Identification of Software NFR based on the Fuzzy-QFD Model

Shucheng Xiao,
Kui Wang,
Jiafeng Wu,
Erhua He,
Zhendong Yang,
Chongqing Logistical Engineering University, China.
E-mail: xiaosc@cqu.edu.cn

Abstract

NFR determination of the software products is an important link in the requirement development. Considering the correlation and inter-dependence between FR and NFR of software, this paper puts forward a NFR system identification method of the software products based on the fuzzy-QFD model through constructing the FR-NFR correlation matrix of software.

Key Words: Software Requirement, NFR, QFD, Trapezoidal Fuzzy Number
1. Introduction

Functional requirement (FR) and non-functional requirement (NFR) are two core parts of software requirement. The former defines the functions that the software product must realize. The uses use those functions to accomplish the specific tasks and business requirements. The latter is the quality description of the software product, including the constraints of software quality, so as to ensure that the software product reliably runs as expected. In fact, NFR of software decides the architecture design of development [1], and FR should also follow it. Thus, clarifying the NFR of a software product is the problem of primary importance in the software requirement development as well as the basis for ensuring the reliability of the software product in the later stage.

The current studies on the software requirement mostly focus on the acquisition and recognition of FR, such as domain-based model [2], ontology description [3], manual [4], opinion [5], scene [6-7], requirement identification [8-11], ethnography-based cognition engineering and other methods [12-13], but little has been carried out on NFR. The existing research is mainly based on the influence of NFR on the software architecture design [14], classified design of NFR [15-20] and importance evaluation of NFR [21-25]. Identifying the NFR of the software product accurately is an important link in the requirement development [26]. QFD can overcome some problems appearing in the requirement analysis [27], effectively identify the user’s requirements and convert them into a series of detailed design specifications. It can also be used to identify the relative importance of different NFR attributes of the software product [28-29]. In addition, the effectiveness of QFD in the software requirement development has been recognized [30-33].

Considering the correlation and interdependence between FR and NFR, this paper puts forwards a NFR determination method containing six steps through constructing the fuzzy-QFD model based on the FR-NFR correlation matrix of the software product. Chapter 1 summarizes the possible NFR of software according to the existing literature research. Chapter 2 describes the NFR determination process of software based on fuzzy QFD in details and builds the mode, which is applied to the determination of non-functional requirement about an example.

2. NFR Determination Process of Software based on the Fuzzy-QFD Model

The NFR determination method based on the fuzzy-QFD model proposed in the paper is shown in Fig.1.
2.1 FR Collection

FR is to define and specify what the software system needs to do. It’s the carrier of NFR, so FR collection of the software product is the first step. At present, FR of the software product can be collected with the BPR process, GORA method, in-depth interview and requirement analysis of the original system. It’s reflected by some basic user requirements and standards, functions, scenes or cases related to the business process. After screening, decomposition, weighing and confirmation, FRs can be expressed in the set form \{FR_1, FR_2, ..., FR_n\}.

2.2 Optional NFR

ISO/IEC 25010, which supersedes ISO/IEC 9126-1, was issued in March 2011. ISO 25010 has eight product quality characteristics (NFRs), and 31 sub-characteristics, but above NFRs focused only on the quality characteristics of software. For the information system development of an enterprise, many technical factors like type of architecture, interface standard and version assessment and social and economic factors like legal permission, organization strategy, market orientation, technical training and support, reputation and ability of the developer should also be taken into account. Therefore, the domestic and foreign scholars [14-20] have added some other NFRs later.

This paper generalizes the NFRs mentions in above literature and proposes the NFR layered model as shown in Fig.2. NFRs in the model are reflected in three aspects: quality characteristic, technical factor and socio-economic factor. Those three aspects are further subdivided into different primary sub-attributes and secondary sub-attributes. According to the definition of IEEE software engineering ISO/IEC 25010-2011, NFRS is used to describe how a software system is realized to meet the user's function. 43 sub-attributes in the NFR layered model can reflect the realization of a software system from different perspectives.
Thus, this paper regards those 43 candidate NFRs of the software system as the column of the FR-NFR correlation matrix.

