The Application of QFD and Information Entropy in Improved Design for the Manned Capsule HMI

Bo Li*, Yan-min Xue and Xiao-min Ji
Faculty of Art and Design, Xi'an University of Technology, Xi'an, 710054, China
*Corresponding author

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Abstract. In order to introduce the user needs into the improved design of HMI (man-machine interface) quickly and reasonably, Be intended for Manned Capsule HMI, the particular field of engineering technology. A product design method and QFD technology based on information entropy is proposed. Aimed at the design characteristics of HMI components, using the QFD technical and to guide the design process of the man-machine interface, through information entropy theory to determine the customer requirements in quality function deployment. Research shows this method can reduce the subjective judgment in the process of HMI design, and through the QFD technical and information entropy theory can enhance the effectiveness and objectivity.

Introduction

In China, the research on ergonomic design is not perfect for man-machine interface. As the special purpose, Manned capsule, due to the use of the crowd and the constraints of the special environment, the design requirements of the acquisition and constraint extraction is very difficult. So that the designer of this kind of product design is hard to have absolute confidence in good design.

According to the characteristics of all kinds of constraints in ergonomics design, the use of scientific design, to avoid the risk of new product development, shorten the development cycle, The concept of new product development like that is gradually being introduced to the manned capsule ergonomics design.

In this paper, a design idea based on QFD and information entropy is proposed, which provides a new design idea for the research and development of ergonomics design for Manned Capsule. The design thought had been put forward which based on the QFD combination with Information entropy, It had been provided using for Manned Capsule HMI ergonomic research. The designer on the basis of related products research achievements at home and abroad, Ergonomic design criteria, and the user needs and user feedback of existing products, to making Quality house for using QFD technology. And then, Using the technology of information entropy for user requirements importance evaluation, and use the evaluation results for further QFD research, Eventually getting the optimal design scheme.

QFD- Quality Function Deployment

Section Headings

QFD theory is a kind of product development method, which is driven by user's demand, and is carried out in the product design stage. American scholars Hauser and Clausing proposed the concept “House of Quality ” in 1988 (HOQ)\(^1\-^2\), it provides a structure which can make the user needs into products and components characteristics into the manufacturing process, that is a kind of matrix framework intuitive form of expression, and the method of QFD tool\(^3\-^5\). The composition of the “House of Quality ” is shown in Figure 1.
Determination of User Needs and Requirements

As can be seen from Figure 1, the importance of user needs and requirements is the most basic input, and is the key step. The importance of user requirements is an important basis for the effective allocation of resources and decision making in QFD planning process\[^6\]. User requirements can be obtained through market research, target customer needs statement, the existing user feedback collection methods.

In the aspect of determining the importance of user requirements, the methods commonly used include expert evaluation, user survey and AHP (analytic hierarchy process)\[^7\].

Because of determining the importance of user needs will make sure the Quality house successful or not, at the same time, which will For the development of the product design and improve design has the vital role. In this paper, the author on the basis of the given basis importance by expert evaluation, With the introduction of information entropy to analyze the market competitive evaluation, evaluating and correcting the user needs importance. So we can get more objective real important degree of user requirements.

Information Entropy

Basic Concepts of Information Entropy

The concept of “Entropy” is derived from thermodynamics. In 1948, that was first put forward by C. E. Shannon, and then the concept of “Entropy” was used to measure the uncertainty in the measurement of information. “Information entropy” is a quantitative representation of the degree of chaos.

For the information contained in discrete probability distribution of \(p_1, \ldots, p_k\), the concept of information entropy means: that the larger the change of \(p_i\), the more information it contains, and vice versa.

Shannon defines this information entropy:

\[
E(p_1, \ldots, p_k) = -\Phi \sum_{i=1}^{k} p_i \ln(p_i)
\]

(1)

Where \(\Phi = \frac{1}{\ln k}\) is positive constant, in order to ensure \(0 \leq E(p_1, \ldots, p_k) \leq 1\). So, the increases of \(E(p_1, \ldots, p_k)\), the less information is contained in \(p_1, \ldots, p_k\).

