The Design of Adaptive User Interface Based on the Grey Relational Grade

Fangzheng Li¹, Wei WANG¹, Jue QU³ and Huating Han¹

¹Air and Missile Defense College, Air Force Engineering University, Xi’an 710051

Abstract. In order to improve the efficiency of human-computer interaction and reduce operating load, a new design method of adaptive GUI (graphical user interface) was proposed in this paper. Firstly, the common GUI was analysed and abstracted, and the five basic composition styles of GUI: Trees, Tabs, Forms, Lists, Filters were obtained, as the basis of interface partition. Then the functional object (large area) activity and area attention degree were defined. According to Shannon’s information theory, the amount of information that the user needs to obtain from a area within some time is obtained. Therefore the activity of functional object (large area) was determined. The attention degree of area was determined by eye movement tracking experiment. Eye-movement factors $F_i$ (fixation count), $T_i$ (Dwell time) and $V_i$ (revisits) were selected as characteristic parameter. In accordance with the principle of equal importance weighted average, the area attention degree are obtained. The Grey relational grade of the functional objects (large area) activity and area attention degree was obtained through Grey relational analysis as the trigger condition for interface change.

1. Introduction

Although automation is becoming more and more important in control system, human operators still play an irreplaceable role in many aspects such as aviation flight operation, weapon equipment operation, manufacturing operation system monitoring and operation, surgery and so on. As the functions of all kinds of control systems are becoming more and more powerful and the control is becoming more and more complex, higher requirements have been put forward to human operators. User interface is the main medium of human-machine interaction. Whether user interface design is good or bad, whether it adapts to user interaction characteristics will directly affect the realization of system function. The traditional graphical user interface uses fixed structure to provide users with interactive information, and does not consider user interaction habits. It does not consider the connection of functional objects in the interface, which seriously restricts the development of users and system functions.

Adaptive interface interaction through monitoring the user’s intention, operation level, style preferences and other characteristics of information, dynamically change the interaction style and layout form for different users, different tasks and provides adaptive and personalized information services[1], which greatly improves the efficiency of man-machine interaction, and reduces the operating load.

Many scholars at home and abroad have done a lot of research on adaptive interface design. Rothrock et al. (2002), Stephanidis et al. (1997), Viano et al. (2000), Norcio and Stanley (1989), Haas
and Hettinger (2001) [2-4] discussed adaptive interfaces in a number of backgrounds. The adaptive interface is to automatically adjust the information processing mechanism and behavior to adapt to the current task target and the ability of the user. This process is accompanied by monitoring user status, system tasks, and current status requirements.

In-Jee Song, Sung-Bae Cho [5] used Bayesian network and behavior network, and an adaptive user interface based on environment and user status is designed in the family environment. Talia Lavie, Joachim Meyer [6] analyzed the advantages and disadvantages of the adaptive interface, set up four different adaptive levels, different task modes, familiar situations and unfamiliar situations, and considered the advantages and disadvantages of the adaptive interface, he thinks that the adaptive interface is not beneficial under any conditions, it depends on many factors, including the frequency of task execution, the age of users, the difficulty of tasks, and the degree of users' participation in tasks.

Zhejiang Sci-Tech University Liezhong Ge team [7-9] studied the adaptive bubble cursor, fixed, the rules and characteristics of fixed, adaptive and adaptable, three different mobile phone mail list and adaptive mouse pointing task efficiency, which showed that the adaptive interaction is better than the traditional fixed interaction. Shandong University, Chenglei Yang and Xu Yin [10] to study the adaptive interface with good touch experience size, improved the touch experience of Android application; Dalian University of Technology Weidong Li, Zuoxin Zhu [11] studied the adaptive displays of the power system operation information, according to the user model and the different interactive scenes, such as normal, emergency, they select the appropriate information display technology and theme display interface.

