A Personalized Courseware Recommendation System Based on Fuzzy Item Response Theory

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Abstract

With the rapid growth of computer and Internet technologies, e-learning has become a major trend in the computer assisted teaching and learning field currently. In past years, many researchers made efforts in developing e-learning systems with personalized learning mechanism to assist on-line learning. However, most of them focused on using learner's behaviors, interests, or habits to provide personalized e-learning services. These systems usually neglected to concern if learner's ability and the difficulty of courseware are matched each other. Generally, recommending an inappropriate courseware might result in learner's cognitive overhead or disorientation during a learning process. To promote learning efficiency and effectiveness, this paper presents a personalized courseware recommendation system (PCRS) based on the proposed fuzzy item response theory (FIRT), which can recommend courseware with appropriate difficult level to learner through learner gives a fuzzy response of understanding percentage for the learned courseware. Experiment results show that applying the proposed fuzzy item response theory to Web-based learning can achieve personalized learning and help learners to learn more effectively and efficiently.

1. Introduction

Many researchers recently have endeavored to provide personalization mechanisms for Web-based learning [1-3]. Restated, personalized service has received considerable attention recently because of information needs different among users. Nowadays, most recommendation systems [4-5] consider learner/user preferences, interests, or browsing behaviors when analyzing learner behaviors for personalized services. These systems neglect the importance of learner ability for implementing personalized mechanisms. On the other hand, some researchers emphasized that personalization should consider different levels of learner knowledge, especially in relation to learning [1-2]. That is, the ability of individuals may be based on major fields or subjects. Therefore, considering learner ability can promote personalized learning performance.

Based on previous analyses, this study proposes a personalized courseware recommendation system (PCRS) based on the proposed fuzzy item response theory to provide Web-based learning services. In the proposed fuzzy item response theory, the fuzzy theory is combined with the original item response theory [6] to model uncertainly learning response. Moreover, the single parameter logistic model with difficulty parameter proposed by Georg Rasch in 1966 [6] is applied to model various difficulty levels of courseware. PCRS can dynamically estimate learner ability based on the proposed fuzzy item response theory by collecting learner feedback information after studying the recommended courseware. Based on the estimation of learner abilities, the novel system can recommend appropriate courseware to learners. Restated, learner ability and the difficulties of courseware are simultaneously taken into account when implementing a personalization mechanism. Experiments show that the proposed personalized courseware recommendation system can recommend appropriate course materials to learners based on individual ability, and help them to learn more efficiently and effectively.

2. System Architecture

In this section, the detailed system architecture will be described in detail.

2.1 Diagram of System Architecture

In this study, an adaptive e-learning system based on the fuzzy item response theory, which includes an off-line courseware modeling process, four intelligent agents and four databases, is presented herein. The system architecture is shown as Figure 1. The learner interface agent aims at providing a friendly learning interface for learners to interact with the feedback agent and courseware recommendation agent. On the other hand, the feedback agent aims at collecting learner explicit feedback information from the learning interface agent and storing them into the user profile database for personalized e-learning services. Moreover, the courseware recommendation agent is in charge of recommending adaptive courseware to learner according to learner's feedback response and his ability. Finally, the courseware management agent with authorized account management mechanism provides a friendly courseware management interface, which can help teachers to create new course units, upload courseware to the courseware database, delete and modify courseware from the courseware database. In Figure 1, the number of 1,2,..,16 indicates the procedure of system operation.

