

Decision Support Systems Intelligent to Predict and Optimize the Assembly Time for New Product Design Using a Fuzzy-Evolutionary Multimodal Approach

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Abstract. In this paper three case studies are presented applying a Fuzzy-Evolutionary Multimodal approach to predict and optimize the prediction assembly time, this methodology can be a good complement of the design for assembly methodology of Boothroy-Dewhurst. This hybrid method analyzes different situations and conditions, identifies sources of variability that should be avoided during the process design because it increases the assembly time. The evolutionary algorithm searches the set of inputs or conditions in the fuzzy model and uses the predicted time to evaluate every set of inputs generated, the best tree conditions with and without constraints design are found by this approach. The research shows the advantages of using a Fuzzy-Evolutionary Multimodal approach in order to analyze the variables behavior to predict, control and optimize the assembly time in the new product design.

Key words: Fuzzy Logic, Evolutionary Strategies Multimodal, Design for Assembly

1 Introduction

The Product design involves a complex group of activities which are affected by diverse sources of variability that should be detected and analyzed carefully to avoid them in the design. A bad product design impacts on the functionality, fitness and the customer satisfaction. The assembly time is a critical activity and is very important to select the appropriate assembly method to reduce cost and time. Historically, motion time study has been used successfully in time measurement of product, the problem is to predict the assembly time of new products because many assembly parts have not been built yet. It causes the need to research and use new methodologies and new technologies to improve the new product design.

The researchers Boothroyd and Dewhurst [1] have developed a successful method to help designers to redesign their products, to reduce costs, improve performance and reduce assembly time; this methodology is called Design for Assembly (DFA). In this methodology the assembly time is divided into two categories, one generated by the insertion time and the second one generated by the handling time or transfer of every one of the components until achieving the total assembly.

The DFA Boothroyd methodology has had great success in a good number of leadings design companies around the world [2, 5]; unfortunately it does not have all the characteristics required in the industry [4, 2]. Others inconveniences of the methodologies are that it is not flexible to different applications and is subject to find the assembly time values in charts (See **Table.1**), it does not have tolerance to lack of entrance data, and it does not have self-learning capacity based on data and previous events.

Table 1. Information to predict manual handling assembly time with one hand without the aid of grasping tools – estimated time (seconds) [1].

		No handling difficulties			Part nests or tangles		
		Thickness > 2 mm		< 2 mm	Thickness > 2 mm		< 2 mm
sym(deg)= (alpha + beta)		size > 15 mm	6 mm ≤ size ≤ 15 mm	size > 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size > 6 mm
		0	1	2	3	4	5
sym<360	0	1.13	1.43	1.69	1.84	2.17	2.45
360≤sym<540	1	1.5	1.8	2.06	2.25	2.57	3.0
540≤sym<720	2	1.8	2.1	2.36	2.57	2.9	3.18
sym=720	3	1.95	2.25	2.51	2.73	3.06	3.34

To aid and solve this problem an intelligent system is proposed, it is a Fuzzy-Evolutionary Multimodal (FEM) approach to predict and optimize the assembly time in a new product. This intelligent system will serve as a decision support system; the goal is to predict the assembly time using fuzzy logic and evolutionary strategies to optimize the assembly time of new products giving the system the best tree options and choose the better for the design, before send the drawings to production.

The object of this research is contribute to the decision support process predicting and optimizing the assembly time improving the design and innovation of products.

This work is organized in the following way: On section 1 a brief introduction will be given, the section 2 has a short summary of previous research using intelligent systems in the manufacturing and assembly process. The research tools foundations, Fuzzy Logic and Evolutionary Strategies, are shown in section 3, experimentation and results are shown in section 4, the research conclusions and future work are given in sections 5 and 6 respectively.

2 Literature Review

In the last two decades, the application of intelligent systems in manufacturing has been subject of extensive research. Different intelligent systems are being proposed to improve the new product design product optimize the manufacturing and the process quality [6,10]. This technology has become in a important computing tool to solve engineering problems [6, 10, 11]. It has led to increasing research on a wide variety of industrial applications, such as product manufacturability control, process planning, etc. The application of this technology on the assembly and disassembly areas is actually in research and it is possible to find intelligent systems using fuzzy logic and neural networks to improve the new product design, [9, 12].

Great utility has been demonstrated the use of Fuzzy Logic, evolutionary computation and neural networks in the parametric design. In these designs a great number of variables and interrelations are involved which generate a great quantity of completely unknown parameters [11]. Fuzzy Logic technology has the ability to handle lexical uncertainties. These systems have been proposed in order to reach a better design process and to improve product design quality [10, 9].

