Study on an Adaptive Learning Support System Design based on Model-based Development

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***Abstract*—This research proposes an adaptive smart learning support system, whose target is a typing support system, based on the Model-Based Development (MBD) approach. The proposed typing support system adaptively adjusts the level of work so that the typing skill of a learner is smoothly grown. In this paper, the goal of an adaptive smart learning support system is briefly explained, and a concrete design scheme of a part of the support system based on the MBD approach is presented. This paper also mentions the work in progress of developing an actual typing support system.**

***Index Terms*—learning support system, leaner model, typing support software, model based development (MBD)**

I. Introduction

Recently, active learning that learners proactively learn through group work, group discussion, debate, and so on has been advocated in education. On the other hand, the role of web-based training (WBT) for acquiring basic knowledge and/or skills is also increasing. To improve the efficiency of learning by WBT, it is important that a WBT system continually presents suitable tasks to a learner. The authors have proposed an adaptive learning support system [1] that adaptively presents tasks corresponding to a learner's property. In this proposed system, a constructed learning support system including a learner is regarded as one of the closed-loop control systems. Moreover, the support system that behaves as a controller in the closed-loop determines the difficulty of the task based on a database stored in the past learner's input/output (IO) data. It must be required a lot of experiments with many learners to evaluate the effectiveness of the proposed system. However, many resources such as learners and/or opportunities to practice are limited, therefore it requires taking much time to verify a proposed system. The above situation deteriorates the speed of developments, and it causes a problem to delay the development of the research field.

On the other hand, in the industrial world, they have been required more product development efficiency to respond to rapid changes in customer needs. In many industrial fields typified by vehicle production, a model-based development (MBD) [2], [3] has been introduced as one of the breakthrough methods for the above situation. MBD describes every component that constructs a complex system such as a vehicle system as a model that can be simulated on a computer, and performs most design, verification, and calibration on computers by using the (multi-connected) component models. In MBD, it expects to speed up development time because a critical system flaw or changes of behavior when some parts of components are changed can be founded before the prototyping test.

This paper proposes a design method of an adaptive smart learning system based on MBD approach that utilizes a typing support system as a development subject. Firstly, a behavior model of a learner in typing learning (learner model) is proposed. In this research, from the viewpoint of control engineering, the learner model is derived as a stochastic model whose input is a difficulty of word and output is the accuracy of its typing (correct answer rate). Moreover, the proposed learner model has an adjustable parameter that expresses a

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typing skill level of the learner. Secondly, a proportional, integral (PI) controller is designed to make the current correct answer rate goal correct answer rate by control. This paper shows it can perform simulation of the feedback control system based on the model-based approach by component models: the learner model, and the controller model. Moreover, it presents a brief overview of the current developing typing support system, and mentions to our future work.

II. Outline of adaptive typing system

The idea of the proposed adaptive typing support system is shown in Fig. 1. The proposed system presents a word as a task of the learner through a user interface (UI) such as a monitor, and the learner types the word by a keyboard. By repeating this sequence the learner gets typing skill gradually. This proposed system is one of the feedback control systems. The system regards the learner to the controlled object, and it constructs the inner loop including C_S and the outer loop including C_P. The output $y(t)$ from the outer loop is the level of the typing skill. The output from the inner loop is the correct answer rate x_ε which is gotten by that the learner's typing result (right or wrong) y_t goes through an estimation filter of correct answer rate F. The controller C_P in the outer loop determines the goal correct answer rate r_ε based on the internal model controller design scheme [4]. The controller C_S in the inner loop decides the difficulty of the presented word u based on r_ε and $\hat{x}_\varepsilon$ using the PI control law. This paper describes the construction of the inner loop with hatching in the figure, the development status of the MILS model design, and its implementation in a real system.

III. System design based model in the loop simulation (MILS)

This section presents a design method of a learner model for designing a system based on MILS and design method of a control algorithm of the learner's correct answer rate.