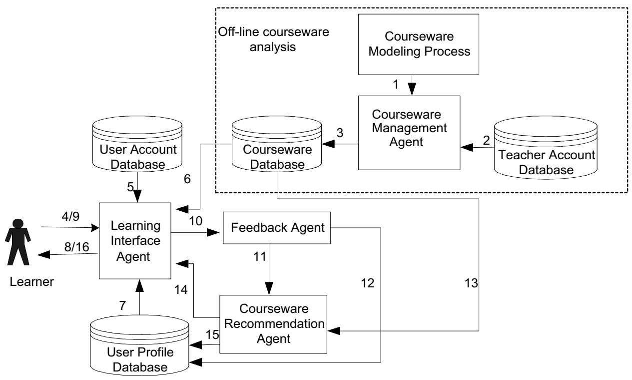

Figure 1. The system architecture

2.2 Learner's Feedback Mechanism

To perform personalized recommendation mechanism more precisely, learner must give feedback responses by replying two simple questions, i.e. the difficult level and the understanding percentage for the recommended courseware. In Figure 1, feedback agent aims at collecting these learners' feedback information from the interface agent into the user profile database. Therefore, we follow the testing logic with crisp response in the original item response theory [6] to modify the method of ability's estimation into a fuzzy response situation. The understanding percentage will be fuzzified as the fuzzy understanding degree by three fuzzy membership functions, which can be predefined by course experts according to real requirement. Assume that the understanding percentage is set as x, the three fuzzy membership functions, i.e. the membership function of lowly understanding $U_l(x)$, the membership function of moderately understanding $U_m(x)$, and the membership function of highly understanding $U_h(x)$, are defined as follows respectively:

(1) The membership function of lowly understanding is defined as follows:

$$U_l(x) = e^{-(\frac{x}{0.5})^2} \qquad for \quad x < 0.4 \tag{1}$$

(2) The membership function of moderately understanding is defined as follows:

$$U_m(x) = e^{-(\frac{x-0.5}{0.125})^2} \qquad for \quad 0.4 \le x \le 0.6 \tag{2}$$

(3) The membership function of highly understanding is defined as follows:

$$U_h(x) = e^{-(\frac{x-1}{0.5})^2} \qquad for \quad x > 0.6 \tag{3}$$

As system gets the understanding percentage from learner's feedback response, our em will fuzzified it to obtain the corresponding fuzzy understanding degrees through three predefined fuzzy membership functions. In this work, the fuzzy maximum operator is applied to obtain the final fuzzy understanding degree $U_u(x)$. The formula is described as follows:

$$U_u(x) = Max\{U_l(x), \;\; U_m(x), \;\; U_h(x)\} \tag{4}$$

where $U_u(x)$ is the final fuzzy understanding degree under the understanding percentage as x, $U_l(x)$ is the mapping fuzzy understanding degree of the lowly understanding membership function under the understanding percentage as x, $U_m(x)$ is the mapping fuzzy understanding degree of the moderately understanding membership function under the understanding percentage as x, and $U_h(x)$ is the mapping fuzzy understanding degree of the highly understanding membership function under the understanding percentage as x.

2.3 Courseware Recommendation Mechanism

Based on the estimation of learner's ability, this system can recommend the appropriate courseware to learners. In this section, how to evaluate learner's ability and recommend appropriate courseware to learner are described in detail.

2.3.1 Learner's Ability Estimation

To estimate learner's ability, the item characteristic function proposed by Rasch with a single difficulty parameter [6] is applied to model the courseware. The formula of item characteristic function with single difficulty parameter can be described as follows:

$$P_j(\theta) = \frac{e^{D(\theta - b_j)}}{1 + e^{D(\theta - b_j)}} \tag{5}$$

where $P_j(\theta)$ denotes the probability that learners can completely understand the j^{th} courseware at a level below their ability level θ, b_j is the difficulty of the j^{th} courseware, and D is a constant 1.702.

Besides, the Bayesian estimation procedure is applied to estimate learner's ability in this study. Bock and Mislevy [6] have given the quadrature form to approximately estimate learner's ability shown as follows:

$$\hat{\theta} = \frac{\sum_{k}^{q} \theta_k L(u_1, u_2, ..., u_n \mid \theta_k) A(\theta_k)}{\sum_{k}^{q} L(u_1, u_2, ..., u_n \mid \theta_k) A(\theta_k)} \quad (6)$$

where $\hat{\theta}$ represents the learner's ability of estimation, $L(u_1,u_2,\cdots,u_n \mid \theta_k)$ is the value of likelihood function at a level below their ability level θ_k and learner's responses are $u_1,u_2,...,u_n$, θ_k is the k^{th} split value of ability in the standard normal distribution function, and $A(\theta_k)$ represents the quadrature weight at a level below their ability level θ_k.

