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AN INTELLIGENT SYSTEM BASED ON ANALYTIC HIERARCHY PROCESS AND FUZZY LOGIC APPLIED TO EVALUATE THE SOFTWARE QUALITY OF SMARTPHONE

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Abstract

According to the analysis report of IDC, there were 82.44 million smartphones that had been shipped worldwide in 2006, and the shipments of smartphone reached more than a hundred million in 2007. Various functions such as e-mail, Bluetooth, camera, Wi-Fi and GPS are embedded into smartphone. It is important to evaluate the software quality for these functions so that the decision makers can determine

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whether the smartphone can be shipped or not. In this paper, an intelligent system based on analytic hierarchy process (AHP) and fuzzy logic is applied to evaluate the software quality of smartphone. In the proposed intelligent system, the software quality of smartphone is performed to fit the characteristics of ISO/IEC 9126. Furthermore, AHP is used to evaluate the importance of each factor categorized from ISO/IEC 9126. After obtaining the weights of characteristics, the fuzzy logic with linear output membership functions is performed to decide the software quality of smartphone.

1. Introduction

The smartphone is a mobile phone with advanced capabilities, and there has been a greater awareness of the importance of software quality management in manufacturing [6, 9]. According to IEEE 610.12, software quality is defined as follows. (1) The degrees of system, component or procedure comply with required demand. (2) The degree of system, component or procedure complies with user or customer expected demand [7]. However, Pressman [18] defined software quality as follows. (1) The accordance degree of distinct described function and efficiency demand. (2) The accordance degree of develop standard stated in distinct described documents. (3) Fulfill professional developers' expectation for not distinct defined characteristics [18]. Hoyer and Hoyer [5] claimed that software quality should comply with product specification and meet user requirements [5]. From above viewpoints, software quality should comply with the demanded functions, user's satisfaction, efficiency and standard.

Software quality evolution model can be mainly divided into two approaches [17]. One is process management. It setups the specification and standard for system design, procedure design, coding, testing, verification, operation and maintenance. Additionally, it improves item by item and then reaches the optimal quality. The other is to evaluate the software quality. It analyzes the software quality of product and establishes software quality model. In this paper, we focus to evaluate the software quality of smartphone. To evaluate the software quality, McCall quality model, Boehm model and ISO/IEC 9126 are three well-known models [2, 8, 15]. The software quality model proposed by McCall et al. in [15] defined factors of software quality including three sectors of product operation, product fix and product shift. These three sectors contain eleven factors [8]. Each factor includes several quality criteria, and every quality criterion is correlative with many factors. Boehm's model is similar to the McCall quality model and includes customers' expectations and requirements. Furthermore, Boehm's model discusses about hardware performance which is not mentioned in McCall model. Boehm's model also utilizes hierarchical structure to explain software validity and to separate it into three characteristics of portability, usability and maintainability [15]. For ISO 9126, it is an international standard. It puts emphasis on the hierarchy process which describes software quality into two parts. (1) External and internal quality. (2) Usability quality. For the external and internal quality, it includes six main characteristics and several sub-characteristics (factors) [2]. The internal and external software quality characteristics of ISO 9126 are shown in Figure 1. The main difference among ISO 9126, McCall and Boehm is that ISO 9126 has a distinctive hierarchical structure. Each sub-characteristic is related to the main characteristic. This implies that each sub-characteristic will only impact on one main characteristic and will not affect others. As a result, it is easy to perform AHP to clarify the characteristics and factors which will affect software quality of smartphone. After analyzing the characteristics and factors for software quality of smartphone, it is still important to judge the severity of software flaws and then can help product developers to efficiently improve software management. Recently, fuzzy logic introduced by Zadeh has the ability to express the amount of ambiguity for decision-making [13]. It can convert the experience into expert knowledge and reduce the subjective influence of expert knowledge [4]. In this paper, an intelligent system based on AHP and fuzzy logic is applied to evaluate the software quality of smartphone.

This paper is organized as follows. The proposed intelligent system uses AHP and fuzzy logic to evaluate the software quality of smartphone. The general idea of AHP and fuzzy logic is introduced in Section 2. In Section 3, the proposed intelligent system is discussed in detail. Results and discussions will be demonstrated in Section 4. Finally, in Section 5, we conclude remarks.