A. Learner Model Design

References Yamane [5] and Nagamatsu [6] have pointed out that an increase of learner's property such as skill and knowledge can be described as the first-order system from the viewpoint of the control engineering. This paper derives the property of the learner's typing skill model by a frequency transfer function based on the above idea. The frequency transfer function can be described as follows.

$$G(j\omega) = \frac{Y(j\omega)}{U(j\omega)} = \frac{K}{1+j\omega T} \tag{1}$$

$U(j\omega)$ and $Y(j\omega)$ indicates the input and output signal, respectively. K and T expresses the system gain and the time constant. The frequency transfer function includes the information of the amplitude and the phase, this research mainly focuses on the equation of the amplitude given as follows.

$$|G(j\omega)| = \frac{K}{\sqrt{1+(\omega T)^2}} \tag{2}$$

(2) indicates that the higher the frequency included in the sin-shape input signal is, the less the amplitude of the output corresponding to the input signal is.

A learner model based on (2) is proposed in this paper. In the proposed model, the input for the model is the difficulty of the presented word, and the correct answer rate $x_\varepsilon(u)$ corresponding to the difficulty are defined, and its model is defined as follows.

$$x_\varepsilon(u) = \frac{1}{\sqrt{1+(u/\alpha_s)^2}} \tag{3}$$

Where α_s is an adjustable parameter which determines the property of the learner. Fig. 2 shows the result of $x_\varepsilon(u)$ when α_s is changed from 0.05 to 50. Note that, the upper figure is a figure that shows the difficulty with normal scale(that is from 0 to 10). The lower figure is a figure that the difficulty in the horizontal axis is shown from $10^{-2} - 10^1$ and the output is shown by the logarithmic scale $20\log x_\varepsilon$.

These figures indicate that the bigger α_s is the wider the range of difficulty that the correct answer rate becomes 0 [dB] corresponding to the difficulty of the presented word is. Therefore, learner models with various properties can be designed by setting their property as α_s. In the simulation, the model output $y_t = 1$ as correct typing result with the probability of $x_\varepsilon(u)$, and outputs $y_t = 0$ as mistyping result with the probability of $1 - x_\varepsilon(u)$.

B. Design of Correct Answer Rate Estimator

The learner model outputs binary output such as correct typing $y_t = 1$ or mistyping $y_t = 0$ from hour to hour following to their probability $x_\varepsilon(u)$. Therefore it is difficult to design a feedback controller such as the PID controller by only using a current binary output. In this research, a correct answer rate estimator that estimates the internal variable by getting series data of $y_t(t)$ is designed. The controller utilizes the output $\hat{x}_\varepsilon(k)$ obtained by the estimator. The correct answer rate estimator is designed as follows.

$$\hat{x}_\varepsilon(k) = -a_1\hat{x}_\varepsilon(k-1) + b_0 y_t(k) \tag{4}$$

$$b_0 = 1 + a_1 \tag{5}$$

Where k indicates a number of steps. Moreover, the value of a must be $-1 < a_1 < 0$ for the estimator's stability.

Fig. 3 shows the transition of the learner's output y_t and the estimator's output $\hat{x}_\varepsilon(k)$ when the word with difficulty $u = 10$ is continuously presented to a learner (note: the property α is set to 5). Moreover, in the figure of the estimator's output, the actual correct answer rate $x_\varepsilon(u)$ is also plotted as a reference. Note that, this simulation result is obtained by setting to $a_1 = -0.95$. The result shows that the estimated value is achieved to the true value after 30 steps, thus it can say that the estimator is able to estimate the correct answer rate in a learner by using typing results for about 30 questions.

