Taxonomy of GUM and Usability Prediction Using GUM Multistage Fuzzy Expert System

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Abstract: *The evaluation of quality of software is an important aspect for controlling, managing so that we can be able to enhance the improvement in a software process. For such evaluation, many factors have been identified by a number of researchers. The quality of software is further dependent on many other factors. Usability of software is one of the most significant aspect on which quality of software is dependent. Many researchers proposed a number of software usability models, each model considering a set of usability factors but these models do not include all the usability aspects and it is hard to integrate these models into current software engineering practices. As far as real world is concerned, we are facing many obstacles in implementing any of these proposed models as there is a lack in its precise definition and the concept of globally accepted usability. This paper aims to define the term 'usability' using the Generalized Usability Model (GUM). GUM is proposed with detailed taxonomy for specifying and identifying the quality components, which brings together factors, attributes and characteristics defined in various Human Computer Interaction (HCI) and Software Models. This paper also shows how to predict the usability of a software application using a fuzzy based expert system which has been implemented using multistage fuzzy logic toolbox.*

Keywords: *Quality of software, usability, factors, GUM, evaluation, fuzzy logic, soft computing.*

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1. Introduction

Over the few decades the software engineering practices have been changing to produce good quality software products. According to International Standard Organization (ISO) [10] there have been different quality factors like efficiency, effectiveness, reliability, usability etc. Usability is a significant quality factor that has to be considered during software development. The term usability is derived from user friendly. Many software engineering experts defines usability in their own term. Usability can be defined as an extent to which a product can be used by a specific group of users to achieve the specified usability goals like effectiveness, efficiency and satisfaction. The degree of satisfaction will vary from one user to another. There are various standard which defines the term usability as follows:

a) The ISO/IEC 9126 defines the usability in terms of the effort needed for use [8].
b) The ISO/IEC 9126 again redefines the definition of usability as capability of the software to be understood by user under certain conditions.
c) The ISO 9241-11 defines usability in terms of efficiency, effectiveness, and effectiveness in a specified context of use [10].
d) The IEEE Std.610.12-1990 defines usability in terms of learnability, Input and output efficiency of system [9].

Usability may be different for different software products; it changes from one perception to another perception. The degree of usability will depend on several factors such as:

- Ease of use.
- Effectiveness of use.
- Subjective satisfaction.
- Knowledge and Experience of user to use the software.

Evaluation of usability of the software's are significant for controlling, managing so that we can be able to enhance the improvement in the software development process. This paper aims to define the term 'usability' using the proposed usability model with detailed taxonomy which includes all the aspects of usability and is globally accepted.

2. The Proposed Model

In [1, 2, 3, 4, 5, 6, 7, 13, 14, 15, 16, 17, 18, 19] we have seen and studied a large number of international standards and usability models which describe usability but with different attributes in non-homogeneous manner creating confusion among experts for its usage and application. This inconsistent approach among usability model is creating major challenge for evaluation of usability of application. This research theme requires a hierarchical based usability model which should be consolidated to incorporate consistency in usability. Hence, usability model would be generic so that developers can measure usability without any confusion.

This section proposes a consolidated, hierarchical usability models named Generalized Usability Model (GUM) with detailed taxonomy. This model can easily measure the usability of the software product. Specifically, the new model combines' usability factors, attributes, characteristics and data mentioned in various models or standards for software product quality and explain them and their relations in a consistent way.

Usability is a quality factor that assesses how easy user interfaces is to use. The word 'usability' also refers to methods for improving ease-of-use during the design process. Usability is defined by GUM proposed model using the following 7 quality factors:

1. Efficiency, it is a measure of software product that enables user to produce desired results with respect to investment of resources.
2. Effectiveness, it is a measure of software product with which user can accomplish specified tasks and desired results with completeness and certainty.
3. Satisfaction, it is a measure of responses, feelings of user when users are using the software i.e., freedom from discomfort, likeability.
4. Memorability, it is defined as the property of software product that enables the user to understand with clarity, learn, and remember the elements after a period of time.
5. Security, it is defined as the degree to which risks and damages to people or other resources i.e., hardware and software can be avoided.
6. Universality, it reflects the accommodation of different cultural backgrounds of diverse users with software product and practical utility of software product.
7. Productivity: it is defined as the amount of useful output with the software product.

