Diagnostic models of intelligent tutor system for teaching skills to construct control object frequency characteristics

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Abstract:

In this paper one solution for teaching skills to construct the control object frequency characteristics method is described. Student's mistakes are discovered and classified. Based on signal-parametric approach to fault diagnosis in dynamic systems mathematical diagnostic models which allow detecting mistake classes by comparing student calculated results and system calculated results are created. Features of proposed diagnostic models application are presented. Intelligent tutor system is developed and used on "Automatic Control Theory" practical training by third year students of National Aerospace University.

1 Introduction

A high level of the professional competence necessary for modern engineers increases the requirements to a quality of educational process at technical universities. At the same time the traditional process of knowledges and skills transfer cannot provide such quality in conditions of mass production.

Considering traditional educational process from the positions of scientific process control it is possible to mark the following destabilizing factors [1]:

1. Low basic level of knowledges and motivations of some students for qualitative training.
2. Weak pedagogical and vocational preparation of some teachers.
3. Action of perturbations both on pupils, and on teachers.
4. Training without wide, deep and regular monitoring of knowledges and skills.
5. Training without adaptation to psychophysiological potentialities of students.

It is possible to eliminate or reduce negative influence of the specified factors on quality of training by means of the intelligent computer tutor systems, which have absorbed pedagogical skill and experience of the best teachers and are capable to adapt to students' psychophysiological features.

The important component of an intelligent computer tutor system is the collection of used diagnostic models [2]. Diagnostic models allow to determine not only presence of a mistake but also its reason. Exact diagnosing of the student mistakes assists to define blanks in knowledge and accordingly to modify process of training.

In the paper the diagnostic models of the intelligent computer tutor system for construction of frequency characteristics of control object are considered. Frequency characteristics are the important tools of the analysis and synthesis of control systems. They allow to determine such parameters of control object quality as an oscillation, a passband, a speed.

2 Problem Definition

1. To analyze control object frequency characteristic finding tasks solutions written by students and on the basis of results discover and classify student's mistakes.
2. On the basis of the signal-parametric approach to fault diagnosis in dynamic systems [3,4] create mathematical diagnostic models which allow detecting mistake classes by comparing student calculated results and system calculated results.
3. To develop intelligent tutor system for control object frequency characteristic finding method learning which includes following main functions: a) support student by guide which covered theoretical questions appeared during method learning; b) task solution sequence control; c) student knowledge and skills step-by-step diagnosis; d) student knowledge and skills remediation by feedback introducing.

3 Computer model description of control object frequency characteristics finding method

Let $A(s) = a_n s^n + a_{n-1} s^{n-1} + ... + a_0$ and $B(s) = b_m s^m + b_{m-1} s^{m-1} + ... + b_0$ are polynoms where a_i and b_g are the numbers: $a_i \in R$, $b_g \in R$, $i = \overline{0,n}$, $g = \overline{0,m}$, $n \in \{0, 1, ...\}$, $m \in \{n, n+1, ...\}$.
Then the transfer function of control object can be presented as follows:

$$W(s) = \frac{Y(s)}{X(s)} = \frac{A(s)}{B(s)} = \frac{a_n s^n + a_{n-1} s^{n-1} + ... + a_0}{b_m s^m + b_{m-1} s^{m-1} + ... + b_0}. \quad (1)$$

It is necessary to construct the frequency characteristics of the given system. The argument s of the transfer function is presented by the operator of Laplace transformation, which is connected with frequency by the following formula:

$$s = j\omega, \quad (2)$$

where $\omega \in (0, \infty)$ is a frequency of an input signal.
Then

$$W(j\omega) = \frac{A(j\omega)}{B(j\omega)}. \quad (3)$$

Let's present the transfer function in the form of

$$W = u + jv. \quad (4)$$

We should get rid of the irrationality of the denominator by means of multiplication of the numerator and denominator by the expression conjugate to denominator.

$$W_{transf}(j\omega) = \frac{A(j\omega)}{B(j\omega)} \cdot \frac{B^*(j\omega)}{B^*(j\omega)}, \quad (5),$$

where $B^*(j\omega)$ is the expression conjugate to denominator.
Then we should build the following diagrams: an amplitude-frequency response (AFR)

$$A(\omega) = \sqrt{u(\omega)^2 + v(\omega)^2}; \quad (6)$$

a phase-frequency response (PFR)

$$\varphi(\omega) = \mathrm{arctg} \frac{v(\omega)}{u(\omega)}; \quad (7)$$

an amplitude-phase-frequency response (APFR)

$$f(\omega) = v(u) \,. \tag{8}$$

Thus, to get the decision of this task the student should execute the following actions:

1. To transit from the operator of Laplace transformation to the frequency domain.
2. To get rid of the irrationality of the transfer function denominator
3. To transform transfer function into the form (5).
4. To define dependences for construction of the characteristics.
5. To construct the characteristics according to the received dependences.