C. Learning Support Controller Design

A learning support controller that controls the learner's correct answer rate by using $\hat{x}_\varepsilon(k)$ is designed. Since the correct

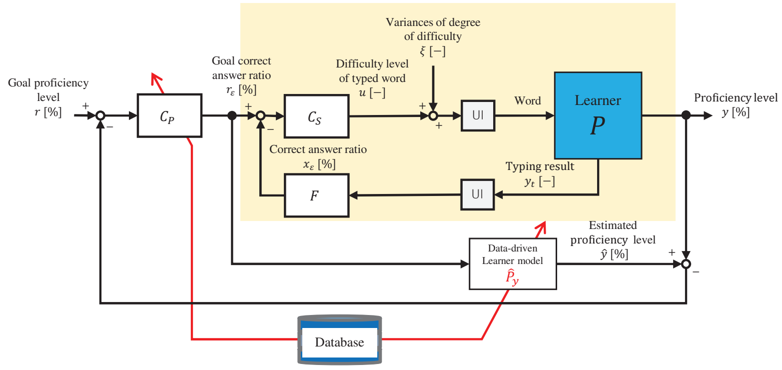


Fig. 1. Block diagram of proposed typing support system.

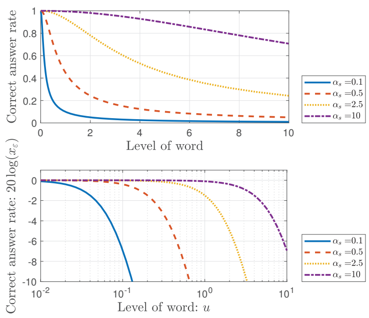


Fig. 2. Skill curves of learners' model (upper: normal scale, lower: log. scale).

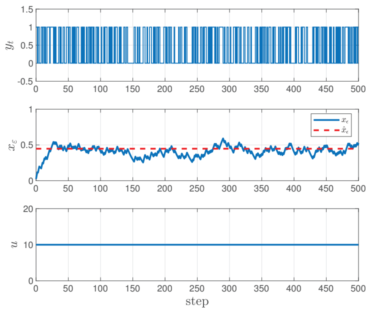


Fig. 3. Step response of learner model and filter output.

answer rate estimator has dynamics, a feedback controller that can compensate for dynamics is adopted. In this research, the following proportional-integral (PI) control law [7] that is usually applied at process controls are introduced.

$$u(k) = u(k-1) - \{K_I e(k) - K_P \Delta \hat{x}_\varepsilon(k)\} \quad (6)$$

$$e(k) := r_\varepsilon(k) - \hat{x}_\varepsilon(k) \quad (7)$$

Where K_P and K_I are the proportional gain and the integral gain. Δ is the differential operator that is defined as $\Delta = 1 - z^{-1}$ by using backward operator z^{-1}. Note that $z^{-1}y(k) := y(k-1)$. Moreover, to improve the correct answer rate, the difficulty of the task is typically adjusted lower value. Therefore, from the controller, since the controlled object which is a learner model is regarded to have negative system

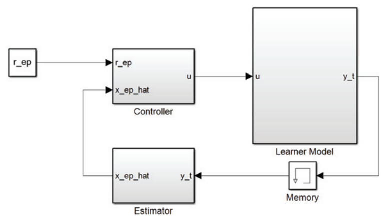


Fig. 4. Typing support system constructed by MATLAB/Simulink.

gain, the correction term after the second term on the right-hand member is subtracted from $u(k-1)$.

A simulation model for MILS that is composed of the learner model, the correct answer rate estimator, and the learning support controller is constructed by using MATLAB/Simulink R2019b as shown in Fig. 4. Note that the Memory block in the model is adopted to avoid the algebraic loop in the simulation. The next section presents a simulation result of the proposed system.

D. Simulation Result

The performance of the proposed system is validated by the simulation. In this simulation, it will be validated that it is able to make the estimated output $\hat{x}_\varepsilon(k)$ follows goal correct answer rate $r_\varepsilon(k)$ by automatically adjusting the difficulty $u(k)$.

