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(Review Article)

The application of fuzzy logic techniques to improve decision making in apparel size

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Abstract

Traditional set theory, or crisp set theory, is built on the concept of crisp sets. These are sets for which the membership of an element within a set is defined as either true or false; in or out; 1 or 0. This construction is extremely useful, as mathematics has shown, but it struggles to model concepts of our world that possess vagueness or uncertainty. Therefore, we explore an expansion of set theory to allow an element to be partially within a set, thus constituting what is known as a fuzzy set. This paper introduces the basic concept of fuzzy sets, which includes fuzzy sets and crisp sets, as well as the operations of a fuzzy set and fuzzy classification systems. Fuzzy logic has been utilized to solve numerous textile-related difficulties, one of which was determining the proper clothing size. In this study, we examined fuzzy logic applications in textiles, such as the construction of fuzzy expert systems and fuzzy logic for predicting clothing size. This research demonstrates that when determining the correct size of clothing, the outcome is heavily reliant on fuzzy logic.

Keywords: Fuzzy sets; Fuzzy logic; Apparel size; Fuzzy numbers; Fuzzy Classification.

1. Introduction

A clear mind is necessary to identify the desired outcome, decide, comprehend the issue, use decision matrices or the information that is already accessible, prioritize important variables, and brainstorm the pros and cons by obtaining as much information as possible. We often have to make choices in real life based on time constraints. Usually, we may not be given enough time to fully evaluate the situation before needing to choose a course of action. When this occurs, we need to respond quickly and think clearly. The fuzziness or ambiguity of the data is a significant problem when dealing with it. Experts in real-world problems often struggle with the challenge of fuzzy data. To solve such issues, Zadeh's fuzzy set (FS) [1] is an interesting technique. Numerous studies have been conducted on fuzzy set theory (FST). Fuzzy logic can be defined as the superset of classical logic or Boolean logic that has been extended to handle the concept of partial truth—truth values between "completely true" and "completely false". This can be made possible by introducing the concept of degree of membership [1].

Fuzzy logic (FL) is composed of multiple logic levels that enable us to define intermediate values between conventional evaluations such as true/false, yes/no, high/low, etc. Concepts like "medium cold" or "very hot" can be represented mathematically and then processed by computers, which initiates a more human-like way of thinking in the programming of computers [2]. Fuzzy logic is an efficient tool for controlling and navigating systems and complex industrial processes, in addition to household and entertainment electronics, and other expert systems and applications such as the classification of SAR data [1]. Fuzzy logic was introduced in 1965 [3], [4], [5] by Lotfi A. Zadeh, a professor of computer science at the University of California, Berkeley.

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Fuzzy logic is designed to mathematically indicate the uncertainty and vagueness associated with notional human activities, such as thinking and reasoning. It has the flexibility and robustness to provide tools to overcome real-world problems with uncertain intrinsic parameters. The following stages can be applied to developing a fuzzy system:

- Ascertain whether fuzzy modeling techniques are appropriate for the issue. FST can solve the issue if the information about the system is imprecise or if there is lack a of information about the issue.
- Define the values of the problem parameters and their ranges.
- Construct a membership function based on the parameter ranges. The decision-maker bases the number of membership functions on the number of ambiguous or imprecise parameters included in the problem.
- Create a representation of the system under management using membership functions that display the degree of system parameter satisfaction.

In this study, a size-matching recommender system has been employed to determine the appropriate apparel size for buyers using fuzzy logic [9], [10]. Similar to other artificial intelligence applications such as neural networks and expert systems, fuzzy logic addresses the ambiguity and subjective human judgment in computing challenges. The theory and practice of fuzzy logic have had a considerable influence on the development and modernization of engineering and computing technology. It has been used in many areas, including the creation of intelligent industrial items, and has benefited customers, making Zadeh's contribution enormous. Fuzzy logic can translate verbal variables (such as small, medium, large, and extra-large) into imprecise ("fuzzy") words for computer-understandable terms in various application fields. Beyond identification, pattern recognition, and optimization, fuzzy logic can solve issues and support decision-making. It is frequently employed in a variety of industries, including the textile and clothing, agricultural, engineering, architectural, and automobile sectors. This study also aims to illustrate the potential benefits of brand-specific size-matching recommender systems for the growth of the apparel sector. When purchasing clothing, the system will offer guidance for both women and men by suggesting the appropriate size based on the brand. By decreasing returns and boosting consumer trust in online shopping, the method is anticipated to have a positive effect on the garment business.