4 Experimental results

To determine specific problems which appear when students construct the frequency characteristics of control object we conducted experiment. 42 third-year students who study on a speciality «Automatic control systems» took part in it.

The control group students received the tasks of three degrees of transfer function complexity: a) the numerator is a polynom of first order and the denominator – a polynom of second order; b) the numerator is a polynom of first order and the denominator – a polynom of third order; c) the numerator is a polynom of second order and the denominator – a polynom of third order. Necessary accuracy of calculations was 4 significant positions.

To reveal a maximum quantity of mistakes during the analysis of student's works we simulated calculations of the student even after detection of mistakes. In that way 95 different mistakes were detected.

Below discovered classes are presented (Table1).

Table 1. Classes of the mistakes

Mistake class	Number of mistakes	%
Ignorance of the condition of object physical realizability	4	4,2
Loss of a sign at calculations	8	8,42
Mistake at polynomial multiplication	21	22,1
Omission of the double product at expression squaring	5	5,26
Writing the single product instead of the double product at expression squaring	5	5,26
Mistake at exponentiation of imaginary unit	3	3,16
Imaginary part contains imaginary unit	24	25,26
Mistake at division of the real and imaginary parts	2	2,1
Ignorance of dependences for the characteristics construction	4	4,2
Negative frequency	2	2,1
Misspelling	8	8,4
Round off mistake	5	5,26
Others	4	4,2

Let's uncover essence of presented classes.

The conceptual mistake "Ignorance of the condition of object physical realization" is caused by misunderstanding that the order of a transfer function numerator cannot be more than the order of a denominator and such control objects are not realized at the given stage of engineering progress.

The class “Loss of sign at calculations” are the widespread mistakes committed because of carelessness in calculations.

The class “Mistake at polynomial multiplication” includes mistakes committed at multiplication of numerator and denominator by the expression conjugated to a denominator (missing of a polynomial member, mistake at work with powers, sign loss etc.).

The classes “Omission of the double product at expression squaring” and “Writing the single product instead of the double product at expression squaring” are connected with a conceptual mistake - ignorance of the formulas of abridged multiplication.

An example of the mistake at exponentiation of imaginary unit is presented in Fig. 1. It happens when the student is ignorant of the following facts: imaginary unit raised to an odd power is a complex number and imaginary unit raised to an even power is a real number.

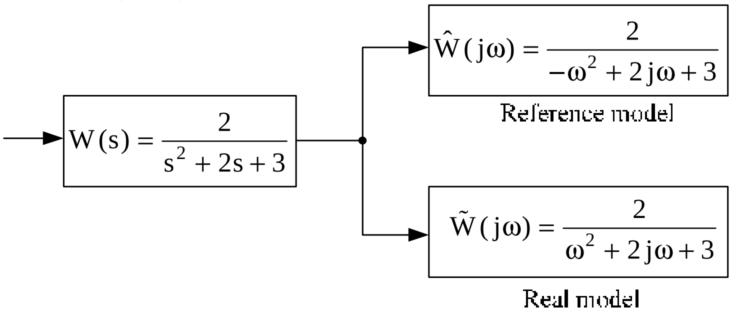

Figure 1. An example of the mistake at exponentiation of imaginary unit

The class «Imaginary part contains imaginary unit» includes conceptual mistakes presented by Fig.2. It don’t allow pass on to characteristics building.