About the research on adaptive user interface layout, only the Realization mechanism of the adaptive user interface in virtual Home Furnishing customization system [12], proposed by Yinting Fan. He put forward an adaptive prediction method of the activity based on history interaction sequence and adaptive distribution mechanism, which magnified the object of the user's attention, and the object that is not concerned is reduced, but the user's operating habits and personalities are not considered. Guohua Zhan [13] makes the functional object activity and region interest degree match in the Web interface according to the interactive habits of the user. But the adaptive layout of interface is overall, it is easy to cause the confusion, increasing the load of users, and in the calculation of the interest degree of region, only considering the region information density, and there is no specific consideration of users' eye attention in interface region.

Based on the above considerations, this paper according to the characteristic of the graphical user interface and provides the basis for the division of the interfacing region; Shannon theorem was determined the amount of information in the interactive process required from the interface region and function object access, namely the function object activity; through tracking eye movement, overall considering the number of fixation the residence time, and the revisit times determine users concern of a certain area.

Finally, grey relational analysis was used to determine the activity of functional objects and the area attention degree. Trigger condition of adaptive layout was determined by the change of the gray correlation degree. Firstly, the positions of large areas are adjusted, then positions of the functional objects in the large area are adjusted. The adjustment of functional objects is only in its large area, thus ensuring the stability of the user interface and improving the interaction efficiency.

2. Brief introduction to the User Interface Graphic Theory & grey correlation analysis

In the first generation of information systems, the user interface is character interface. With the appearance of graphical interface, the user interface has been rapid development, the first graphical user interface is created by Xerox Corporation in Palo Alto Research Center. New form of user interface such as Microsoft's Windows 10, apple computer, apple OSX mobile phone IOS, and Android. These interfaces have concepts such as windows, icons, menus, pointers, and so on, which are defined by Palo Alto.

2.1. Basic behavior of the user interface
The behavior of the user interface determines how the data is managed and stored, and the basic behavior of the user is as follows:

**CRUD**: Its meaning is Create, Read, Update, and Delete, which represent the four basic operations of user in the process of interaction. For example, in the mobile phone address book, creating is creating a new contact; Updating refers to updating mobile phone address book; and deleting refers to deleting the information of the contacts that are not used.

### 2.2. The basic components of the user interface

The basic user interface components are obtained through abstracting the common user interfaces, such as hotels, finance, accounting, Microsoft windows system, apple OS system, etc., [14]. As shown in Figure 1, an instance of the user interface abstraction. The basic components of the graphical user interface include:

- **Form**: the form is generally in a certain window, consisting of a series of control functions, and usually associates with the CRUD operation.

- **List**: there is an additional list around the Form, which allows users to select and access to responding data in the list, and the detailed information of the corresponding data will be displayed in the Forms. Lists and Forms are usually associated with four basic operations (CRUD) in the same window.

- **Filter**: the main implementation of Filter is filtering functions and data.

- **Tree**: generally in the side of the graphical user interface, the interface structure can be quickly mastered through a tree, and the Tree can facilitates the user to find the desired functional objects.

![Figure 1](image_url) The common graphical interface abstraction

The basic components of the user interface is shown in Figure 2.
Figure 2 The five basic composition style of the user interface

Common graphical user interfaces can generally be abstracted into Figure 2 five basic components or combinations of one or several basic components. Based on the basic components partition, the graphical user interface partition can retain the basic structure of the interface and keep the spatial and logical connections between the functional objects. Of course, the above abstract components can not include all the elements of graphical user interface, and still need to partition the interface reasonably according to the actual composition of the interface.

2.3 Brief introduction to grey correlation analysis

The basic idea of grey relational analysis is to judge whether the relationship is close according to the similarity of several shapes of the sequence curves. The closer the curve is, the greater the degree of correlation[15].

Set the system behavior sequence

\[ X_0 = (x_0(1), x_0(2), \cdots, x_0(n)) \]
\[ X_1 = (x_1(1), x_1(2), \cdots, x_1(n)) \]
\[ \cdots \]
\[ X_m = (x_m(1), x_m(2), \cdots, x_m(n)) \]

It is sequences of related factors.