In Eqn. (6), the likelihood function $L(u_1,u_2,\cdots,u_n \mid \theta_k)$ can be further described as follows:

$$L(u_1,u_2,\cdots,u_n \mid \theta_k) = \prod_{j=1}^{n} P_j(\theta_k)^{u_j} Q_j(\theta_k)^{1-u_j} \quad (7)$$

where $P_j(\theta_k) = \frac{e^{D(\theta_k - b_j)}}{1 + e^{D(\theta_k - b_j)}}$, $Q_j(\theta_k) = 1 - P_j(\theta_k)$, $P_j(\theta)$ denotes the probability that learners can understand the j^{th} courseware at a level below their ability level θ_k, $Q_j(\theta_k)$ represents the probability that learners cannot understand the j^{th} courseware at a level below their ability level θ_k, and U_j is the answer of completely understanding or not understanding answer obtained from learner feedback to the j^{th} courseware, i.e. if the answer is completely understanding then $U_j = 1$; otherwise, $U_j = 0$.

Moreover, based on the proposed mapping approach of final fuzzy understanding degree, the estimation value of new learner's ability for a new learned courseware can be defined as follows:

$$\theta_{j+1} = \begin{cases} \theta_j + (\theta_w - \theta_j) \times U_u(x) & when \quad x < 0.4 \\ \theta_j & when \quad 0.4 \le x \le 0.6 \\ \theta_j + (\theta_c - \theta_j) \times U_u(x) & when \quad x > 0.6 \end{cases} \quad (8)$$

where θ_j is estimation value of learner's ability for total number of j previous learned courseware, θ_{j+1} is the estimation value of new learner's ability for the $(j+1)^{th}$ courseware, θ_w is estimation value of learner's ability under assuming that learner cannot completely understand the $(j+1)^{th}$ courseware, θ_c is estimation value of learner's ability under assuming that learner can completely understand the $(j+1)^{th}$ courseware, and $U_u(x)$ is the final fuzzy understanding degree.

2.3.2 Courseware Recommendation

Finally, the information function is applied to evaluate the recommendation index of courseware in order to recommend appropriate courseware to individual learner. The information function is defined as follows:

$$I_j(\theta) = \frac{(1.7)^2}{\left[e^{1.7(\theta - b_j)}\right]\left[1 + e^{-1.7(\theta - b_j)}\right]^2} \quad (9)$$

where $I_j(\theta)$ is the information function value of the j^{th} courseware at a level below their ability level θ, b_j is the difficulty parameter of the j^{th} courseware.

Restated, after calculating the corresponding information function values of all courseware, the course recommendation agent can recommend a series of courseware to learner with ability θ according to the ranking order of information function value. A courseware with the maximum information function value under learner with ability θ indicates that the system presented here gives the highest recommendation priority.

3. Experiments

In this section, the detailed functions of this system and experimental results are described.

3.1 System's Functions

Figure 2 shows the entire layout of the learning interface. In the left frame, system shows the course categories, course units and the list of all courseware in the courseware database. While a learner clicks a courseware for learning, the content of selected courseware will be exhibited in the upper-right window. Besides, the feedback interface is arranged in the bottom-right window. System can get learner's feedback response from the feedback interface through learner replies two simple questions illustrated as Figure 3.