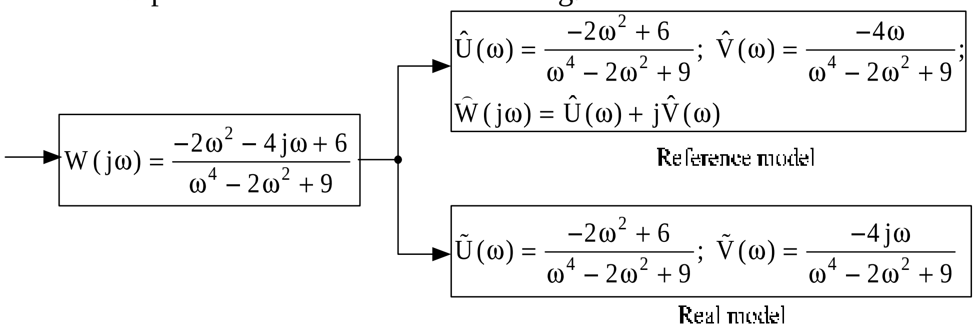

Figure 2. An example of the mistake – imaginary part contains imaginary unit

The mistake at division of the real and imaginary parts is their permutation.

The class « Ignorance of dependences for the characteristics construction » includes mistakes at calculation of expressions: a radical or squares were missed for AFR; a mistake in argument of arctangent function or loss of a sign in arctangent function for PFR.

The class “Negative frequency” is connected with finding values $A(\omega)$ and $\varphi(\omega)$ for negative values of frequency. The frequency can accept only zero value (constant signal) or positive value (sine wave signal).

The “Misspelling” class includes such typical spelling or input errors as single transcription, symbol deletion and symbol addition.

The “Round off mistake” covers rounding mistakes and ignorance of computing accuracy requirements.

The „Other mistakes” class includes mistakes which reason is not established.

5. Diagnostic models

Diagnostic model (DM) is a mathematical model which connects mistake with its symptom and allows solving of inverse problem [3, 4].
Let’s introduce symbols: $\tilde{x}$ is a value calculated by student, $\hat{x}$ is a reference value calculated by tutor program.
Then DM for mistake detecting is $\tilde{x} \neq \hat{x}$.
After mistake detecting we should identify its cause. So we use DMs for class finding.
For instance, DM for finding «Ignorance of the condition of object physical realization» class is $\tilde{n} > \tilde{m}$.
DM for “Loss of a sign at calculations” is defined as follows $\tilde{x} = -\hat{x}$.
DM for “Mistake at exponentiation of imaginary unit” may be written as $((pow(\hat{b}_i) \bmod 2 <> 0) \wedge (\tilde{b}_i \in R)) \vee ((pow(\hat{b}_i) \bmod 2 = 0) \wedge (\tilde{b}_i \in C))$, where $pow(\hat{b}_i)$ is an argument of $B(s)$ i-th member exponent.
Before creation DM „Omission of the double product at expression squaring” for a transfer function denominator as a polynom of second order let’s $y = B(j\omega)\cdot B^*(j\omega) = (x_{L1} + x_{L2})^2 - x_R^2$. Then DM is presented as follows $\tilde{y} - \hat{y} = -2\hat{x}_{L1}\hat{x}_{L2}$, where $\tilde{y}, \hat{y}$ are the real and reference formulas. DM for “Writing the single product instead of the double product at expression squaring” is $\tilde{y} - \hat{y} = -\hat{x}_{L1}\hat{x}_{L2}$.
For finding “missing of a polynomial member” we can use DM $\left|\left\{\tilde{k}_0, \tilde{k}_1, ..., \tilde{k}_a\right\}\right| \leq \left|\left\{\hat{k}_0, \hat{k}_1, ..., \hat{k}_b\right\}\right|$, where $\tilde{k}_i \neq 0$ is a coefficient at i-th member of a reference polynom; $\hat{k}_i \neq 0$ is a coefficient at i-th member of a real polynom.
DM for “Mistake at division of the real and imaginary parts” is $(\tilde{u} = \hat{v}) \wedge (\tilde{v} = \hat{u})$ and DM for “Imaginary part contains imaginary unit” is $\tilde{v} \in C$.
For “Negative frequency” mistake finding we can use DM $\exists\omega : \omega < 0$.
Let's introduce an auxiliary function $r\_f(x, h)$ to present by the rounding rules any real number x with a floating decimal point to within h digits after the point: $r\_f(x, h) = (-1)^t \cdot (z_0 + z_1 \cdot 10^{-1} + z_2 \cdot 10^{-2} + ... + z_h \cdot 10^{-h}) \cdot 10^p$, where $z_b \in \{0, 1, ..., 9\}, t \in \{1, 2\}$, p is an integer number, $(z_0 > 0) \oplus (\forall b\, z_b = 0)$.
Then DM for “Ignorance of dependences for the characteristics construction” are defined as follows. $\tilde{A} = r\_f(\hat{u}^2 + \hat{v}^2, h)$ means that a radical is missed for AFR; $\tilde{A} = r\_f(\sqrt{u + v^2}, h)$ signifies that a square of real part is missed for AFR; $\tilde{A} = r\_f(\sqrt{\hat{u}^2 + \hat{v}}, h)$ stands for missed square of imaginary part for AFR; $\tilde{\varphi} = r\_f(\mathrm{arctg}\frac{\hat{u}}{\hat{v}}, h)$ implies the transposition of real and imaginary part for PFR; $\tilde{\varphi} = r\_f(\mathrm{arctg}\,\hat{u}, h)$, $\tilde{\varphi} = r\_f(\mathrm{arctg}\,\hat{v}, h)$ means the presence of mistakes in the argument of arctangent function for PFR; $\tilde{\varphi} = r\_f(-\mathrm{arctg}\frac{\hat{u}}{\hat{v}}, h)$ matters the loss of a sign in arctangent function for PFR.
DMs for “Round off mistake” class are defined by two following models.