Given real number

\[ \varphi(x_0(k), x_i(k)) = \frac{\min_k \min_j \left| x_0(k) - x_i(k) \right| + \xi \max_k \max_i \left| x_0(k) - x_i(k) \right|}{\left| x_0(k) - x_i(k) \right| + \xi \max_k \max_i \left| x_0(k) - x_i(k) \right|} \] (2)

\[ \varphi(X_0(k), X_i(k)) = \frac{1}{n} \sum_{k=1}^{n} \varphi(x_0(k), x_i(k)) \] (3)

\( \xi \in (0,1) \) Called the resolution coefficient, \( \varphi(X_0(k), X_i(k)) \) is the Grey relational degree between \( X_0 \) and \( X_i \).

The calculation steps of grey correlation degree are as follows:

1. Calculating the initial value (or mean value, or the interval value etc.) for each sequence;
   \[ X'_i = (x'_i(1), x'_i(2), \cdots, x'_i(n)), i = 0,1,\cdots, m; \]

2. Calculating the difference sequence;
$$\Delta_i(k) = \lbrack x_i^0(k) - x_i^i(k) \rbrack, i = 1, 2, \cdots, m$$  \hspace{1cm} (4)$$
$$\Delta_i = (\Delta_i(1), \Delta_i(2), \cdots, \Delta_i(n))$$  \hspace{1cm} (5)$$
③ Calculating the polar difference most and least;
$$M = \max \max_{i, k} \Delta_i(k), m = \min \min_{i, k} \Delta_i(k)$$  \hspace{1cm} (6)$$
④ Calculating the correlation coefficient;
$$\varphi_{w_i}(k) = \frac{m + \xi M}{\Delta_i(k) + \xi M}, \xi \in (0, 1)$$  \hspace{1cm} (7)$$
⑤ Calculating the correlation degree;
$$\varphi_{w_i} = \frac{1}{n} \sum_{k=1}^{n} \varphi_{w_i}(k), i = 1, 2, \cdots, m$$  \hspace{1cm} (8)$$

3. Adaptive user interface

The user interface, as the medium of human interaction with the system, plays an important role in the process of communication computer. The requirements for the interface are different because of the people's habits, interests, the degree of perception, and the degree of familiarity with the system operation. This provides a higher requirement for the user interface, which is able to adapt to the characteristics of different users.

To achieve this, the first thing to do is to dig out the user's personalized information. Interface information mining can be divided into three main categories[16]: structure mining, to find useful knowledge from the link of the representation structure; content mining, to extract useful information and knowledge from the interface content; Usage Mining, to mining the user's access pattern from the log of each user clicking on the situation. These three mining methods play an important role in adaptive interface. This paper mainly uses eye tracking equipment and user click log, to mining user interaction habits and azimuth perception.

The user interface is generally composed of a plurality of basic components, each component of interface contains multiple functional objects, and each functional object contains subfunction. The active degree of each functional object is different, and there is a certain connection between the various functional objects. When users use functional objects on the interface, there are several situations and the worst case is to spend a lot of time searching for functional objects that they will use. The goal of this adaptive interface is to dynamically adjust the layout of functional objects based on tracking and analyzing user interaction habits, so that users can find corresponding functional objects in the most habitual location and improve interaction efficiency. For this reason, the interface designer must know the degree of activity of the functional object and the user's attention to the functional object area, and judge whether the two match. If not, then adjust the location of the function object. Therefore, there are the following definitions:

**Definition 1.** The activity of functional objects (large areas): in an interactive period, the user needs the amount of information obtained from the function object (large area).

**Definition 2.** Area attention degree: the attention which users pay attention to the corresponding interface areas, mainly based on the user's eye movement data in this area.

The goal of the adaptive interface is to achieve the overall adaptation of the two and reduce the user's search load.