2.3 FR-NFR Correlation Matrix

It’s assumed that \( FR_n \) is the FR of No. \( n \) and \( \{ FR_1, FR_2, \ldots, FR_n \} \) is the FR set of the software. For each \( FR_i \), the relevant participants need to give the correlation evaluation between \( FR_i \) and 44 NFRs \( \{ NFR_1, NFR_2, \ldots, NFR_{44} \} \) above. The evaluation is described with the 7-level natural language variable (very strong, strong, a little strong, ordinary, a little weak, weak and very weak). The evaluation results constitute the FR-NFR correlation matrix, as shown in Table 1.

<table>
<thead>
<tr>
<th>( FR_i )</th>
<th>( NFR_1 )</th>
<th>( NFR_2 )</th>
<th>( \ldots )</th>
<th>( NFR_{44} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( FR_1 )</td>
<td>( R_{11} )</td>
<td>( R_{12} )</td>
<td>( \ldots )</td>
<td>( R_{144} )</td>
</tr>
<tr>
<td>( FR_2 )</td>
<td>( R_{21} )</td>
<td>( R_{22} )</td>
<td>( \ldots )</td>
<td>( R_{244} )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( FR_n )</td>
<td>( R_{n1} )</td>
<td>( R_{n2} )</td>
<td>( \ldots )</td>
<td>( R_{n44} )</td>
</tr>
</tbody>
</table>

The FRs of software whose behaviors have been confirmed in the matrix, 44 possible NFRs. \( R_{ij} \) in the matrix is the evaluator’s natural language evaluation on the correlation between the \( i \)th FR and the \( j \)th NFR.

2.4 Calculation Process of the Fuzzy QFD

(1) Fuzzy Number Expression of Natural Language Evaluation

Due to the complexity and uncertainty of the software system development and the fuzziness of human thinking, the FR-NFRS correlation can be described with only the fuzzy number rather than the specified number. Triangular fuzzy number and trapezoidal fuzzy number are widely used at present. The membership function of triangular fuzzy number has simple shape, which cannot reflect the decision information of the decision-makers well in many cases. In particular, when the decision is made based on certain factors, the evaluation
result is often greatly different from the actual situation. The shape of the membership function of trapezoidal fuzzy number is more complicated, so it’s able to deal with the actual decision-making information well and reflect the uncertainty of factors.

Definition 1 If the trapezoidal membership function \( \mu_a(x) : R \rightarrow [0,1] \) meets:

\[
\mu_a(x) = \begin{cases} 
\frac{x - a}{b - a}, & X \in [a, b); \\
1, & X \in [b, c); \\
\frac{1}{d - X}, & X \in [c, d); \\
0, & \text{other}
\end{cases}
\]

where \( a, b, c, d \in R \), \( a \leq b \leq c \leq d \), and \( \tilde{a} = (a, b, c, d) \) is the standard trapezoidal fuzzy number.

In this paper, the FR-NFRS correlation evaluation is made with the 7-level natural language \{C1, C2, C3, C4, C5, C6, C7\}, and fuzzily processed with the standard trapezoidal fuzzy number. The trapezoidal fuzzy membership function with 7-level language evaluation is shown in Fig.3. The interval [0, 1] is divided into 13 pieces, (0.077, 0.154, 0.231,...., 0.846, 0.923, 1).

**Figure 3: Trapezoidal Fuzzy Membership Function of Level 7 Language Variable Set**

(2) Defuzzification of the Trapezoidal Fuzzy Number

Since the direct calculation of the FR-NFR correlation matrix which is identified with the trapezoidal fuzzy number will cause the rapid expansion of the computing size and obstruct the practical application of this method (for example, for a 50 x 44 matrix, only three evaluators can produce 6600 evaluation data. If it’s calculated with the trapezoidal fuzzy number, a most basic computation will have 26400 steps). Thus, the FR-NFR matrix expressed with the trapezoidal fuzzy number is defuzzified in the paper.