Using Entropy Method to Determine Important Degree of User Requirements\[^9\]

For \(k\) design units and \(m\) item of user needs, the evaluation matrix \(X\) which gained from industry competitive evaluation of the product contains the after evaluation information of \(m\) items user requirements. For user needs item \(CA_j\) (\(CA_j\) stand for the \(j\) items user needs), the result of competitive evaluation about users of \(k\) design units is \(x_{jk}\) (\(x_{jk}\) means competitive evaluation result the \(k\) design unit about the \(j\) item user needs), make

\[
x_j = \sum_{i=1}^{k} x_{ji}
\]

(2)

\(x_j\) means the sum of the competitive evaluation result about users of \(k\) design units for the \(j\) item user needs. make

\[
p_j = \frac{x_{jk}}{x_j}
\]

(3)
\( p_{ji} \) means probability event the user for \( i \) design units about \( j \) item user needs the result of competitive evaluation relative to the sum of \( k \) design units about \( CA_j \), the discrete probability distribution of the sample. For definition of evaluation of information entropy:

\[
E(CA_j) = -\Phi(\sum_{i=1}^{k} p_{ji} \ln(p_{ji})) = -\Phi(\sum_{i=1}^{k} \left( \frac{x_i}{x_j} \right) \ln \left( \frac{x_i}{x_j} \right))
\]

(4)

\( E(CA_j) \) Used to reflect a user needs \( CA_j \) the relative competitive advantage. And then, \( E(CA_j) \) make sure doing the normalized processing.

\[
e_j = \frac{E(CA_j)}{\sum_{j=1}^{n} E(CA_j)}
\]

(5)

Can be obtained the corresponding vector: \( e = (e_1, \ldots, e_n) \). When we don’t consider other factors, it shows relative priorities which from Industry competitive evaluation perspective, to improved the user needs, Thus it can be as the correction of the fundamental importance ratings information to the user demand.

In combination with user requirements basic importance and fix the important degree, can be obtained the user requirements the final importance ratings of the vector \( f = (f_1, f_2, \ldots, f_m) \).

\[
f_m = s_m e_m
\]

(6)

\( s_m \) means the \( m \) user requirements basic importance.

**Application Example for HMI Design of the Manned Capsule**

The application comes from the school enterprise cooperation projects between the users want the man-machine interface, the manned capsule improved to reflect the unique humanistic care, product structure have good ergonomic and lightweight. In order to meet the needs of users, the QFD and information entropy are used to improve the design of the man-machine interface.

**User Needs and Requirements**

The key part of the user's requirements in the design of the man-machine interface of the spacecraft is introduced briefly, and the related technical features of the product are given. The building of the improved design of the man-machine interface of the spacecraft is shown in figure 2:

<table>
<thead>
<tr>
<th>Component</th>
<th>Importance</th>
<th>Element</th>
<th>Function</th>
<th>Design</th>
<th>Manufacturing</th>
<th>Material</th>
<th>Control</th>
<th>Environment</th>
<th>Communication</th>
<th>Safety</th>
<th>Service</th>
<th>Maintenance</th>
<th>Storage</th>
<th>Abroad</th>
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</thead>
<tbody>
<tr>
<td>Health</td>
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<td>Control box</td>
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<tr>
<td>Transmitter</td>
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<tr>
<td>Observation</td>
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</tbody>
</table>

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Among the strongest correlation degree, 4: correlation degree is strong, 3: correlation degree is the general, 2: weak correlation degree, 1: the worst correlation degree.

The more numerical value of importance value closer to 1, the more important it is. And means the more competitive advantage in the industry.

From Figure 2 we can get that priority of user needs importance: Display Table > Workbench = Control button = Control knob > Seat > Transmitter > Observation window.