Based on the basic components of the user interface, the interface is divided into large areas. Because the large area of the user interface is relatively independent, it does not consider the transformation of the location of the function objects in the large area, and maintains the basic stability of the interface. The oversize of the interface change will reduce the user's trust in the interface, and increase the user's operating load. In this paper, a "hierarchical adaptive method" is used to determine whether the large area is adaptive or not. First, then we can determine the layout of the
basic components of the interface based on user interaction habits, and further determine the location of the functional objects in the corresponding large areas.

Due to the interrelation between functional objects, including functional objects in parts of the same area and different regions, we must consider the relationship between the contexts of operations in the process of adaptation.

3.1 Determination of attention degree of large area
It is assumed that the basic elements that contain information such as graphics, symbols and words in the user interface are independent of each other and are calculated according to the average amount of information. Formula (12) can be simplified to large area

The number of basic units Forms, Lists, Tabs, Trees, Filters, etc. is \( N \) in the user interface and the corresponding interface is divided into \( N \) regions. \( F_i \) (fixation count), \( T_i \) (Dwell time) and \( V_i \) (revisits) etc. in the corresponding region are recorded through eye movement tracking experiment. Because the units of the data are different, the original data are processed without Dimensionalization.

\[
F_i^* = \frac{F_i}{F_{\text{max}}}, T_i^* = \frac{T_i}{T_{\text{max}}}, V_i^* = \frac{V_i}{V_{\text{max}}}
\]  

(9)

In accordance with the principle of equal importance weighted average, The area attention degree are obtained:

\[
I_i = \frac{1}{3}(F_i^* + T_i^* + V_i^*)
\]  

(10)

3.2 Determination of the activity of large area
According to Shannon's information theory [17], for an attribute in a set of data, its attribute domain is \( \{a_1, a_2, \ldots, a_n\} \), and the corresponding probability distribution is \( \{p(a_1), p(a_2), \ldots, p(a_n)\} \). The following matrix can be obtained:

\[
(X, P) = \begin{pmatrix}
a_1, a_2, \ldots, a_n \\
p(a_1), p(a_2), \ldots, p(a_n)
\end{pmatrix}
\]  

(11)

The average amount of information for each symbol of the source, that is the entropy of information

\[
h(x) = \sum_{i=1}^{n} p(a_i) \log_2 \frac{1}{p(a_i)}
\]  

(12)

It is assumed that the basic elements that contain information such as graphics, symbols and words in the user interface are independent of each other and are calculated according to the average amount of information. Formula (13) can be simplified to:

\[
h(x) = \log_2 \frac{1}{p(a_i)}
\]  

(13)

The total amount of information contained in the area \( i \) is

\[
H_i(x) = \sum h_i(x)
\]  

(14)

then normalization processing is carried out:

\[
H_i^*(x) = \frac{H_i(x)}{H_{\text{max}}(x)}
\]  

(15)

The use probability of area \( i \) in a monitoring time period is \( P_i \). Assuming that the user's operation in large area is the same as a whole, then the amount of information that the user needs to obtain from the area \( i \) within this period is
(16)

\[ \tilde{H}^*_i(x) = P_iH^*_i(x) \]

Two behavior sequences are got:

\[ I = (I_1, I_2, \cdots, I_N) \]

\[ \tilde{H}^* = (\tilde{H}^*_1, \tilde{H}^*_2, \cdots, \tilde{H}^*_N) \]

(17)

Grey correlation analysis is used to determine the two sequences' initial grey correlation that is \( \phi_{sa}(I(k), \tilde{H}^*(k)) \), after the monitoring time, the grey correlation degree changed into \( \phi_{sa}(I(k), \tilde{H}^*(k)) \), if \( \phi_{sa}(I(k), \tilde{H}^*(k)) < \phi_{sa}(I(k), \tilde{H}^*(k)) \). The active components of interface is adjusted to the area of great concern, or no adjustment of the interface. At the same time, the initial grey correlation degree of the next interface adjustment becomes \( \phi_{sa}(I(k), \tilde{H}^*(k)) \).