In the defuzzifying method, the gravity of the trapezoid can mostly represent the essential characteristics of the trapezoidal fuzzy number. It expresses the concentration place of the membership degree of the fuzzy numbers in the field, so the gravity of the fuzzy set can be used to describe the distribution of the membership function. In other words, the gravity of the fuzzy set can represent the evaluation of the experts.

Definition 2 If universe \( \sigma \) is the bounded measurable value in the real number field, the gravity \( g(A) \) of the trapezoidal fuzzy number \( A \) in \( \sigma \) is:
The gravity of a trapezoidal fuzzy number \( A(a,b,c,d) \) can be expressed as follows through the gravity calculation formula of trapezoid:

\[
G(A) = \frac{\int \mu(x) \cdot x \, dx}{\int \mu(x) \, dx}
\]

The defuzzified values of different levels of trapezoidal fuzzy numbers can be calculated with the above formula, as shown in Table 2.

<table>
<thead>
<tr>
<th>Level</th>
<th>Trapezoidal fuzzy numbers</th>
<th>Defuzzified values</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>((0, 0, 0.077, 0.154))</td>
<td>0.060</td>
</tr>
<tr>
<td>C2</td>
<td>((0.077, 0.154, 0.231, 0.308))</td>
<td>0.193</td>
</tr>
<tr>
<td>C3</td>
<td>((0.231, 0.308, 0.385, 0.462))</td>
<td>0.347</td>
</tr>
<tr>
<td>C4</td>
<td>((0.385, 0.462, 0.538, 0.615))</td>
<td>0.500</td>
</tr>
<tr>
<td>C5</td>
<td>((0.538, 0.615, 0.692, 0.769))</td>
<td>0.654</td>
</tr>
<tr>
<td>C6</td>
<td>((0.692, 0.769, 0.846, 0.923))</td>
<td>0.808</td>
</tr>
<tr>
<td>C7</td>
<td>((0.846, 0.923, 1, 1))</td>
<td>0.940</td>
</tr>
</tbody>
</table>

(3) Calculation of Relative Importance and Absolute Importance

Assuming there are \( m \) relevant personnel evaluating the FR of \( n \) systems, the importance evaluation given by the \( k \)th evaluator is \( W_{i}^{k} \), \( W_{1}^{k}, W_{2}^{k}, \ldots, W_{n}^{k} \) and the FR-NFR correlation matrix is \( D^{k} = \left( R_{ij}^{k} \right)_{n \times n} \), the following can be obtained:

\[
\begin{pmatrix}
R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & w_{1i}^{k} \\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & w_{1i}^{k} \\
\vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & R_{i1}^{k} & \cdots & w_{1i}^{k}
\end{pmatrix}
\]

where \( R_{ij}^{k} \) is the \( FR_{i} - NFR_{j} \) correlation evaluation given by the \( k \)th evaluator with the natural language; \( W_{i}^{k} \) is the importance of \( FR_{1}, FR_{2}, \ldots, FR_{n} \), expressed with the natural language. If \( \overline{W}_{i} \) is the average importance of \( FR_{i} \) and \( \overline{R}_{ij} \) is the average correlation between \( FR_{i} \) and \( NFR_{j} \), the following can be obtained:

\[
\overline{W}_{i} = \frac{1}{m} \sum_{k=1}^{m} G(\text{fuzz}(w_{i}^{k})) \quad \overline{R}_{ij} = \frac{1}{m} \sum_{k=1}^{m} G(\text{fuzz}(R_{ij}^{k}))
\]
Note: fuzzy in the formula is the trapezoidal fuzzy function of the natural language variable and G is the gravity defuzzifying function.