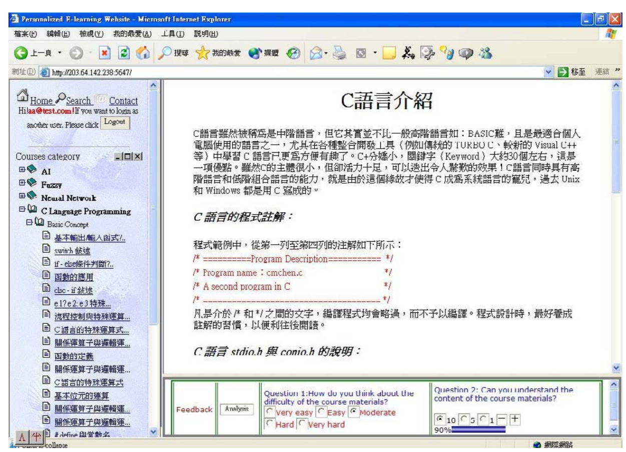

Figure 2. The learning interface for learner

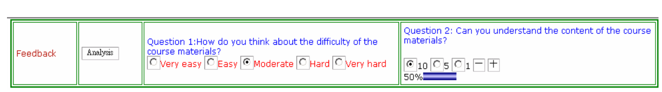

Figure 3. Two questionnaires for getting learner's

feedback information

Figure 4 shows an example of courseware recommendation based on learner ability after learner gives corresponding feedback response, and the recommended courseware ranked by the order of their information function values.

Figure 4. An example of courseware recommendation ranked by the information function values

3.2 Experimental Results

In our experiments, the loop concept in C language programming is selected as a course unit to provide personalized learning services. Figure 5 shows the relationship between the understanding percentage of the clicked courseware and the adjustment of the learner's ability. In Figure 5, we can find that the trend of learner's estimation ability follows his response of understanding percentage for the learned courseware. Besides, Figure 6 shows the relationship of the learner ability with the difficulty parameter of the recommended courseware. We find that the difficulty parameter of the recommended courseware is highly relevant with the learner ability. This result shows that the proposed system can indeed recommend appropriate courseware to learner according to individual learner ability.

4. Conclusion

This study proposes a personalized courseware recommendation system (PCRS) based on the proposed fuzzy item response theory (FIRT), which can on-line estimate the abilities of learners and recommend appropriate courseware to learners. Compared to the traditional item response theory, the fuzzy item response theory can accept non-crisp feedback response to correctly estimate learner's ability via the revised estimating function of learner's ability. PCRS provides personalized Web-based learning according to courseware visited by learners and their feedback responses. Experimental results show that the proposed system can precisely provide personalized courseware recommendations on-line based on learner abilities and responses, and moreover can accelerate learner learning efficiency and effectiveness. Importantly, learner only needs to reply two simple questions for personalized services.

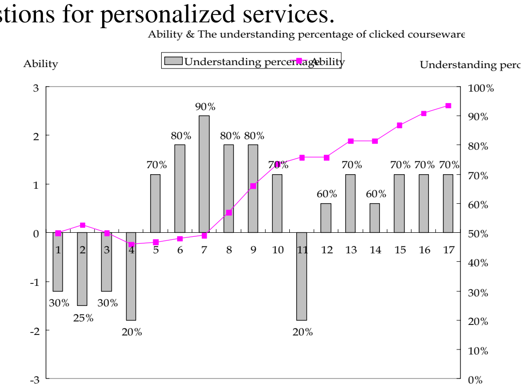

Figure 5. The relationship between the understanding percentage of the clicked courseware and the adjustment of the learner's ability

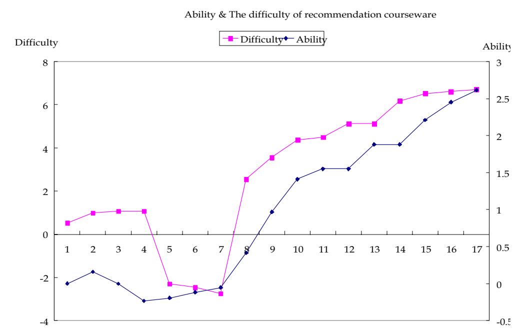

Figure 6. The relationship between learner's ability and the difficulty parameter of the recommended courseware

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