3.3 Determination of area attention degree for the functional object

The partitions of the user interface are A, B, C, \( \cdots \), and the functional objects that each area contains are \( A_1, A_2, \cdots, A_k, B_1, B_2, \cdots, B_j, C_1, C_2, \cdots, C_m, \cdots \). In order not to add to the user's operating load, the location of the function object is adaptive only in the corresponding partition.

Because the area of the functional object is smaller, the error is larger if 4.1 is used to determine the attention of the large area.

Take the area A, for example, to establish a rectangular coordinate system in the area A, as shown in Figure 3.

![Figure 3](image)

**Figure.3** Schematic diagram of the right angle coordinate system in A large area

The subregion where each function object is located is \( z_i(x, y, s_x, \tilde{H}^*_{z,R}(z)) \), \( x_i, y_i \) represent the horizontal and longitudinal coordinates of the area center, \( s_{z_i} \) is Area area, \( \tilde{H}^*_{z,R}(z) \) is the amount of modified information that needs to be obtained for the user to operate on this functional object.

The area attention degree determined by 4.1 is \( I_{zi} = \frac{1}{3} \left( F^*_z + T^*_z + V^*_z \right) \). The area of the large area is large, and the influence of the area factor on user attention is not significant. The area of the functional object is small, and the difference between the areas will affect the attention of the functional object area. It is therefore necessary to further modify area attention of the functional objects as follows:

\[ I_{zi,R} = \frac{1}{3} \eta \left( F^*_z + T^*_z + V^*_z \right) \]

(18)

\( \eta \in (0,1) \) is the area coefficient, \( \eta = \frac{s_{\min}}{s_{z_i}} \). The larger the area, the smaller the \( \eta \).
3.4 Determination of function object activity

User interface is $U$, and all the functional objects that the user interface contains are $U_1, U_2, \ldots, U_m$. The vector consisting of a functional object is $U = [U_1, U_2, \ldots, U_m]^T$. Through the tracking and analysis of functional objects’ usage, the relationship between functional objects can be obtained.

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1m} \\ u_{21} & u_{22} & \cdots & u_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ u_{m1} & u_{m2} & \cdots & u_{mm} \end{bmatrix}$$

(19)

$u_{ij}$ represents the usage count of the functional object $U_j$, which is used after the functional object $U_i$. $u_i = \sum_j u_{ij}$ is the total usage count of $U_i$, $u = \sum_i \sum_j u_{ij}$ is the number of use of all functional objects. Thus, the use probability of the function object $U_i$ is

$$p_{U_i} = \frac{u_i}{u}$$

(20)

By the 4.2 information theory, the amount of information that the user needs to get from the function object in a given time period is

$$\hat{H}_{U_i}^*(U) = P_{U_i}H_{U_i}^*(U)$$

(21)

$H_{U_i}^*(U)$ is the amount of information processed by normalization. Because the user operation of each functional object is different, the user operation of the functional object directly affects the amount of information transmitted from the functional object. Amend the form (21) and get

$$\hat{H}_{U_i}^*(U) = \mu P_{U_i}H_{U_i}^*(U)$$

(22)

$\mu$ is the corresponding operating coefficient. Finally, two association sequence of the functional object is got.

$$I_{sr} = (I_{s,r}, I_{s,r}, \ldots, I_{s,r})$$

$$\hat{H}_{sr}^*(U) = (\hat{H}_{sr}^*(U), \hat{H}_{sr}^*(U), \ldots, \hat{H}_{sr}^*(U))$$

(23)