Relative importance $AR_j$ and average relative importance $AAR$ of NFRs can be calculated through $\bar{w}_j$ and $\bar{r}_{ij}$.

$$AR_j = \sum_{i=1}^{n} \bar{w}_j \cdot \bar{r}_{ij}, \quad AAR = \frac{1}{44} \sum_{j=1}^{44} AR_j$$

Absolute importance $RR$ of NFR can be got through the standardized treatment of relative importance $AR$. For example, the absolute importance $RR_j$ of the $j$th NFRj is

$$RR_j = \frac{AR_j}{\sum_{j=1}^{44} AR_j}$$

(4) NFR Screening Algorithm

If the absolute importance $RR_j$ of NFRj is equal to or greater than the overall average relative importance $AAR$, it means NFRj is necessary; in contrary, if the absolute importance $RR_j$ of NFRj is less than the overall average relative importance $AAR$, it means that the software system does not need this NFR. The screening algorithm is shown in Fig.4.

Figure 4: The Screening Algorithm

2.5 Example Calculation

Due to the limitation of space, this paper makes calculation with the defuzzified correlation evaluation matrix which is composed of 20 NFRs and 10 FRs as shown in Table 3. $ARs$, $RRs$ and $ARRs$ of different NFRs and the final screening results are shown in Table 4.

<table>
<thead>
<tr>
<th>FR1</th>
<th>FR2</th>
<th>FR3</th>
<th>FR4</th>
<th>FR5</th>
<th>FR6</th>
<th>FR7</th>
<th>FR8</th>
<th>FR9</th>
<th>FR10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replaceability</td>
<td>0.295</td>
<td>0.749</td>
<td>0.398</td>
<td>0.251</td>
<td>0.449</td>
<td>0.354</td>
<td>0.354</td>
<td>0.398</td>
<td>0.501</td>
</tr>
<tr>
<td>Installability</td>
<td>0.896</td>
<td>0.647</td>
<td>0.302</td>
<td>0.749</td>
<td>0.295</td>
<td>0.347</td>
<td>0.456</td>
<td>0.456</td>
<td>0.200</td>
</tr>
<tr>
<td>Consistency</td>
<td>0.500</td>
<td>0.705</td>
<td>0.896</td>
<td>0.551</td>
<td>0.596</td>
<td>0.647</td>
<td>0.398</td>
<td>0.845</td>
<td>0.500</td>
</tr>
<tr>
<td>NFR</td>
<td>AR</td>
<td>RR*100</td>
<td>result</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Portability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replaceability</td>
<td>3.06</td>
<td>4.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installability</td>
<td>3.36</td>
<td>4.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consistency</td>
<td>4.48</td>
<td>6.60</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptability</td>
<td>3.63</td>
<td>5.34</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Maintainability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testability</td>
<td>2.76</td>
<td>4.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>3.50</td>
<td>5.16</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Changeability</td>
<td>3.30</td>
<td>4.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyzability</td>
<td>2.87</td>
<td>4.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource Behaviour</td>
<td>3.55</td>
<td>5.22</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Usability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understandability</td>
<td>3.62</td>
<td>5.32</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operability</td>
<td>3.60</td>
<td>5.30</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recoverability</td>
<td>3.66</td>
<td>5.38</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maturity</td>
<td>3.42</td>
<td>5.03</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault Tolerance</td>
<td>3.15</td>
<td>4.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Functionality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suitability</td>
<td>3.54</td>
<td>5.21</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td>2.95</td>
<td>4.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>interactivity</td>
<td>3.77</td>
<td>5.55</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interoperability</td>
<td>3.30</td>
<td>4.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>3.36</td>
<td>4.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| ARR | 5.00 |
3. Conclusion

This paper generalizes 44 NFRs based on the literature research and puts forward a systemized fuzzy-QFD-based NFR determination method of software according to the correlation and interdependence between FR and NFR of software, which provides a new solution for the identification of NFR in the real software program.

References


www.globalbizresearch.org