2. The Basics of Analytic Hierarchy Process and Fuzzy Logic

AHP and fuzzy logic play an important role in the proposed intelligent system for evaluating the software quality of smartphone. In this section, the basics of AHP and fuzzy logic are briefly introduced.

2.1. The introduction of AHP

AHP, developed by Saaty in 1970, is a multi-criteria decision-making (MCDM) method applied in many fields such as evaluation, planning, decision-making, and so on [12, 19-21]. AHP can rank the importance of decision factors and model a complex problem into a hierarchical structure. It contains of four steps, decomposition, comparative judgment, priority synthesis and consistency [12, 19, 20]. In decomposition, it uses top-to-down procedures to construct the hierarchical structure. The top level (root) represents the overall objective, and the lowest level (leaf) represents decision factors. Comparative judgment uses pairwise matrix to help decision-makers to judge the weights of decision factors. For priority synthesis, it first computes the weight of each decision factor and then the relative priority can be evaluated. Finally, the consistency ratio (CR) is performed to check the consistency. It is considered adequate to accept the results when the value of CR is less than 0.1 [19, 20].

2.2. The introduction of fuzzy logic

Fuzzy logic is a marvelous way to map an input space to an output space and has advantages of excellent capability to deal with complex systems [1, 3, 10, 11, 24]. Typically, fuzzy logic consists of four parts, a fuzzification interface, a knowledge base, an inference engine and a defuzzification interface. It is to take the inputs into membership functions of considered fuzzy sets in the fuzzification interface. In knowledge base, it consists of a number of fuzzy if-then rules characterizing the system behavior. In inference engine, it performs fuzzy reasoning upon fuzzy rules. Finally, it transforms the output of fuzzy inference into a non-fuzzy (crisp) value as a real output in the defuzzification interface. The Sugeno-type fuzzy method is one of the most efficient fuzzy logics in which output membership functions are either linear or constant [22, 23], and its rules can be expressed as Equation (1).

$$R^i : \text{If } x_1 \text{ is } M_1^i \text{ and } x_2 \text{ is } M_2^i, ..., x_m \text{ is } M_m^i$$

$$\text{then } y^i = a_0^i + a_1^i x_1 + \cdots + a_m^i x_m, \quad (1)$$

where R^i $(i = 1, 2, ..., k)$ is the ith fuzzy rule, x_j $(j = 1, 2, ..., m)$ is the input, M_j^i is the fuzzy set of the ith rule for x_j, y^i is the output of the fuzzy rule R^i, and $a_0^i, a_1^i, ..., a_m^i$ is the parameter set in the consequent parts. The final output of the fuzzy logic is the weighted average of all rule outputs, computed as Equation (2).

$$\hat{y} = \frac{\sum_{i=1}^{k} y^i w^i}{\sum_{i=1}^{k} w^i}, \quad (2)$$

where w^i is the ith rule's firing strength. In the proposed intelligent system, the parameter set in the consequent parts can be expressed as the weight of characteristic obtained from AHP. Decision makers can use the value of output to evaluate the software quality of smartphone.

3. The Proposed Intelligent System

In the proposed intelligent system, AHP is used to compute the weights of characteristics and factors for the software quality of smartphone. In this study, four senior software quality engineers are invited to join this research from H Company. H Company, in Taiwan, produced about 9.6 million smartphones in 2007. Its sale area includes North America, South America, European, Asia, Australia and Mid-Eastern. First, we listed all the characteristics and factors for software quality of smartphone into questionnaire and discussed with four experts until all of the experts' opinions had been narrowed down. Then, all the characteristics and factors were fitted into the software quality model of ISO 9126.