GUM consists of the seven factors representing a specific facet of usability; these factors are decomposed into a total of twenty three attributes, which are further divided into 42 characteristics. The factors, attributes and the characteristics are related to each other in a hierarchical manner. The 7 factors of GUM proposed model include efficiency, satisfaction, effectiveness, memorability, productivity, security, and universality. based on these factors, the 23 attributes are quantifiable, which consist of either a fuzzy rule or countable data. The relationship between the factors and their attributes is depicted in Table 1 and taxonomy of GUM is depicted in Table 2.

Table 1. Relationship between GUM factors and their attributes.

	Factors						
Attributes	**Efficiency**	**Effectiveness**	**Satisfaction**	**Memorability**	**Security**	**Universality**	**Productivity**
Resource	+						
Time	+						
User effort	+						
Economic costs	+						
Likeability/ Attractiveness			+				
Convenience			+				
Aesthetics			+				
Task accomplishment		+					
Operability		+					
Extensibility		+					
Reusability		+					
Scalability		+					
Approachability						+	
Utility						+	
Faithfulness						+	
Cultural universality						+	
Useful User Task output							+
Learnability				+			
Memorability of Structure/ Elements/ Functionality				+			
Comprehensibility				+			
Consistency in Structure/ Of Elements/ Of Functionality				+			
safety					+		
Error Tolerance					+		

*In Table 1 '+' shows the collection of attributes for a factor.

3. Fuzzy Expert System Methodology

The concept of fuzzy logic was introduced in 1970s by a professor at University of California, Berkley named Lotfi Zadeh, and it is introduced as a way of processing data by allowing partial set membership. The fuzzy logic Toolbox in MATLAB acts as a tool for solving problems with fuzzy logic thus generating a system call fuzzy expert system. Fuzzy expert system uses fuzzy inference, fuzzy data, and fuzzy rules. The Fuzzy Inference Systems (FIS) are very important tools as they hold the non-linear universal approximation [11]. Fuzzy expert system uses Fuzzy inference systems and fuzzy rules to express human expert knowledge and experience which can be represented in "if-then" statements. Following the fuzzy inference mechanism, the output can be a fuzzy set of certain features [12]. There are different types of fuzzy systems are introduced i.e., Mamdani fuzzy systems and TSK fuzzy systems. To design fuzzy expert system for predicting usability, the Mamdani fuzzy systems will be utilized due to the fact that the fuzzy rules representing the expert knowledge in Mamdani fuzzy systems and it take advantage of fuzzy sets in their consequences [20].

The general process of constructing such a fuzzy expert system from initial model design to system evaluation is shown in Figure 1.

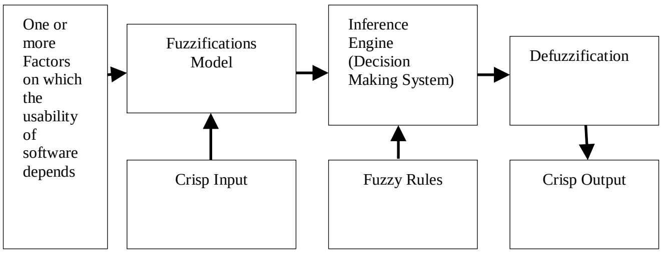

Figure 1. Fuzzy inference system.

Table 2. Taxonomy of GUM.

Factors	Attributes	Characteristics
Efficiency	Resource	Utilization, Expansion, Command utilization, Throughput, Consumption of resource.
	Time	Response time, Time spend on errors, Memory load, Perform actions by users.
	Economic cost	System cost, Human resource cost, Cost of equipment, Cost of consumables.
	Documentation	-
	User Effort	Physical, Mental.
Effectiveness	Task accomplishment	Quality, Quantity.
	Operability	Accuracy, Integrity.
	Extensibility	Conformability, Controllability.
	Reusability	-
	Scalability	-
Satisfaction	Likeability	Interest
	Convenience	Design, Use of product.
	Aesthetics	-
Memorability	Learnability	Simplicity, Learning time.
	Memorability of structures	-
	Comprehensibility	Clarity
	Consistency in structures	-
Security	Safety	User safety, Third party safety, Environment safety.
	Error tolerance	-
Universality	Approachability	Visual, Vocal, Motor, Auditory.
	Utility	User guidance, Interactivity of assistance, Stability of documentation.
	Faithfulness	Stability, Reputation, Intention.
	Cultural universality	Language, Cultural conventions.
Productivity	Useful user task output	-