2. Fundamental idea of fuzzy sets

2.1. Fuzzy Sets and Crisp Sets

The fuzzy set (or subset) is the core concept in fuzzy systems. The term "crisp set" is well-known in classical mathematics. For example, consider a number x. A subset S can be defined from the set R of all real numbers between 0 and 1, (e.g. all values for which $0 \leq x \leq 0.4$). The characteristic function of S, (i.e. it assigns a number 1 or 0 to each element in R, depending on whether the element is in the subset S or not) is shown in Figure 1.

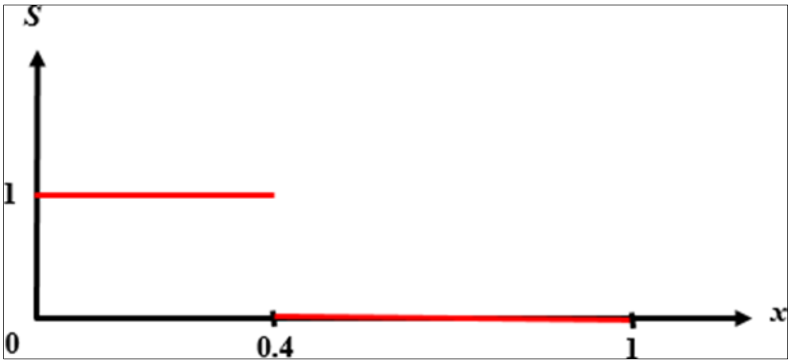

Figure 1 Characteristic function of a crisp set

The elements which have been assigned the number 1 can be interpreted as the elements that are in the set S and the elements which have been assigned the number 0 as the elements that are not in the set S. For many areas of applications this idea is sufficient, but as we can see, it has less flexibility for some applications like classification of remotely sensed data analysis. Take the temperature of a room as an example, which is simpler. Boolean logic states that the temperature can only be either "HOT" or "COLD.". If we define HOT as 30^0C and COLD as 10^0C, then according to Boolean logic, the room cannot have an intermediate temperate e.g. 20^0C, or 25^0C. Fuzzy logic provides a way to take intermediate values between 0 and 1, e.g. 20^0C is 0.5HOT or 0.5COLD, while 25^0C is 0.75HOT or 0.25 COLD. This is shown in Fig. 2.

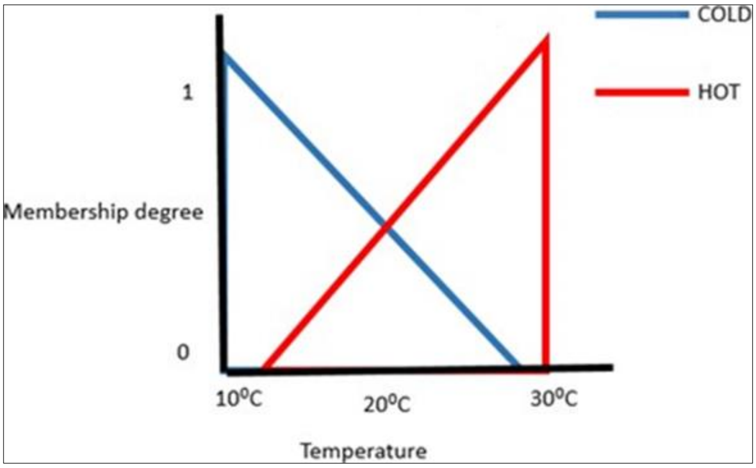

Figure 2 Example of membership function of a Fuzzy Set

Fuzzy sets aim to make computers more 'intelligent', therefore fuzzy sets allow more values between 0 and 1. An infinite number of values can be allowed between the boundaries 0 and 1. For example, in the above room temperature problem the numbers 0.5, 0.25, and 0.75 have been used which are between 0 and 1. Numerous other values in this range like 0.1, 0.01, and 0.55 could be taken to make the system more precise.