The structure for software quality of smartphone is shown in Figure 2. In Figure 2, the software quality of smartphone can be measured as functionality, reliability, usability, efficiency, maintainability, and portability. Functionality contains of eight factors. (1) Conformance with specification. (2) Accuracy of system setting. (3) Interoperability with various platforms. (4) Compliance with specified certification. (5) Data survivability and security. (6) Accuracy of radio telecommunication. (7) Bluetooth and wireless network (WLAN) connectivity. (8) System compatibility. Reliability includes seven factors. (1) Reliability of transmission. (2) Reliability of system operation. (3) Reliability of radio. (4) System fault tolerance. (5) Recoverability with system errors. (6) Mean time to failure (MTTF). (7) Battery Life. Usability includes seven factors. (1) Operation and understandability. (2) Consistence of user interface. (3) System auto-configuration. (4) Detailed user guide and help files. (5) Sound quality. (6) Detailed warning message. (7) Design of man-machine interface. Efficiency has seven factors. (1) System efficiency. (2) Efficiency of transmission. (3) Efficiency of data access. (4) Display performance. (5) Multitask performance. (6) Resource consumption. (7) Virtual memory allocation. Maintainability contains of six factors. (1) NO side effect after modification. (2) Analyzability with exception. (3) Resolvability with system defects. (4) Changeability with new requirement. (5) Testability and verifiability. (6) Modularized architecture. Six factors are included in portability. (1) Adaptability with hardware. (2) Replace ability with new operating system (OS). (3) Radio portability with specified system. (4) Install ability with new OS. (5) Conformance with standard. (6) Program optimization. A questionnaire research had been done in the H Company by sending e-mail to product assurance engineers and asking them to fill it in the internet. 50 e-mails were sent and 31 questionnaires were received in this study. Based on AHP, a pairwise matrix for software quality of characteristics and factors was established and then the eigenvalues were calculated in each level. The questionnaire was posted in ASP webpage located in IIS and SQL server. For the purpose of authentically understanding of each question in questionnaire, user could read the detail explanation of every item via hyperlink. The consistency index (CI) and consistency ratio (CR) were verified in each questionnaire. Some questionnaires were eliminated since the values of CR were too high. Thereafter, only 25 questionnaires were obtained because their values of CR were smaller than 0.1. By above procedures, the weights of functionality, reliability, usability, efficiency, maintainability, and portability can be computed by AHP. Additionally, these weights can be applied to fuzzy logic for constructing the intelligent system.

After obtaining the weights of characteristics and factors from AHP, fuzzy logic is performed. In this paper, the Sugeno-type fuzzy method is adopted from MATLAB and illustrated in Figure 3. This model consists of membership functions, if-then rules, defuzzification and inference system [16]. The linguistic values of inputs are {BAD, NORMAL, GOOD}, and the output is described as {WORSE, BAD, FAIR, EXCELLENT, PERFECT}. In this model, Gaussian curve is used as membership function. The membership functions of inputs are shown in Figure 4. The fuzzy rules are listed in Figure 5. Finally, the output of defuzzification computed from Equation (2) is used to evaluate the software quality of smartphone. In this paper, a threshold value of output is set to judge the performance for the software quality of smartphone.

4. Results and Discussions

The results of AHP research are showed in Tables 1 and 7. The weights of functionality, reliability, usability, efficiency, maintainability and portability obtained from AHP are tabulated in Table 1. In Table 1, reliability (0.25) has the highest weight and functionality (0.116) has the lowest weight. It shows that most product assurance engineers take care of stability of system and speed of operation. For functionality, they only ask for meeting the basic demand. In Table 2, the weight for the factor of data survivability and security (0.235) and the factor of accuracy of radio communication (0.211) outweigh other factors. The above two factors are the most demanded while conformability with specification (0.05) is the most neglected. For reliability, two important weights are the factor of transmission reliability (0.226) and operation reliability (0.194). Because smartphone combines mobile telecommunication and functions, it is important to care about the factors of transmission reliability and operation stability. From the perspective of usability, the weight for the factor of sound quality (0.319) and the factor of operability and understandability (0.144) are two important factors, because smartphone has various levels of usages. Two factors, virtual memory allocation