According to the calculation step by grey correlation degree, the initial grey relational degree of $I_{sr}$ and $\hat{H}_{sr}^*(U)$ was got, $\varphi_{q_0}(I_{sr}, \hat{H}_{sr}^*(U))$. After $t_a$ monitoring time, gray correlation degree change into $\varphi_{q_0}(I_{s,r}, \hat{H}_{sr}^*(U))$. If $\varphi_{q_0}(I_{s,r}, \hat{H}_{sr}^*(U)) < \varphi_{q_0}(I_{s,r}, \hat{H}_{sr}^*(U))$, we adjusts the function objects with large activity to the area of more attention. If $\varphi_{q_0}(I_{s,r}, \hat{H}_{sr}^*(U)) > \varphi_{q_0}(I_{s,r}, \hat{H}_{sr}^*(U))$, there is no adjustment. At the same time, the grey correlation degree of the next interface adjustment becomes $\varphi_{q_0}(I_{s,r}, \hat{H}_{sr}^*(U))$. The interface adapts to the optimal through the adaptive of the large area activity and the attention degree, the function object activity and the area attention of the region.

4 Conclusion

A method of adaptive layout is proposed in this paper. The feasibility and effectiveness of the method need further experimental verification.
Reference

[1] Kobsa A. Generic user modeling systems [J]. User Modeling and User Adapted Interaction, 2001, 11(1/2): 49-63.

[2] Rothrock, L., Koubek, R., Fuchs, F., Haas, M., Salvendy, G., 2002. Review and reappraisal of adaptive interfaces: toward biologically inspired paradigms. Theoretical Issues in Ergonomics Science 3 (1), 47–84.

[3] Shneiderman, B., 1992. Designing the User Interface: Strategies for Effective Human-computer Interaction. Addison-Wesley Longman Publishing Co., Inc,Boston, MA, USA.

[4] Stephanidis, C., Karagiannidis, C., Koumpis, A., 1997. Decision Making in Intelligent User Interfaces. Paper Presented at the Proceedings of the 2nd International Conference on Intelligent User Interfaces

[5] In-Jee Song, Sung-Bae Cho. Bayesian and behavior networks for context-adaptive user interface in a ubiquitous home environment[J]. Expert Systems with Applications, 40(2013): 1827-1838.

[6] Talia Lavie, Joachim Meyer . Benefits and costs of adaptive user interfaces [J]. Int. J. Human-Computer Studies 68 (2010) 508–524.

[7] Xinqin Jin. Study of Adaptive Bubble Cursor [D]. Hangzhou: Zhejiang Sci-Tech University, 2015.

[8] Lu Zheng. Ergonomic Study on Static, Adaptive and Adaptable in Mobile Directory [D]. Hangzhou: Zhejiang Sci-Tech University, 2011.

[9] Hua Liu. Pointing task performance study on adaptive-based mouse [D]. Hangzhou: Zhejiang Sci-Tech University, 2014.

[10] Xu Yin, Yalin YU, Yuan WANG, et al. A Method to Generate Adaptive User Interface with Touch-Friendly Size [J]. Journal of Computer—Aided Design&Computer Graphics, 2014, 26(4): 662-668.

[11] Zuoxin Zhu. Preliminary research on adaptive display of power system operating information [D]. Dalian: Dalian University of Technology, 2013.

[12] Yinting Fan, Dongxing Teng, Gongzheng Wang, et al. Implementation Mechanism of Adaptive User Interface for Furniture Layout Customizing System [J]. Journal of Computer-Aided Design& Computer Graphics, 2011, 23(4): 705-712.

[13] Guohua Zhan, Wei Wei. A Web Adaptive Interface Design [J]. Journal of Hangzhou Normal University (Natural Science Edition) 2011, 10(2):163-167.

[14] Paulo Roberto Lumertz , Leila Ribeiro , Lucio Mauro Duarte. User interfaces metamodel based on graphs [J]. Journal of Visual Languages and Computing, 32(2016)1-34.

[15] Linghao Kong. Study on Substation-Area Protection of Fuzzy Cluster Based on Fault Degree and Gray Correlation Degree [D]. Beijing: North China Electric Power University, 2014.

[16] Bing Liu. Web data mining [M]. Beijing: Tsinghua University Press, 2009: 5-9.

[17] Long Zhang. Research on feature selection and classification algorithms based on information theory [D]. Chongqing: Southwest Agricultural University, 2005.