The term "membership function" refers to a graphic depiction of the relative size of each input's contribution. Each of the inputs is processed as it is associated with a weighing number. The membership function also defines functional overlap between inputs, and in the end, establishes an output response. To calculate their impact on the fuzzy output sets of the final output conclusion, the rules analyze the input membership values. A value between 0.0 and 1.0 is returned by the membership function, which in this instance operates on the fuzzy set of temperature. For example, a temperature of 20^0C has a degree of membership of 0.5 (see Fig. 2). It is essential to mention the difference between fuzzy logic and probability. Probability and fuzzy logic both operate across the same numeric range and have values that are similar to 0.0, which stands for False (or non-membership), and 1.0, which stands for True (or full-membership). Nevertheless, there is a difference to be made involving the two statements: The probabilistic approach yields the natural-language statement, "There is a 50% chance that temperature is COLD or HOT," while the fuzzy terminology corresponds to room temperature's degree of membership within the set of temperature which is 0.50 for 25^0C." The semantic difference is substantial: the first interpretation supposes that temperature is HOT or COLD; it is just that we only have a 50% chance of knowing which set (HOT or COLD) it is in. On the contrary, fuzzy language assumes that temperature is “more or less” HOT/COLD, or in some other term corresponding to the value of 0.50.

2.2. Operation of a Fuzzy sets

Basic operations can be introduced on fuzzy sets, similar to the operations on crisp sets. Additionally, we want to intersect, combine, and oppose fuzzy sets. In his first publication on fuzzy sets, L. A. Zadeh proposed the minimum operator for the intersection and the maximum operator for the union of two fuzzy sets [19]. If we simply take the membership degrees 0 and 1 into consideration, these operators match with the crisp unification and intersection. For example, consider A is a fuzzy interval between 6 and 9 and B is a fuzzy number of about 5 as shown in Fig. 3 below

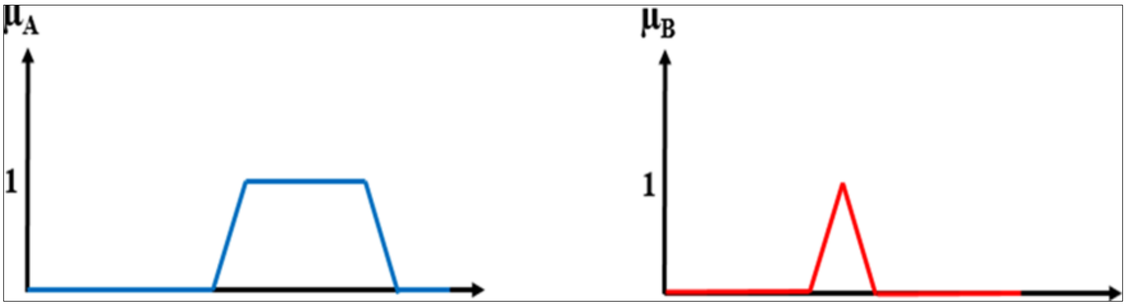

Figure 3 Example: Fuzzy Sets

In this case, the fuzzy set between 6 and 9 AND about 5 (intersection) is shown in Fig. 4.

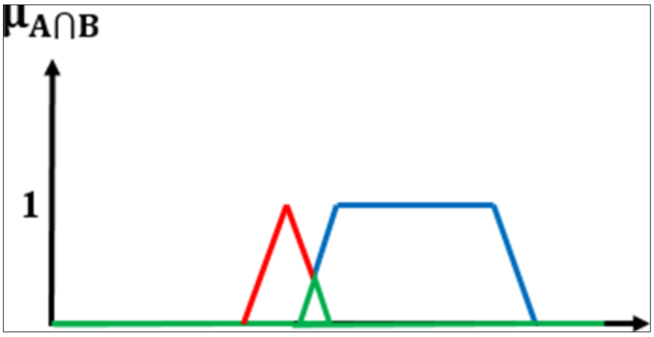

Figure 4 Fuzzy logical AND operator

The intersection of two fuzzy sets A and B is the largest fuzzy set within both A and B. The intersection is a logical AND operator written as $A \cap B$ or A.B, where the membership function is defined as:

$$\mu_{A.B}(x) = \mathrm{Min}[\mu_A(x), \mu_B(x)]$$

The set of values between 6 and 9 OR about 5 (union) is shown in Fig. 5.