(0.203) and resource consumption (0.191), have the highest weights in efficiency. Due to the limitation of smartphone size, structure and battery can not be extended as general computer. Therefore, it is important to manage virtual memory and system resources. For maintainability, the factor of no side effect after modification (0.256) has the highest weight. When developing and maintaining software, software engineers shall examine modified parts and whole structure to reach optimal quality. Any occurrence of side effect will result in difficulty of evaluating software quality. For portability, the factor of program optimization (0.259) has the highest weight and it also complies with the basic software engineering requirement [24]. Thereafter, the Sugeno-type fuzzy method is performed to the process of formulating the mapping from the characteristics of functionality (x_1), reliability (x_2), usability (x_3), efficiency (x_4), maintainability (x_5) and portability (x_6) to an output. The output is described as {WORSE, BAD, FAIR, EXCELLENT, PERFECT}, where

$$\text{PERFECT} = 0.9 + 0.116x_1 + 0.25x_2 + 0.17x_3 + 0.21x_4 + 0.129x_5 + 0.125x_6$$

$$\text{EXCELLENT} = 0.7 + 0.116x_1 + 0.25x_2 + 0.17x_3 + 0.21x_4 + 0.129x_5 + 0.125x_6$$

$$\text{FAIR} = 0.5 + 0.116x_1 + 0.25x_2 + 0.17x_3 + 0.21x_4 + 0.129x_5 + 0.125x_6$$

$$\text{BAD} = 0.3 + 0.116x_1 + 0.25x_2 + 0.17x_3 + 0.21x_4 + 0.129x_5 + 0.125x_6$$

$$\text{WORSE} = 0.1 + 0.116x_1 + 0.25x_2 + 0.17x_3 + 0.21x_4 + 0.129x_5 + 0.125.$$

This output provides a basis for the decision makers to judge the software quality of smartphone. The fuzzy inference system is shown in Figure 6. The output ranges from 0 to 10. The value of software quality is 5.09 when all values of six characteristics are set as 0.5, and the software quality of smartphone is acceptable when the values of output are greater than 6.0 obtained from heuristics.

5. Conclusions

Quality is the life of product as decision is the core of management. Because enterprise usually rushes to market for obtaining more business opportunities, it will bring troubles in quality control and decision-making. It is important to analyze the weights of characteristics and factors to provide the basis of software quality of smartphone for quality management, improvement and decision-making. In this study, the most important characteristic of smartphone quality is reliability. Therefore, mobile company should focus on quality control of system operation and radio reliability. The data survivability and security, sound quality, virtual memory allocation, no side effect after modification are also significant factors for other characteristics. It is easy and attractive for decision makers to use the proposed intelligent system to evaluate the software quality of smartphone. In future work, decision makers may add more fuzzy sets and extend the rule bases according to their requirements.

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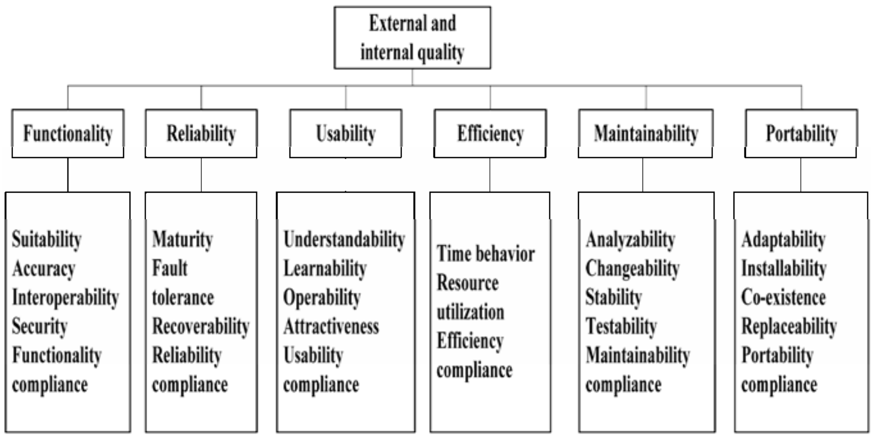

Figure 1. The internal and external software quality characteristics of ISO 9126 [8].