$(r\_f(\tilde{x},h) - r\_f(\hat{x},h) = -1\cdot 10^{ex(r\_f(\hat{x},h))-h}) \wedge (\hat{z}_{h+1} \geq 5)$ serves for finding mistakes in rounding, where $\hat{z}_{h+1}$ is a stored reference (h+1) significant position.

DM for finding mistakes connected with ignorance of computing accuracy requirements is defined as follows $r\_f(\tilde{x},h) = r\_f(\hat{x},b),\ 0 \leq b < h$.

To find single transcription we use DM which defined as $\exists b\,(\tilde{z}_b \neq \hat{z}_b) \wedge (\forall s \in \{0,1,...,h\} - \{b\}\ \tilde{z}_s = \hat{z}_s)$.

For finding all of “Misspelling” mistakes similar strings detecting methods [5,6] can be used.

One of the possible scenarios of obtained DM application is presented in Fig 3.

If student makes mistake the program will inform that mistake have been made, analyze mistake and then allow student to correct it. If mistake is made twice the program again will inform that mistake have been made, analyze mistake and offer to repeat operations by steps. And only if student makes mistake on i-step the program will produce diagnostic message about mistake with specifying its class.

Such approach is agreed with a principle that student should at first work on mistakes without assistance. Thus the diagnostic message with a hint about the cause of the mistake is not given immediately. Instead of it, the opportunity to find and correct a mistake is given to the student. At the same time results of the mistakes analysis which is performed by the program on each step are stored in the student model.