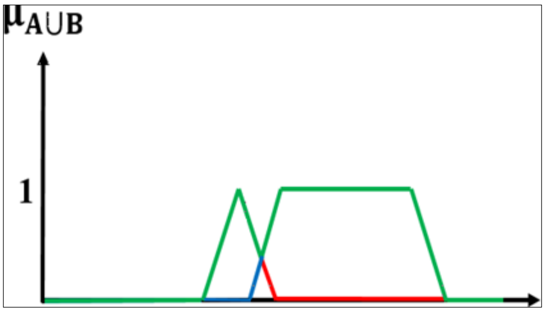

Figure 5 Fuzzy logical OR operator

The union of two fuzzy sets A and B is the smallest fuzzy set which includes all articles in A or B or A and B. The union is a logical OR operator written as A+B or $A \cup B$, where the membership function is defined as:

$$\mu_{A+B}(x) = \mathrm{Max}[\mu_A(x), \mu_B(x)]$$

The NEGATION (complement) of the fuzzy set A is shown in Fig. 6 below.

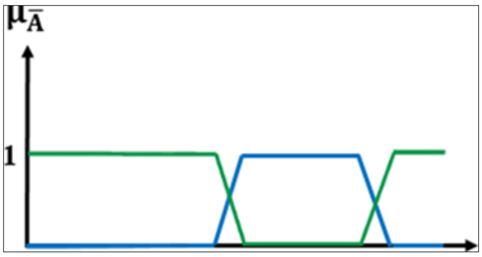

Figure 6 Example: Fuzzy NEGATION

The complement of fuzzy set A is defined as $\mu_{\bar{A}}(x) = 1 - \mu_A(x)$.

Complement of A = {*x* | *x* is not near an integer}.

3. Fuzzy classification

The fuzzy classifier is one example of how fuzzy theory is applied. Fuzzy sets are described using linguistic variables to express detailed information in a very natural way.

Table 3.1 shows the general form of an example with 25 rules, The detailed information for these variables can be expressed as a rule like IF feature A is at LEVEL 2 AND feature B is at LEVEL 4 THEN ACTION = ACTION 17.

A table like Table 1 can combine the rules. A rule base table is the one that contains all of the fuzzy rules combined.

Table 1 Example of a fuzzy rule base. Rules read as an example: RULE No.1: IF A isat level 3 AND B is at level 5 THEN do action number 23

Feature a **Feature b**	**Level1**	**Level2**	**Level3**	**Level4**	**Level5**
Level 1	Action 1	Action 2	Action 3	Action 4	Action 5
Level 2	Action 6	Action 7	Action 8	Action 9	Action 10
Level 3	Action 11	Action 12	Action 13	Action 14	Action 15
Level 4	Action 16	Action 17	Action 18	Action 19	Action 20
Level 5	Action 21	Action 22	Action 23	Action 24	Action 25

The "*levels*" mentioned in the above example are replaced when making actual fuzzy models with words like *close, heavy, light, big, small, smart, fast, slow, hot, cold, tall, short, near, far,* etc. depending upon the system. Because of this incredible flexibility and simplicity, the system is said to "think like a human".

There are two elements to the linguistic rules that describe the control system: an antecedent block (between the IF and THEN) and a consequent block (after THEN). Evaluation of all possible input combinations may not be required because some combinations may never take place depending on the system. Fewer rules can be evaluated by performing this sort of evaluation, which is often carried out by an experienced operator, which simplifies the processing logic and may even enhance the performance of the fuzzy logic system.

The inputs in this example are combined logically using the AND operator to produce output response values for all expected inputs. The active decisions are then combined into a logical sum for each membership function.

