the RGB color of each apple pixel-by-pixel and calculating the two diameters of apples. The standard values for grade of an apple and various defects of them were computed by comparing its feature with the reference one. These values can then be used for training a fuzzy logic system, which can grade Golden Delicious apple according to its color and size, i.e. it may be regarded as a color based ripeness detector.

The program can generate all the 125 rules automatically for each apple. The output of the program (i.e., the rules) is a text file that can be exported to Matlab for further investigation (www.mathworks.com). The generated rules are then used by Matlab in order to grade apples off-line. For this purpose Matlab's Fuzzy Logic Toolbox is utilized. The FIS editor of our developed program is shown in Fig. 6. Summary of which is given bellow:

Type = 'mamdani'

Decision method for fuzzy logic operators AND: ' MIN '

Decision method for fuzzy logic operators OR:' MAX'

Implication method: 'MIN'

Aggregation method: 'MAX'

Defuzzification: ' CENTROID' (centre of gravity).

RESULTS AND DISCUSSION

The output of our FIS after running the program for Good grade of apples is shown in Fig. 7. According to the boundary conditions of the output variable's MFs (Fig. 3) confirms strongly the results in the Table II. For example, if the color is 90.47 (Very High), Height is 65.03 (Large) and Width is 59.64 (Normal), then the output after defuzzification is 231 that belong to the range of Good grade of Golden Delicious apple (180 - 260).

In Fig. 8 we can see the output surface in the terms of the input surfaces covering both the whole input space and the whole output space, in order to show the interaction between inputs and output. This result confirms strongly that the rules were defined very good, because in this graph we don't see any big jumps then it is likely to working well. In Fig. 8 we can observe how a determinate value of two input values affects the one output, it is very useful because

Fig. 6. Schematic of our FIS model for grading Golden Delicious apples

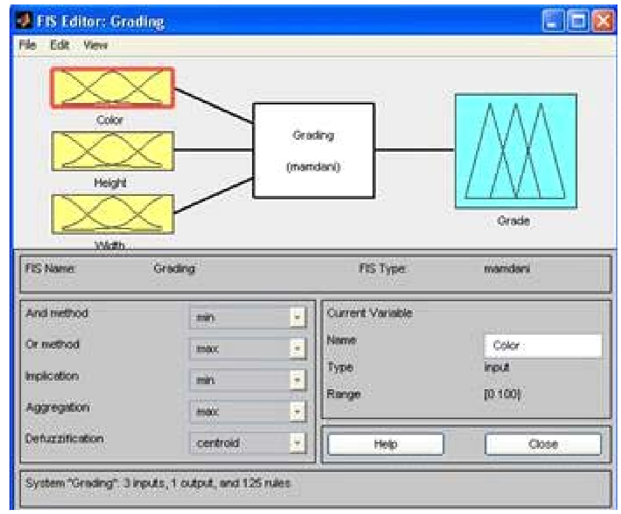
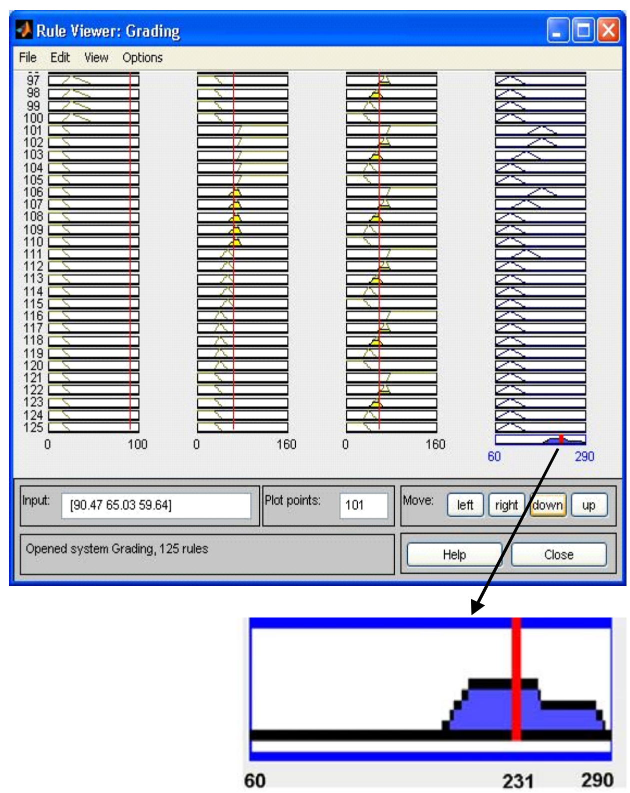