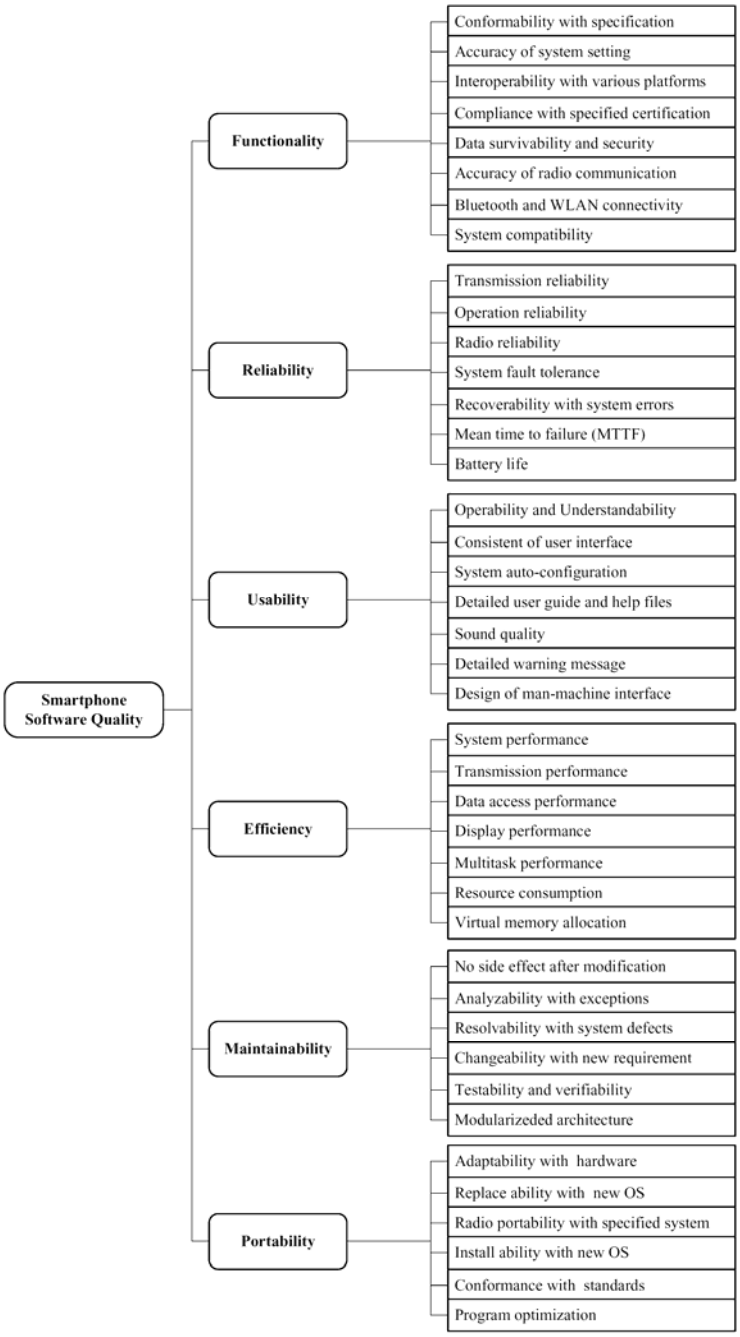

Figure 2. The structure for software quality of smartphone.