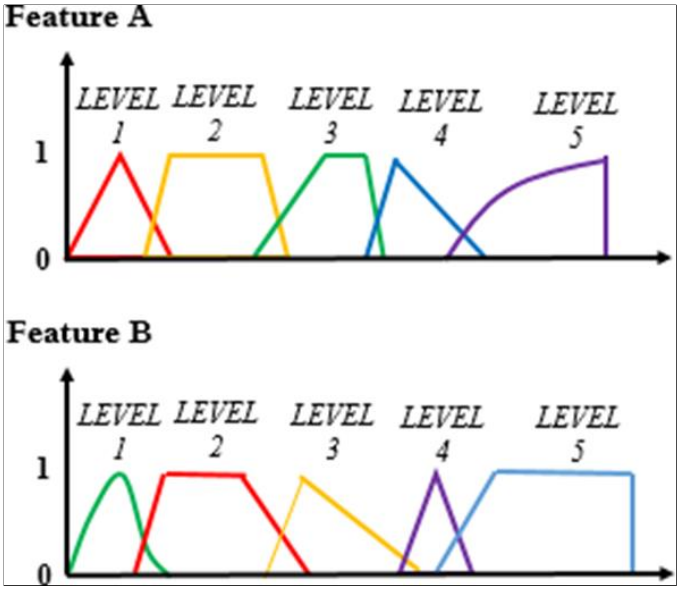

Figure 7 Example: linguistic variables and membership functions

The fuzzy outputs for all rules are finally aggregated into one fuzzy set. To obtain a crisp decision from this fuzzy output, the fuzzy set is defuzzified, where one representative value is chosen as the final output. One heuristic approach (defuzzification method) that is widely used for fuzzy sets is the center of gravity of the fuzzy set, as shown in Fig. 8. In the case of discrete values with singletons usually, the maximum method is used where the point with the maximum singleton is chosen.

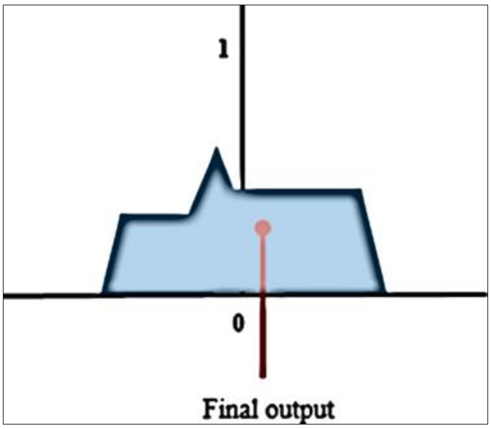

Figure 8 Defuzzification using the center of gravity approach

4. Application of fuzzy logic in apparel size

4.1. Structure of Fuzzy expert system

This work introduces a fuzzy logic expert system for predicting color strength in cotton blended fabric dyeing. Figure 9 depicts the general configuration of the fuzzy expert system, which is separated into four major parts: (1) Fuzzification-takes crisp numeric inputs (Dye%, time, and temperature) and turns them into fuzzy information. (2) Knowledge base-which stores a set of language terms and if-then rules that measure knowledge in the same way that human specialists do. (3) Decision making logic-creates control actions based on information provided by the fuzzification module by applying knowledge about how to best regulate the plant, and (4) Defuzzification calculates the real output, i.e. converts the fuzzy output into a precise numerical value (crisp value) and then sends them to the physical system (plant)[7].