The application of intelligent systems to predict the assembly time and optimize the assembly sequence is on research, this area have many variety opportunities to make new developments and new applications. This research proposes a approach to predict and optimize the assembly time in new products. This hybrid method use Evolutionary Strategies Multimodal to optimize the estimated time by the fuzzy system. (See Flow Diagram **Fig. 1**).

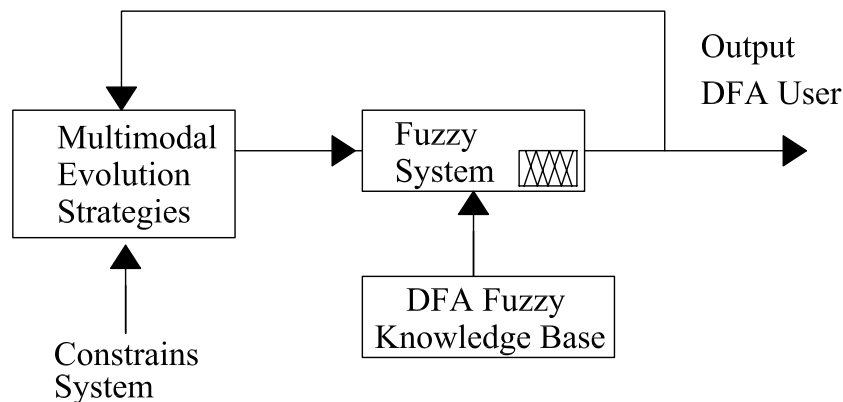


Fig. 1 Fuzzy-Evolutionary approach flow diagram, the output of DFA system is optimized by evolution strategies multimodal.

3 Research tools

3.1 Fuzzy Logic

The Fuzzy logic was developed by Lofti Zadeh a professor from Berkeley University in California who did not agree with the unique existence of classical sets (crisp sets) [4, 5]. Fuzzy logic technology has the ability to handle lexical uncertainty with imprecision, it is very common in most human words used to evaluate concepts and to get conclusion compared to the conventional logic which works with well defined information; this is a methodology that gets a conclusion from poor, ambiguous or not precise information. In general the fuzzy takes decisions based on information with previously mentioned characteristics.

A basic principle of the fuzzy set is called membership relations it is something that cannot be determined easily. The fuzzy logic theory is based on the principle that the group is not always defined clearly, a classic example is the person height, and it can be classified as tall, medium or short.

Definition 3.1 (Fuzzy Set): A fuzzy set A on universe X is a set defined by the membership function $\mu_A(x)$ mapping from the universe X into the unit interval:

$$\mu_A(x) : X \rightarrow [0,1] \quad (1)$$

$f(x)$ Denotes the all fuzzy sets on X . If the value of the membership function, called the membership degree ($\mu_A(x)$), equals one, “ x ” belongs completely to the fuzzy set. If it equals zero, “ x ” does not belong to the set. If the membership degree is between 0 and 1, “ x ” is a partial member of the fuzzy set:

$$\begin{aligned} \mu_A(x) = 1 & \quad x \text{ is a full member of } A \\ \mu_A(x) = (0,1) & \quad x \text{ is a partial member of } A \\ \mu_A(x) = 0 & \quad x \text{ is not member of } A \end{aligned}$$

A fuzzy inference system has the capacity of processing numeric and linguistic variables, giving a numeric variable or linguistics as a result. (See **Fig. 2**).

The proceeding to build a fuzzy system is.

1. Inputs and outputs definition
2. Linguistic values definition associated to the input and output required
3. Membership function definition
4. Logical operators definition
5. Rules development and evaluation
6. Defuzzification of the system
7. System output

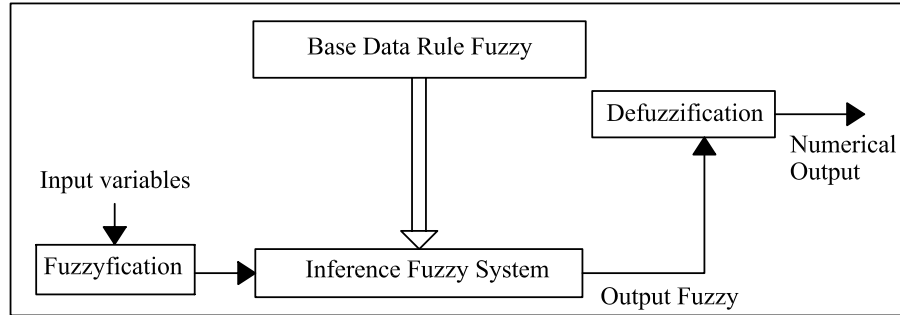


Fig. 2 Mandany Type Fuzzy evaluation process

The key point is to transform all the linguistic variables into numeric variables and process them by logical formulas or rules. The rule has the following structure type:

If (The weight piece is heavy)
And (the piece size is big) **and** (the handling method is two hands with tools)
Then (the assembly time is high).