4. The Proposed Fuzzy Expert System

The following steps are followed to design a multistage fuzzy expert system which helps in predicting the usability of a software application:

- *Step* 1: Identify the Inputs and Outputs for the expert system for each model.
- *Step* 2: Divide the Inputs into two categories i.e., software related and user related inputs.
- *Step* 3: Decompose the inputs from each category, such that total rules will be minimized.
- *Step* 4: Define the range of each input and output based on domain expert.
- *Step* 5: Select a membership functions and create fuzzy partition for each input and output.
- *Step* 6: Specifying the rules for making the relations clear between Inputs and outputs by experts.
- *Step* 7: Combine the rules and defuzzify them to get output

5. Implementation of The Proposed Fuzzy Expert System

- *Step* 1: Inputs**:** Effectiveness (EF), Efficiency (E),Security (S), Universality (U), Productivity (P),Memorability (M), Satisfaction (SA) Output**:** Usability (US) We can write it in the short form notation as US=[EF E S U P M SA].
- *Step* 2: If the usability factors which involved in the GUM model are considered, it could be seen that the usability factors such as effectiveness, security, universality, productivity are related to the ability of the software to inspire the user to perform the task correctly. On the other hand, efficiency, satisfaction and memorability characteristics reflect the end user's ability to perform the task. With this understanding, the usability factors in the proposed model can be grouped as in Table 3.

Table 3. Grouping of factors.

Group	Critical Factors
Software Related	EF, S, U, and P
End User Related	E, M, and SA

- *Step* 3: GUM model considers all the inputs (the usability factors) together, so that will lead generating too many rules and additionally it will be difficult for the experts to consider all formulates rules with proper emphasis, since each input parameter has three linguistic values (Low, Medium and High). Hence, the GUM with seven usability factors will have a maximum number of 3^7 =2187 rules. This means, the Matlab-Fuzzy Tool Box isn't applicable, since the number of inputs is limited to two in the Matlab [12]. Therefore, we had decomposed the factors into sub categories just to minimize a Hugh number of rules. Total six Fuzzy Interface System (FIS) namely sub-us-1, sub-us-2, soft-us, sub-us-3, end-user, and US have been created in Matlab using a Fuzzy Logic toolbox [11]. Consequently, input/output variables, their membership functions, and fuzzy control rules have also been created for each FIS. Table 4. shows an example of FIS.

Table 4. Decomposing Inputs a outputs to minimize the total rules.

FIS	Inputs	Output
FIS-1	EF, U	Sub-us-1
FIS-2	S, P	Sub-us-2
FIS-3	E, M	Sub-us-3
FIS-4	Sub-us-1, sub-us-2	Soft-us
FIS-5	Sub-us-3, SA	End-user
FIS-6	Soft-us, End-user	US

- *Step* 4: defining universe of Discourse and fuzzification of usability characteristics.

Each of the seven usability factors have been given a Universe Of Discourse (UOD) of range [0-9] and have been fuzzified with three linguistic values (fuzzy sub set: Low, Medium, and High) using linear triangular membership functions [11]. On the other hand, in order to achieve more accurate output, all the fuzzified output parameters have been fuzzified with four linguistic values (fuzzy sub set: Low, Medium, High, and Very High). Figures 2, 3, and 4 shows examples of fuzzified input and output parameters.

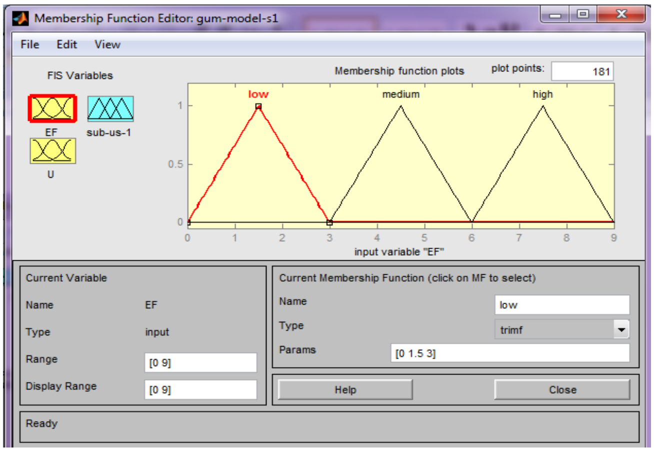

Figure 2. Fuzzified input parameter- EF.