Fig. 7. The fuzzy system output in Rule viewer for Good grade of apples



just with one view we can see the interaction and it helps us to improve the fuzzy rules if some characteristics of performance aren't right.

What we see in Fig. 8 is not different from what we explained before. If the color is very high (values close to 100) and the height is very large (values close to 150) and

Table I. Main characteristics of Induction Motor used in this study

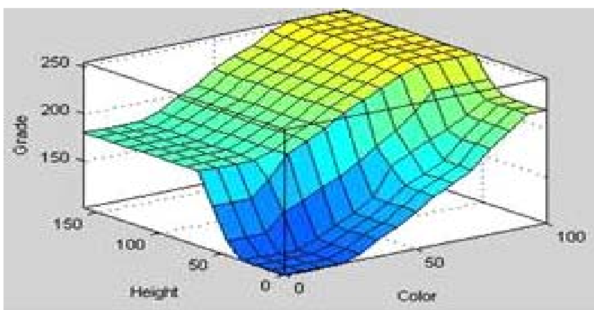
MOTOGEN induction motor		Made: Tabriz - ran	Type: 71 - 4B
Power: 0.37 KW	IP: 54	Frequency: 50 Hz	No. of Phases: 3
rpm:1390	$\cos\phi$:0.69	Volt:220 Δ /380 Y	Amp:2.1 Δ /1.2 Y

Table II. Comparison of proposed fuzzy system and human expert in grading of Golden Delicious apples

		Fuzzy Logic Prediction						
	Apple Grade	Very Good	Good	Normal	Bad	Very Bad	No of apples used for each grade	correctly classified apples(%)
Human	Very Good	49	1	0	0	0	50	98.0
Expert	Good	4	43	2	1	0	50	86.0
	Normal	0	1	48	1	0	50	96.0
	Bad	0	1	5	41	3	50	82.0
	Very Bad	0	0	1	3	46	50	92.0
Total Observed		53	46	56	46	49	227*/250	
(%)		92.5	93.5	85.7	89.1	93.9		90.8

*Number of apples correctly classified by proposed fuzzy system

Fig. 8. Surface: output variable: Grade, Input variables: Color and Height



the width is very large (values close to 150) then the Grade will be very good (values close to 290). We can observe also that when we decrease the values of Color making the Height less short.

For evaluation of the developed FIS, we graded the apples by fuzzy system designed for this purpose. The same set of apples was graded by human expert, too. Results of this comparison are shown in Table II. In previous studies, apples were classified with recognition accuracies of 86.1% and 85.9% using Fisher's linear classifier and Boltzman's perceptron network classifier, respectively based on color features (Kavdir *et al*., 2003). The authors suggested that the low accuracy rate could be due to the variations in the visual properties of apples. Fuzzy logic, on the other hand, involves less computation and has clear implementation and working schemes. Based on the results in Table II, our FIS has increased the accuracy of grading (90.8%).

CONCLUSION

Fuzzy logic is successfully applied to serve as a decision support technique in grading Golden Delicious apples. Grading results obtained from fuzzy logic show a very good general agreement with the results from the human expert. Furthermore, it provides good flexibility in reflecting the expert's expectations and grading standards (United States Standards for Grades of Apples, 2002) into the results. It is also seen that selection of color and two perpendicular diameters (size) of apples are 3 important criteria in apple grading. The developed FIS can be adapted for grading other fruits as well as vegetables such as peach, pears, apricots, tomatoes etc. Currently working in the area of adapting FIS and VB programs for online sorting of Golden Delicious apples is underway by authors.

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