3.2 Evolution Strategies

Evolution strategies (ES) were developed by Bienert, Rochenberg and Schwefell from the Technical University of Berlin, Germany in the 1960[14], it was inspired by the evolution that an individual can suffer and how he can be affected during the mutation and recombination processes of the ancestors genes. The evolution strategies are similar to the genetic algorithms (AG), but they have two main differences: In ES it is not necessary to code solutions, and the main operator is the mutation, while in AG is necessary to use codification and the main operator is the crossover.

There are several ES algorithms, some use recombination, another consider correlations between variables [2]. In the methodology it is used the most simple version of the algorithm, the ES without recombination. The algorithm is the following.

- 1) Generation of a population of μ parents
- 2) Generation of λ off springs from μ parents
- 3) Evaluation of off springs
- 4) Selection of the best μ off springs to be new parents.
- 5) Repeat (2), (3), and (4) until N generations reached

All the individuals (parents and off springs) have a mutation parameter that changes through time (self-adaptation). The generation of offspring is only by mutation according to:

$$O_i \leq O_{i+N(0,k)} \quad (2)$$

Where i indicates the parameter involved and $N(a,b)$ is a random number generator with normal distribution with mean and standard deviation b . Every mutation parameter k changes according to:

$$k_i \leq k_i * \exp(\tau * N(0,1) + \varphi * N(0,1)) \quad (3)$$

Where i indicate the parameter involved, $\tau = 1/\sqrt{2 * NT \text{ Pr}}$,
 $\varphi = 1/\sqrt{2 * \sqrt{NT \text{ Pr}}}$ and
 $NT = N(0,1)$ are used without change for all the parameters.

The evolutionary strategies algorithm with multimodal property uses a selection procedure where only similar individuals compete. The distance between the solutions vectors is calculated by the Euclidean distance. The solution promotes the population diversity.

4 Experimentation and Results

Three study cases were developed to analyze the performance of the Fuzzy-Evolutionary multimodal approach to predict and optimize the assembly time in a new product. In the first case the assembly time was predicted using fuzzy logic, in the second case using the same data base used in case 1 and the resultant assembly time as the output variable it was optimized by evolution strategies multimodal to find the conditions to get the best tree minimum assembly time. In the third case was added two restrictions design and the goal was detect the best three assembly time prediction.

4.1 Study Case 1: Assembly Time Calculations by Fuzzy Logic

The assembly time is classified in two categories, insertion time and handling time [1]. The fuzzy logic method is used for manipulating the characteristic fuzziness of insertion and handling difficulty problems. In this research we will focus on time handling estimation,

Using the assembly people's experience of a local company, it was possible to develop a database. Different ranges were established for each variable, according to the assembly features of a product. (See **Table 2**). The codification used for the "symmetry variable", "assembly methods" and accessibility were in a range between 0 through 1. The variable that has the highest value between zero and one could correspond to the one having the most critics, the heaviest or the most difficult accessibil-

ity. In the assembly time the ranges were: Lowest time 10-25 min, normal time 15-35 min and the highest time upper 35 minutes.

Table 2. Data base, showing ranges for each variable used in this research, according to assembly features of a product.

Definition of linguistic variables

Weight	Normal	0-2 kgs
	Heavy	0.75-3.25 kgs
	Very heavy	2-4 kgs
Part size	Small	0-7 cms
	Medium	2-12 cms
	Large	7-17 cms
	Very Large	17-25 cms
Part symmetry	Complete	0 - 0.3
	Symmetric	0.1 - 0.5
	Symmetry acceptable	0.3 – 0.7
	Asymmetric	0.5 - 1
Handling_methods	One_hand/without_tools	0 - 0.3
	Two_hands / without_tools	0.1 - 0.5
	One_hand/with_tools	0.3 – 0.8
	Two_hands / without_tools	0.5 - 1
Easy to reach	Far	0 - 0.5
	Medium	0.2 - 0.8
	near	0.5 - 1
Time	Low time	10 – 25 min
	Medium time	15 – 35 min
	High time	over 35 min

It was very important to decide the appropriate membership functions for each linguistic variable that should be used in the research. Several researches have suggested many advanced types of memberships functions for linguistic variables [3, 4], in this paper, we decide to use the following types of membership functions: Trapezoidal-type and Triangular-type, the defuzzification method used in this research was the center of maximum (CoM). See **Fig. 3**.