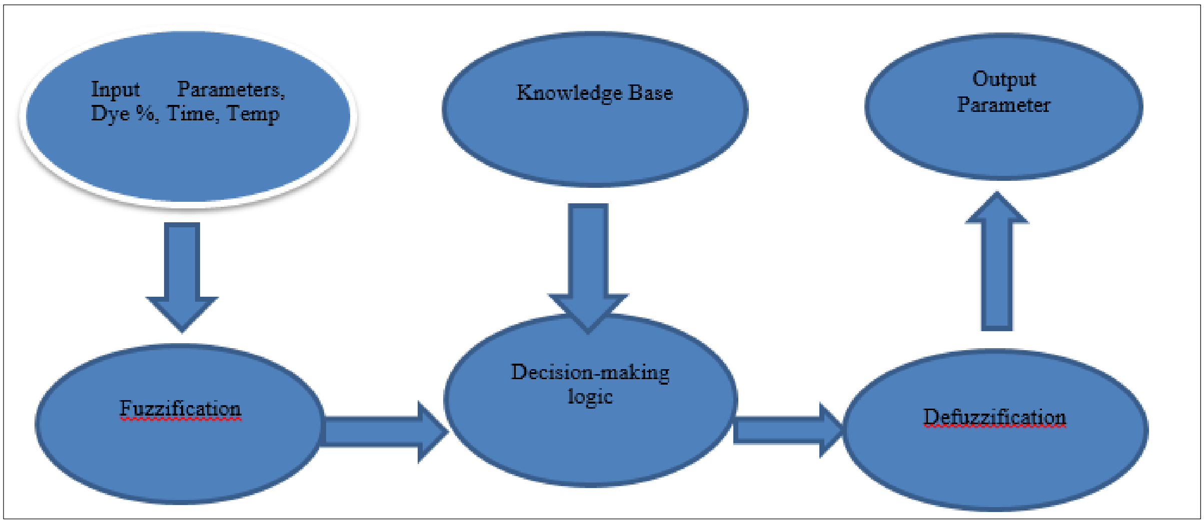

Figure 9 Basic Structure of Fuzzy expert systems

4.2. Fuzzy logic for determining the correct size of clothing

Each size of a brand is considered a different product in this study, and all different products are numbered 1, 2,... p. As an example, a specific brand X (a product) is expected to come in sizes ranging from "Small (S)" to "Medium (M)", "Large (L)", "X Large (XL)" and "XX-Large (XXL)". Table 2 shows the measurements for these brand X sizes.

Table 2 The Measurement of The Brand X

	Small (S)	Medium (M)	Large (L)	X Large (XL)	XX-Large (XXL)
Collar	35-38	39-40	41-42	43-44	45-46
Shoulder	38-42	43-44	45-46	47-48	49-50
Chest	90-98	99-104	105-110	111-114	115-118
Waist	40-46	47-52	53-54	55-56	57-58

The following rules are considered for constructing suitable fuzzy intervals

- Measurements that are smaller than the client's attribute value are not suitable for the client's size of body.
- The most appropriate size for the customer is 96.5% of the higher value of the associated size (taking comfort into account).
- Loose sizes for a client have some fitness degree as well, but smaller sizes are NOT suited for a customer.

The fuzzy numbers constructed for sizes "S", "M", "L", "XL" and "XXL" are in the form of triangular fuzzy numbers defined as T (a, b, c), where T denotes one of the sizes of "S", "M", "L" or "XL" or "XXL", *a* is the bottom limit of all sizes, *b* is the optimum measurement for the handled size and *c* is the upper limit of the related size (see Fig. 10). The following figure is an example of membership function used for collar circumference for all sizes in a brand. Functions for the shoulder, chest, and waist have similar shapes but different lower and upper limits and core point values.

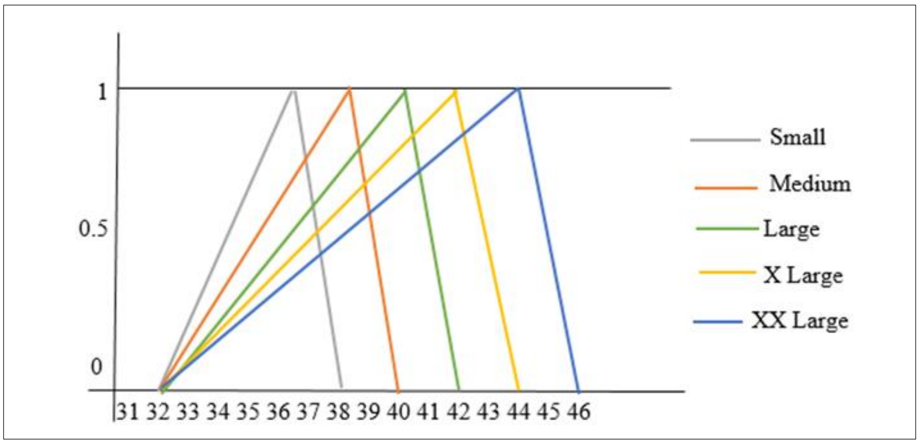

Figure 10 Membership function example for collar circumference

An online interface is built for users to enter their body size measures (weight, length, collar circumference, shoulder width, chest width, waist circumference, and arm length) in the study. In addition, the measurements of specific brand shirts are saved in a database. A triangular membership value is computed using the user's measurements and the size measurements of the apparel to discover the optimal size of goods for a user.

The system computes all class membership values based on the user's measurements (neck, shoulder, chest, and waist measurements in cm) and compares them to all sizes. The minimal membership value is taken into account for all sizes. Among these minimum membership values, the user is assigned to the size with the maximum membership degree.