Where the goal of the correct answer rate $r_\varepsilon(k)$ at each step are set as follows.

$$r_\varepsilon(k) = \begin{cases} 0.3 \ (0 \leq k < 300) \\ 0.6 \ (300 \leq k < 600) \\ 0.9 \ (600 \leq k < 900) \end{cases} \quad (8)$$

The parameters of the learner model and the estimator are set to $\alpha_s = 5$, $a_1 = -0.95$ as same as the previous section, respectively. Moreover, the saturated region of the difficulty of the word u are set as $u_{\min} = 1$, $u_{\max} = 16$, respectively. When setting the difficulty level of a word in the actual system described in the next section, the length of the word is used as the difficulty level, and the minimum and maximum values of the word length are 1 character and 16 characters, respectively. This is the reason why the saturated region is set. Note that, in

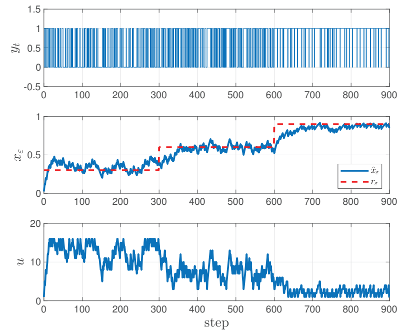
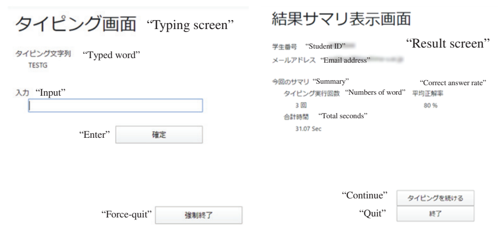


Fig. 5. Control result of proposed system.



the simulation, the difficulty calculated by (6) is rounded, and the rounded value is input to the learner model. The control result where the PI gains are set as follows is shown in Fig. 5.

$$K_P = 50, \ K_I = 2 \tag{9}$$

This result shows that the estimated output $\hat{x}_\varepsilon(k)$ from the estimator follows the goal of the correct answer rate $r_\varepsilon(k)$ by automatically decreasing the difficulty of the word $u(k)$ determined by the proposed controller.

IV. Developing Typing Support System

In this section, as work in progress, it explains the developing status of typing support system. Fig. 6 shows the interface part of the proposed system. As shown in the left figure, the English word as a task is presented, and a learner input the word in the text box. After a predetermined number of words have been entered, information such as the number of typing executions, total time, and the average correct answer rate is fed back to the learner by showing on the result summary display screen. Learner's input results are managed as a database using MySQL so that the system can refer to it at any time. The list of English words to be assigned uses 8000 words (JACET8000) selected by the Japan Association of College English Teachers (JACET). The English words included are 1-16 words long, and in this study, the difficulty of the words is assumed to be "word length" in the simulation. However, in typing training, it is considered that the difficulty of typing a word is affected not only by the word length but also by the keyboard layout and the frequency of use in everyday life. Therefore, the setting of this difficulty level needs to be studied in the future.

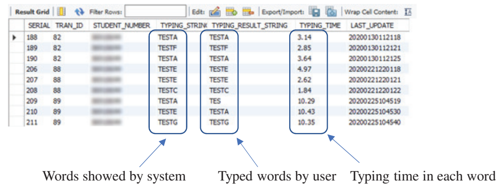


Fig. 7. Typing results in database of proposed system.

V. Conclusions

This study proposed a method for constructing an adaptive smart learning support system based on MBD approach using typing support software as a development subject. First, it was shown that the adaptive smart learning support system is composed of two loops, an outer loop and an inner loop, and then a specific design method of the inner loop was outlined. In the inner loop, it was shown that MILS is realized by three elements: the learner model, the correct answer rate estimator, and the learning support controller, and the performance of the proposed system was verified by simulation. Moreover, the development status of the actual support system based on the simulation results was also mentioned.

In developing this system, the following points will be major issues in the future.

- Verification of the validity of the simulation model by operating the real system.
- Definition and modeling of internal state related to learner's proficiency.
- Establishment of outer loop construction method using a database.

Especially, in the second item, there is a problem that the growth model of the learner model has not been described In other words, though the skill of a learner model in this typing system is defined by α_s in eq. (3), the mechanism of changing α_s has not been made clear. If the mechanism of the growth of the learner will make clear, this system is expected to support learner's growth strongly. In the future, the above issues and aim will be worked on for the full-scale operation of the proposed system as a WBT system.

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