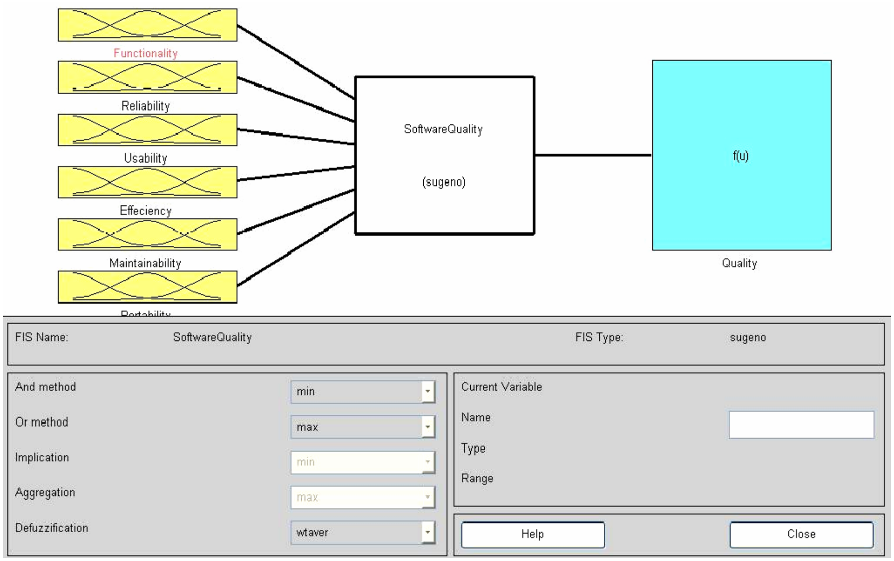

Figure 3. The Sugeno-type fuzzy method for the software quality of smartphone.

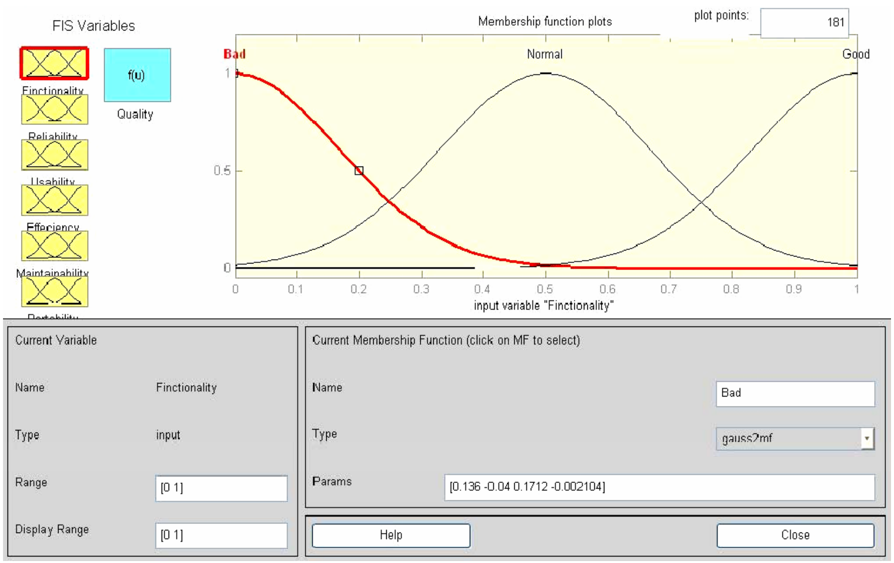

Figure 4. The membership functions of inputs.

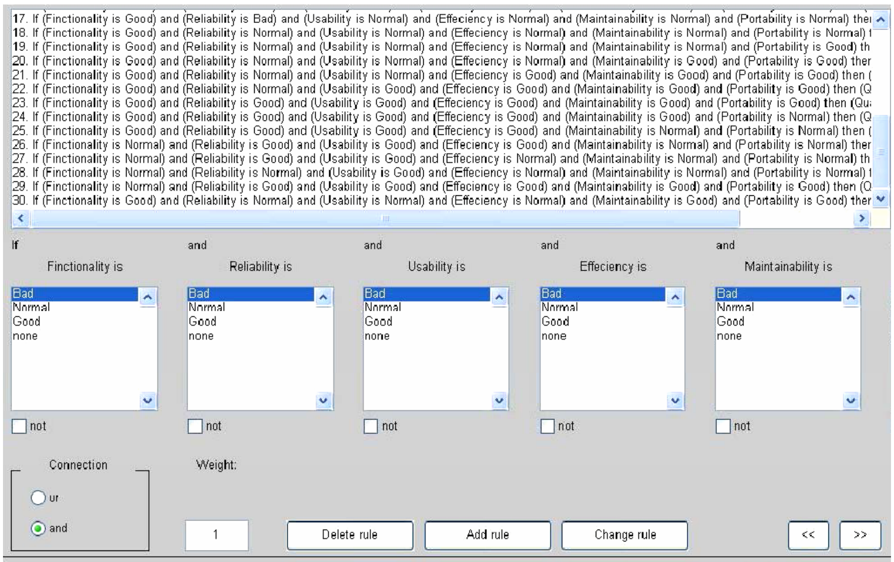

Figure 5. The if-then rule bases.