Assume that client C has the following measurements: C (neck = 38cm, shoulder = 43cm, chest = 103cm, waist = 93cm). For convenience, the lower limit of the size is calculated as 83% of the upper limit. This value serves as the lowest limit for all sizes in related measurements. The size with the best fit is estimated to be 3.2% less than the highest limit. The criteria for "Small" size of "Collar" measurement, for example, are (32.3, 36.67, 38). Table 3 shows the parameter table for the "Collar" in "Small" size [9] [10].

Table 3 The Parameter Table for the "Collar" in "Small" Size

Size (Collar)	**a**	**b**	**c**
Small (S)	32.3	36.67	38
Medium (M)	32.3	38.6	40
Large (L)	32.3	40.53	42
X Large (XL)	32.3	42.46	44
XX Large (XXL)	32.3	44.51	46

With triangular membership for "S" size with parameters (32.3, 36.67, 38), we get,

$\mu_{S,collar}(38) = 0.$

$$\mu_{S,Collar}(x) = \begin{cases} \dfrac{x - 32.3}{36.67 - 32.3}, 32.3 < x \leq 36.67 \\ \dfrac{38 - x}{38 - 36.67}, 36.67 < x \leq 38 \\ 0, \ otherwise, \end{cases}$$

If the membership of this client to the "M" size class is calculated, the parameters (32.3, 38.6, 40) are used. For the medium size of client C, we get $\mu_{M,Collar}(38) = 0.905$.

$$\mu_{M,Collar}(x) = \begin{cases} \dfrac{x - 32.3}{38.6 - 32.3}, 32.3 < x \leq 38.6 \\ \dfrac{40 - x}{40 - 38.6}, 38.6 < x \leq 40 \\ 0, \ otherwise, \end{cases}$$

In the same way, values for "L", "XL" and "XXL" ($\mu_{L,Collar}(38), \mu_{XL,Collar}(38), \mu_{XXL,Collar}(38)$) are calculated. This operation is applied to the other attributes of the user. The degree of fitness for this client C to size class "S" is computed as

$$\mu_{C,S} = \min\{\mu_{S,Collar}(38), \mu_{S,Shoulder}(44), \mu_{S,Chest}(104), \mu_{S,Waist}(94).$$

After computing class membership values for each product (i.e. "S", "M", "L", "XL", "XXL") for client C, the product (size) with the highest membership value is assigned as the most suitable product (size) for the client. In other words, a size that provides $\max\{\mu_{C,S}, \mu_{C,M}, \mu_{C,L}, \mu_{C,XL}, \mu_{C,XXL}\}$ is the best-fitting size for the users within the given parameter.

Table 4 shows an example classification for a user. The user is said to be best fitted in the "Large" size of this brand

Table 4 An Example of Classification for a User

Measurement	**S**	**M**	**L**	**XL**	**XXL**
Collar (38 cm)	0.00	0.42	0.32	0.26	0.22
Shoulder (44 cm)	0.00	0.00	0.55	0.45	0.35
Chest (104 cm)	0.00	0.00	0.55	0.45	0.35
Waist (94 cm)	0.00	0.39	0.33	0.29	0.26
Member to	0.00	0.00	0.32	0.26	0.20

5. Conclusion

Fuzzy sets provide a very easy-to-understand introduction to the core concepts and techniques of fuzzy set theory in this paper. The presentation is authoritative, rigorous, and updated. The application covers a wide range of issues, including fuzzy logic and expert systems, as well as information retrieval and decision analysis. We are aware that fuzzy logic has a wide range of different applications. A small subset of fuzzy logic, based on the methodology of fuzzy rules and their induction from observation, is used in the majority of current applications of fuzzy logic in the areas of textiles, industrial systems, and consumer items. In this paper, we also build fuzzy expert systems and fuzzy logic to estimate apparel size. This study indicated that when identifying the correct size of clothing, the outcome is strongly dependent on fuzzy logic. The success of this technique is directly tied to accurate body measurements. As a result, while users establish a profile with their body size, each measurement is shown with illustrations that clarify how and which part to measure, and users can find the correct size of the required clothes here.

Compliance with ethical standards

Acknowledgement

We are also grateful to all our well-wishers, who provided their support towards accomplishing this task successfully. Finally, we beg pardon and apologize for the faults and any unintentional mistakes that might be recurred in this article even after all the care that was taken.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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