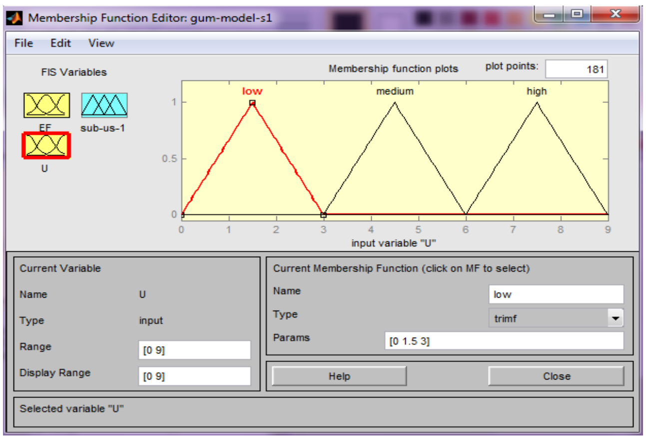

Figure 3. Fuzzified input parameter-U.

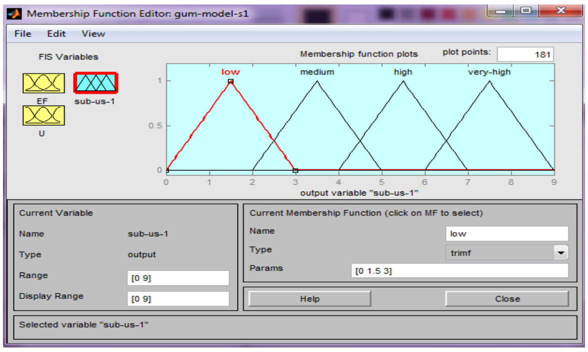

Figure 4. Fuzzified output parameter-sub-us-1.

- *Step* 5: GUM model consists of total six (6) Fuzzy Interface System (FIS). The first FIS between the the factors EF and U is shown in Figure 5.

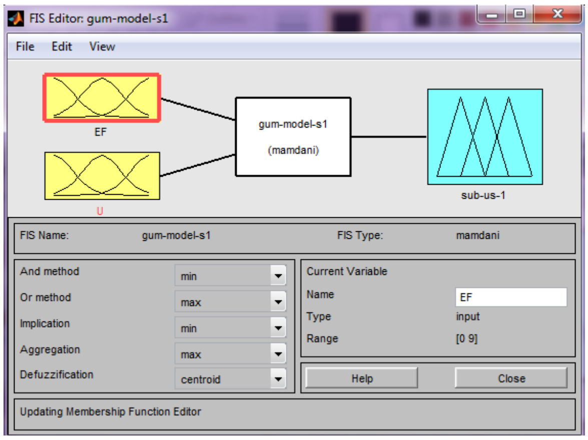

Figure 5. FIS of EF and U.

- *Step* 6: The fuzzy control rules of first fuzzy interface system FIS (sub-us-1) have been defined as follows:

EF and U are the fuzzy input variables and sub-us-1 is the fuzzy output variable. Fuzzy linguistic values of input/output variables are set as [Low, medium, high, or very high]. The fuzzy control rules have been defined based on the opinions of academicians, researchers, and GUM developers. Figure 6 shows the fuzzy control rules of FIS1 using rule viewer.