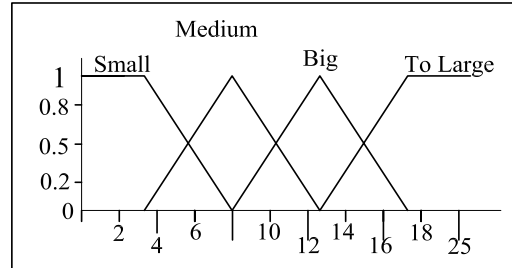


Fig. 3 Belonging degrees of dimension variable Inference rule based on experience

Based on this information, different simulations with different conditions were done for all variables. In the Fuzzy Logic system was possible to calculate the assembling time in a fast and precise way without looking up information from tables /charts as it is suggested in the methodology proposed by Boothroy [1].(See results **table 3**).

Table 3. Results of study case No.1 to estimate the assembly time.

Weight	2 Kgs.
Dimensions	25 cms
Part symmetry	acceptable
Handling Methods	One hand /with tools
Easy to reach	Medium
Easy to insert	Medium
Total assembly time	25.4 seg.

By fuzzy logic is possible predict the assembly time and can be usefully adapted to different companies.

4.2 Study Case 2: Optimizing the Assembly Time by Fuzzy-Evolutionary Multimodal approach

To get a minimum assembly time, suitable conditions are required. The ES algorithm searches the best input value that maximizes or minimizes the assembly estimated time. To develop the second study case was used the same fuzzy data base, the target now was to find the three different inputs combinations that will produce the best minimum assembly time. The output of the fuzzy logic system was optimize by evolutionary multimodal getting the tree best options that produce the best minimum assembly time, was used the Euclidian distance to find the near neighbor. The results are shown at **Table 4**.

Table 4 Results of study case No.2 shows the minimums assembly times

Weight	3.87 Kgs.	3.84 Kgs.	2.51 Kgs.
Dimensions	3.41 cms	7.38 cms	9.36 cms
Part symmetry	asymmetry acceptable	asymmetry	asymmetry acceptable
Handling Methods	Two hand /with tools	Two hand /with tools	One hand with tools
Easy to reach	Near	Medium	Medium
Easy to insert	Easy	Medium	Medium
Total assembly time	7.62 seg.	8.47 seg.	9.28 seg.

With this information is possible have three alternatives to design the part according our convenience, so with this characteristic we assure a minimum assembly time

4.3 Study Case 3

To develop the third study we continue using the same data base the difference now was that the input variables has two constrains of design, the dimension part must have a size between 8 and 20 centimeters and the weight should be between 2 and 3 Kilograms, the results are shown at **Table 5**.

Table 5 Results of study case No.3. The target was to find the inputs variables that produce the best minimum assembly time, according to the constrains and could have three possible alternatives to design the part.

Weight	2.95 Kgs.	2.0 Kgs.	2.59 Kgs.
Dimensions	8 cms	17.2 cms	15.3 cms
Part symmetry	asymmetry acceptable	asymmetry	asymmetry acceptable
Handling Methods	Two hands /with tools	Two hands /with tools	One hand with tools
Easy to reach	Medium	Medium	Medium
Easy to insert	Easy	Medium	Medium
Total assembly time	8.42 seg.	9.0 seg.	9.5 seg.

So it is preferable the parts with this characteristic because its variables assure a minimum assembly time. This Fuzzy-Evolutionary Multimodal approach can easily used to optimize the assembly time product and it can be adapted to different industrial situations.

5 Conclusions

1. We have shown how fuzzy logic can help to predict the assembly time and how it could be used as a complementary technique to design for assembly methodology (DFA). The following are the main advantages and disadvantages found when developing the fuzzy logic system.

Advantages of the fuzzy system

- It is easy to incorporate qualitative linguistic information.
- It is a robust system because in absence of a rule, it will be replaced by others.

Disadvantages of the fuzzy system

- If the entrances to the system are increased, the rules are increased.
- Hard to integrated quantitative knowledge to a function.

2. The research showed the advantages of using a Fuzzy-Evolution Multimodal approach to analyze the variables behavior to predict, control and optimize the assembly time in a new product. With this hybrid method is possible to find the input variables that produce the best minimum and worst assembly time. It is very important to find the conditions that a piece must have in order to achieve reduced assembly time. With this methodology these conditions can be easily found.

Finally, It is possible conclude that the Fuzzy-Evolutionary Strategies method is a suitable methodology to predict and optimize the assembly time of new products.

6 Future Work

It is convenient to keep on working in techniques to supplement these methodologies, analyze different evolutionary algorithms. To continue improving results is possible and recommendable to integrate evolutionary multiobjective algorithms.

To improve the Fuzzy-Evolutionary Multimodal approach, will be increasing the data base rules is necessary to get new rules to improve the performance of the methodology. The use of type II fuzzy systems can get a better performance of the proposed system because it can consider uncertain and tolerances of the assembly components.

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