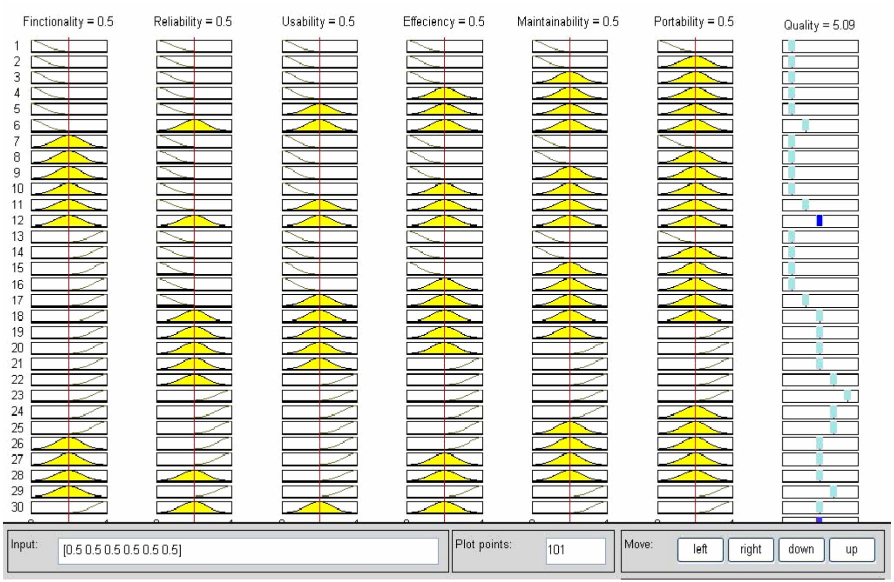

Figure 6. The fuzzy inference system.

Table 1. AHP weight for six characteristics

Characteristics	Weight	Priority
Reliability	0.25	1
Efficiency	0.21	2
Usability	0.17	3
Maintainability	0.129	4
Portability	0.125	5
Functionality	0.116	6

Table 2. AHP weight for the characteristic of functionality

Functionality	Weight	Priority
Data survivability and security	0.235	1
Accuracy with radio communication	0.211	2
Bluetooth and WLAN connectivity	0.13	3
Accuracy with system settings	0.114	4
System compatibility	0.095	5
Compliance with specified certifications	0.084	6
Interoperability with various platforms	0.08	7
Conformability with specification	0.05	8

Table 3. AHP weight for the characteristic of reliability

Reliability	Weight	Priority
Radio reliability	0.226	1
Operation reliability	0.194	2
Recoverability with system errors	0.171	3
Mean time to failure (MTTF)	0.118	4
System fault tolerance	0.115	5
Transmission reliability	0.091	6
Battery life	0.085	7

Table 4. AHP weight for the characteristic of usability

Usability	Weight	Priority
Sound quality	0.319	1
Operability and Understandability	0.144	2
Detailed warning message	0.12	3
Man-machine interface designing	0.119	4
System auto-configuration	0.117	5
Consistent of user interface	0.104	6
Detailed user guide and help files	0.077	7

Table 5. AHP weight for the characteristic of efficiency

Efficiency	Weight	Priority
Virtual memory allocation	0.203	1
Resource consumption	0.191	2
Multitask performance	0.175	3
System performance	0.134	4
Display performance	0.177	5
Data access performance	0.099	6
Transmission performance	0.08	7

Table 6. AHP weight for the characteristic of maintainability

Maintainability	Weight	Priority
No side effect after modification	0.256	1
Testability and verifiability	0.185	2
Modularized architecture	0.161	3
Resolvability with system defects	0.154	4
Analyzability with exceptions	0.129	5
Changeability with new requirement	0.116	6

Table 7. AHP weight for the characteristic of portability

Portability	**Weight**	**Priority**
Program optimization	0.259	1
Install ability with new OS	0.166	2
Conformance with standards	0.165	3
Radio portability with specified system	0.151	4
Replace ability with specified OS	0.139	5
Adaptability with hardware	0.12	6