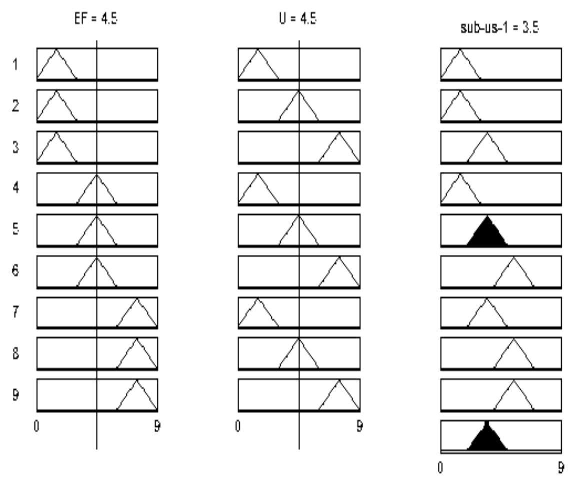

Figure 6. Rule viewer for First FIS (sub-us-1).

As seen from the above Figure, this FIS includes total 9 rules. For all combinations usability is either classified as Low, Medium, or high. The rules of sub-us-2 and sub-us-3 FIS had been defined in the same way. Regarding, soft-us and end-user FIS that is an intermediate stages fuzzy controller, output variables (sub-us-1 and sub-us-2) of sub-us-1 and sub-us-2 FIS respectively, are taken as input variables and soft-us is an output variable. Similarly output variables (sub-us-3) of sub-us-3 FIS and SA are taken as input variables and end-user is an output variable. The fuzzy linguistic values of output variables are again at [Low, Medium, High, and Very High]. Figure 7 shows fuzzy control rules of this FIS. These rules are also defined based on the opinion of academicians, researchers, and software developers.

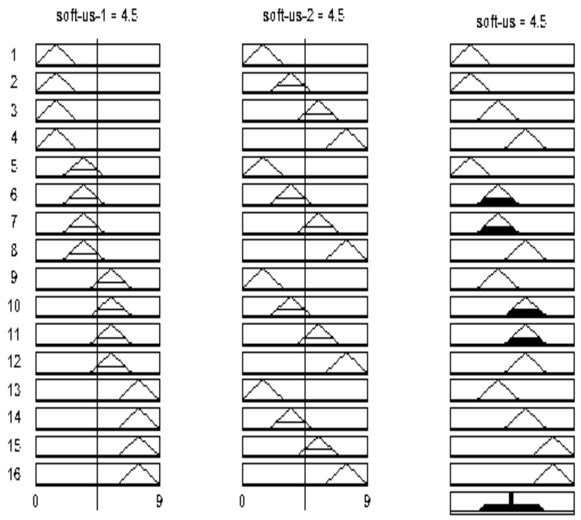

Figure 7. Rule viewer for First FIS (soft-us).

US FIS is the final stage fuzzy controller. The output variables of soft-us and end-user FIS are taken as an input variables and US is an output variable. Fuzzy linguistic values of output variables are at [Low, Medium, High, and Very High]. Figure 8 shows fuzzy control rule viewer. These rules are also defined based on the experience of academicians, researchers, and software developers.

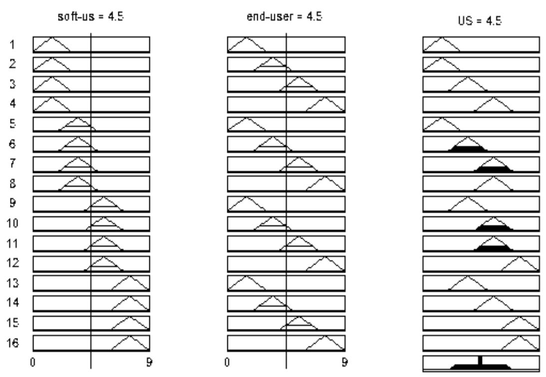

Figure 8. Rule viewer for first FIS (US).

- *Step* 7: In this step, Matlab Simulink software (Fuzzy Logic Toolbox) has been employed, in order to develop an approach model for proposed stage wise fuzzy reasoning. This model connects sub-us-1, sub-us-2, sub-us-3, soft-us, end-user, and US. Figure 9 shows a fully functional the fuzzy logic model.