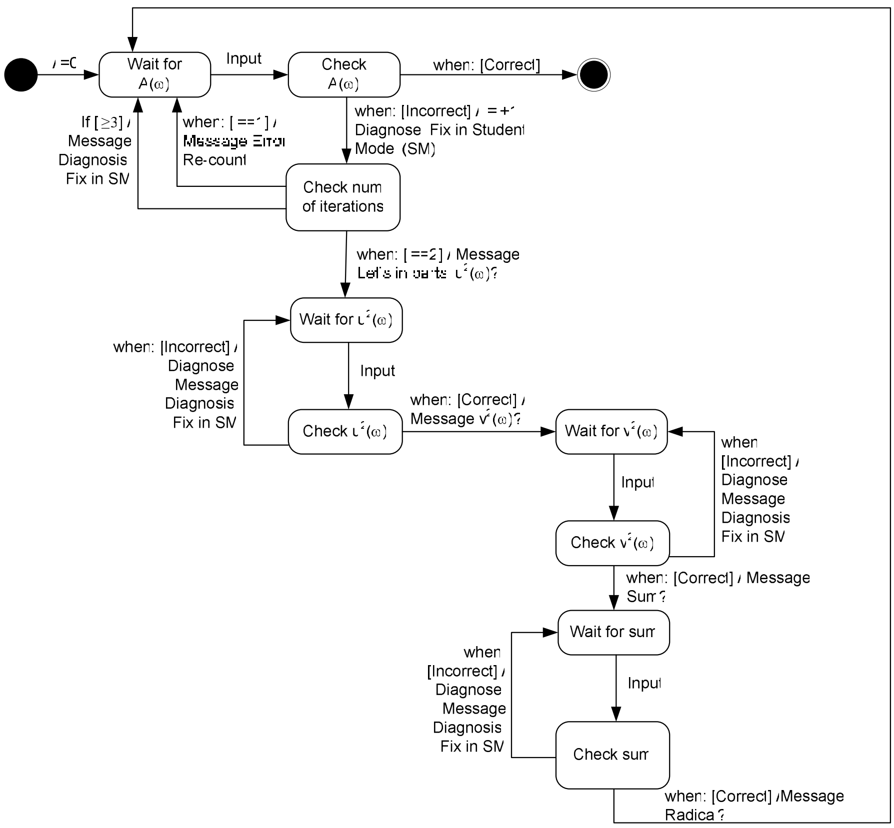

Figure 3. Fragment of diagnostic models application scenario

We have implemented in Delphi such intelligent tutor system screenshots of which are presented in Fig. 4. This system includes all defined above diagnostic models. When student misconception is found system returns him to the theory learning. It is used on “Automatic Control Theory” practical training by third year students of our university. As for results we increased the training efficiency because every student correctly solves his task without teacher’s assistance, system helps to a teacher to understand where gaps in one's knowledge are and to correct training adaptively.

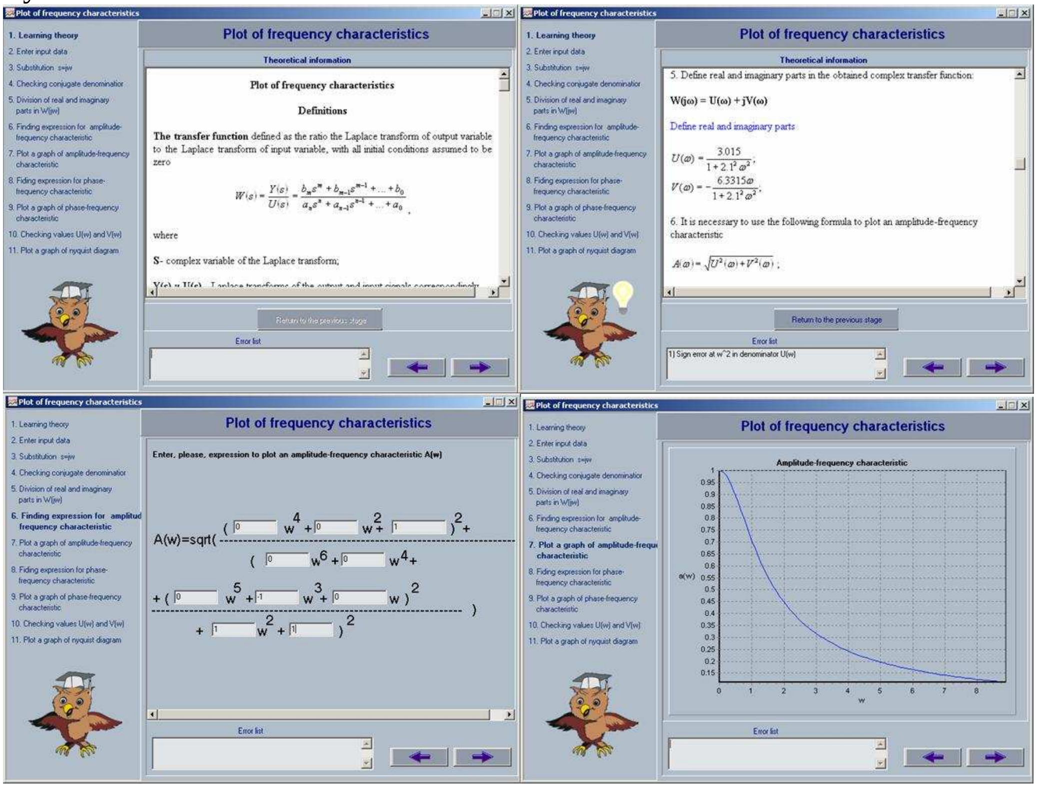

Figure 4. Intelligent tutor system screenshots

6. The Conclusion

The main contributions of present paper are first of all the results of student’s professional mistakes experimental research and secondly based on it proposed diagnostic models to form a diagnostic service as a part of intelligent tutor system for professional skills training without teacher’s assistance.

Now we are implementing diagnostic models in interpreted language and store it in database. Such approach allows to add/modify diagnostic models without any changes in program shell. Moreover program shell in mode of self-learning is able to generate new diagnostic models, store it in database and then interpret it. We are also going to create intelligent tutor web portal.

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