**Determination of Priority Order for User Requirement Improvement**

In figure 2 by expert evaluation system is given the fundamental importance ratings of the user requirements, and domestic and foreign similar products in the design of unit competitive evaluation matrix. We can find that due to user demand importance determination method has certain defects, difficult to accurately determine the workbench, control button, control knob to the user demand important degree of relative priorities, Introduced the technology of information entropy to the user demand importance for further processing, in order to make the result more accurate and more reasonable.

According to the Figure 2, The fundamental importance ratings of the customer requirements in QFD:

$$g = (g_1, g_2, \cdots, g_7) = (0.64, 0.64, 0.24, 0.48, 0.80, 0.56, 0.64)$$

Industry competitive evaluation matrix of user requirements are as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{17} \\ x_{21} & x_{22} & \cdots & x_{27} \\ \vdots & \vdots & \ddots & \vdots \\ x_{71} & x_{72} & \cdots & x_{77} \end{bmatrix} = \begin{bmatrix} 0.24 & 0.16 & 0.20 & 0.28 & 0.40 \\ 0.42 & 0.50 & 0.55 & 0.50 & 0.56 \\ 0.70 & 0.84 & 0.374 & 0.78 & 0.82 \\ 0.68 & 0.32 & 0.77 & 0.56 & 0.48 \\ 0.46 & 0.74 & 0.325 & 0.86 & 0.76 \\ 0.52 & 0.42 & 0.35 & 0.46 & 0.55 \\ 0.36 & 0.32 & 0.43 & 0.42 & 0.30 \end{bmatrix}$$

The use of information entropy analysis of industry competitive evaluation, According to the formula (2) ~ (3), It is concluded that the market competitiveness value of customer requirements as shown in table 1:

<table>
<thead>
<tr>
<th>Customer requirements $CA_i$</th>
<th>$CA_1$</th>
<th>$CA_2$</th>
<th>$CA_3$</th>
<th>$CA_4$</th>
<th>$CA_5$</th>
<th>$CA_6$</th>
<th>$CA_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information entropy value $E( CA_i)$</td>
<td>0.9692</td>
<td>0.997</td>
<td>0.979</td>
<td>0.9748</td>
<td>0.9656</td>
<td>0.9924</td>
<td>0.9937</td>
</tr>
</tbody>
</table>

According to the formula (1), It is concluded that the user needs the competitive evaluation of information entropy value as shown in table 2:

<table>
<thead>
<tr>
<th>Customer requirements $CA_i$</th>
<th>$CA_1$</th>
<th>$CA_2$</th>
<th>$CA_3$</th>
<th>$CA_4$</th>
<th>$CA_5$</th>
<th>$CA_6$</th>
<th>$CA_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information entropy value $E( CA_i)$</td>
<td>0.8675</td>
<td>0.997</td>
<td>0.979</td>
<td>0.9748</td>
<td>0.9656</td>
<td>0.9924</td>
<td>0.9937</td>
</tr>
</tbody>
</table>

According to the formula (5), After normalization, the user requirements vector of the fix important degree is:
According to the formula (6), the final important degree vector is:
\[ e = (e_1, \cdots, e_7) = (0.141, 0.1451, 0.1425, 0.1419, 0.1405, 0.1444, 0.1446) \]

The priority order of importance which corrected by the changes in the information entropy:
Display Screen > The workbench > Control button > Control knob > microphone > The seat > The window.

**Summary**

According to the above analysis, the manned capsule ergonomics design already completed, the final part of the improved design as shown in figure 3.

![Figure 3. The final design scheme of man machine interface.](image)

The experiment proved that the concept of information entropy is introduced in QFD, was modified to determine the importance of customers' requirements, not only to consider the importance of the basic information needs of users, while also taking into account the industry competitive evaluation, the importance of customers' requirements is more scientific and reasonable, can make the product design more reasonable to meet user’s requirements.

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**References**