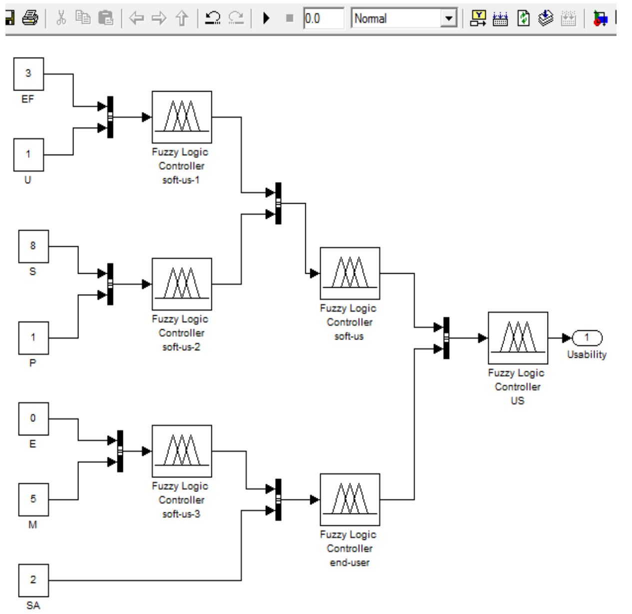

Figure 9. Fuzzy approach model of gum usability.

6. Analysis of Proposed Expert System

The data set in Figure 10 is generated on the basis of the result of questionnaire given to 10 people, who are pursuing their graduation. Each participant is given 5 set of questionnaire consisting of 42 questions. Each set is for the specified software application. All these 42 questions are based on the characteristics of the software application. The result of the questionnaire is used to generate the values of all the 7 factors of GUM model. The values of the 7 factors based on the inputs received by the participants are given in Figure 10.

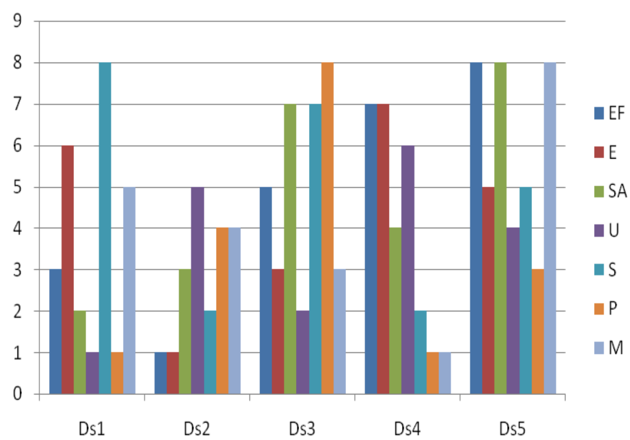

Figure 10. Data set.

Each DataSet values are applied as an input to GUM model for simulation as shown in step 7) of the proposed fuzzy expert system and the result produced is shown in Figure 11.

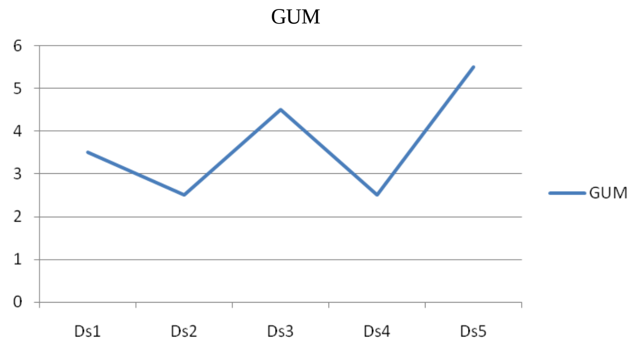

Figure 11.Usabiltiy of the data set (DS1-DS5).

As seen in the Figure 11, for the GUM model, the usability decreases when any of the given attribute is either missing or having low value.

7. Conclusions

In this paper, we have discussed the term 'usability' which is defined by various researchers, ISO and IEEE standards. Then we suggest a consolidated, hierarchical usability models GUM with detailed taxonomy for specifying and identifying the quality components and measuring usability. Our model can easily measure the usability of the software product by integrating 7 factors, 23 attributes, 42 characteristics and data mentioned in various models for software product quality and explain them and their relations in a consistent way.

We would like to highlight that main goal of developing GUM, is to keep it as easy, simple and understandable as possible. To achieve this significant goal, we have developed GUM expert system. This expert system is implementation using multistage fuzzy logic toolbox and simulink available in matlab. The inputs of this proposed model consist of seven usability factors and it generated the total usability of the application under test (Figure 9). Our analysis of existing models conducted us to the validation and definition of 7 factors, 23 attributes of GUM expert system.

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