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DIAGNOSTIC SUPPORT OF INTELLIGENT TUTOR SYSTEM FOR TEACHING SKILLS TO CONSTRUCT CONTROL OBJECT FREQUENCY CHARACTERISTICS

This article describes a solution for learning how to build the method of frequency characteristics of the control object. Nowadays, the level of competencies required in the work of a modern engineer is becoming higher and higher, and the more difficult it is to provide the necessary level of knowledge and skills using only the traditional approach. This problem can be solved by implementing automated learning systems that will relieve teachers, reach more students, and unify the quality of work. The subject of the research is the possibility of building a certain abstract system that will be able to provide complex skills for students in an automatic mode. The basis for this research is a complex task that requires various skills from the learner. As a system that requires well-developed skills, we can cite the system of construction of the frequency characteristics of the control object. This work studied the methods for building such systems, as well as to study the learning ability of students and for extracting the most frequent and possible errors of students. The goal is to design and run a system that allows the student to acquire skills in constructing the frequency characteristics of an object. This work allows use of one of the possible methods for implementing such a task, as well as identifying the most common problems at the stage of learning this technique and the most successful method to prepare the system for use. In the process of the task, the following results were obtained: student errors were identified and classified. Based on the signal-parametric approach to the diagnosis of faults in dynamic systems, mathematical diagnostic models were created, that allow the system to identify classes of errors by comparing the calculation results of the student and the calculation results of the system. The peculiarities of the application of the proposed diagnostic models are presented. The intelligent tutor system is developed and used in practical classes on "Theory of automatic control" by third-year students of the National Aerospace University "Kharkiv Aviation Institute".

Keywords: Intelligent tutor system; student mistake; diagnostic model.

Introduction

The high level of professional competencies required by modern engineers increases the requirements for the quality of the educational process in technical universities. At the same time, the traditional process of transferring knowledge and skills cannot provide such quality in the conditions of mass production [1].

Considering the traditional educational process from the perspective of scientific process management, the following destabilizing factors can be noted:

1. Low basic level of knowledge and motivations of some students for qualitative training.

2. Weak pedagogical and vocational preparation of some teachers.

3. The action of perturbations both on pupils and on teachers.

4. Training without wide, deep, and regular monitoring of knowledge and skills.

5. Training without adaptation to psychophysiological potentialities of students [2].

To eliminate or reduce the negative impact of these factors on the quality of education is possible with the help of intelligent tutoring systems (ITS) that absorbed the pedagogical skill and experience of the best teachers and can adapt to the psycho-physiological characteristics of students.

The main features of the ITS are:

− interactive functioning in three modes: demonstration, training and testing;

− automatic generation of tasks and correct solutions using special mathematical models;

− in-depth diagnosis of the knowledge and skills of each student using a new class of mathematical models − diagnostic models that connect direct and indirect signs of mistakes made by students;

− modeling the knowledge and skills of learners in conditions of uncertainty;

−a two-level approach to learning: the 1st level is a task to apply some algorithms; 2nd level (higher level of competence) − the task of composing the same algorithms;

−an individual and adaptive approach to everyone who is taught, due to the external cycle - adaptive selection of the next task for a specific student and the internal cycle - adaptive selection of the next step when performing a specific task;

−optimal (minimal from the point of view of necessary transformations) training sequences;

−learning in game mode.

An important component of ITS is a collection of diagnostic models used [3]. Diagnostic models allow determining not only the presence of an error but also its cause. Accurate diagnosis of student errors helps to identify gaps in knowledge and modify the learning process accordingly.

Diagnostic models serve as a productive knowledge base and a mechanism for responding flexibly and adapting to each individual learner.

It is also necessary not to forget about the motivation and emotions that students experience during their studies. Correct motivation and work from a psychological point of view are extremely important when working with people - and the correct processing of the system's feedback and the principle of interaction with the student can be one of the key factors in creating such systems [4].

It is also necessary to mention the specifics of working directly with the mathematical sciences - as the correct determination of the source of the problem in the student's education is extremely important and always needs the most accurate calculations - respectively, the system must work with the maximum accuracy of calculations in its field, as well as to select the correct algorithms for different kinds of task [5].

The article deals with the diagnostic models of intelligent computer learning systems for constructing the frequency characteristics of the control object. Frequency characteristics are an important tool for the analysis and synthesis of control systems. They allow determining such quality parameters of the control object as oscillation, bandwidth, and velocity [6].

The main purpose of this article is to study the methods of building such systems, as well as to identify and classify possible errors of students.

In contrast to previous research and development, it was decided to add not only classification and error detection, but also to develop and implement a real and a reference model in the system (diagnostic models). The method is based on comparing models and determining the differences, to build and train an automated learning system. Thanks to this approach it is possible to achieve more flexibility, speed, and accuracy in the future system.

1. Problem Definition

The main problem is not so much the identification of errors made by students, but the possibility of subsequent correction of these errors and improvement of student performance.

Most modern systems can easily identify and point out errors, but they are not able to identify the weaknesses and strengths of the student, give feedback, and, accordingly, the opportunity for the student to improve his level of knowledge.

On this basis, the following plan of action for the creation of the system was proposed:

1. Analyze the frequency characteristic of the control object, find solutions to the tasks written by students, and, based on the results, identify and classify students' errors.

2. Based on the signal-parametric approach to diagnosing faults in dynamic systems [7 - 9], create mathematical diagnostic models that allow to identify classes of errors by comparing the calculated results of the student and the calculated results of the system.

3. Develop an intelligent training system for teaching the method of finding the frequency characteristics of the control object, including the following main functions:

a) support the student with a guide, which addresses theoretical issues arising in the study of the method;

b) control the sequence of problem-solving;

c) step-by-step diagnosis of knowledge and skills of the student;

d) correction of knowledge and skills of the student with feedback.

Based on this, the first step would be to develop a computer model description of the control object frequency characteristics finding method.

The system will need this model to identify different errors, group them, and identify key areas to work on and give more detailed feedback to students.

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 polynomials where a_i and b_g are the numbers:

$$a_i \in R, b_g \in R,$$
$$i = 0, ..., n, g = 0, ..., m,$$
$$n \in \{0, 1, ...\}, m \in \{n, n+1, ...\}.$$

Then the transfer function of the control object can be presented as follows:

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

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

$$s = j\omega,$$

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

Then

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

Let's present the transfer function in the form of

$$W = u + jv.$$

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

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

where $B^*(j\omega)$ is the expression conjugate to the denominator.

Then the following diagrams should be created: an amplitude-frequency response (AFR)

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

a phase-frequency response (PFR)

$$\varphi(\omega) = \frac{v(\omega)}{u(\omega)} ;$$

an amplitude-phase-frequency response (APFR)

$$f(\omega) = v(u).$$

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

1. Move from the Laplace transform operator to the frequency domain.

2. Get rid of the irrationality of the transfer function denominator.

3. Convert the transfer function to the form:

$$W_{transf}(j\omega) = \frac{A(j\omega)}{B(j\omega)} * \frac{B^*(j\omega)}{B^*(j\omega)}.$$

4. Determine the dependencies for characterization.

5. Construct the characteristics according to the obtained dependencies.

2. Experimental results

To determine the specific problems arising when students build the frequency characteristics of the control object, an experiment was conducted. It was attended by 42 third-year students enrolled in the specialty "Automatic control systems".

Students in the control group were assigned three degrees of transfer function complexity:

a) the numerator is a first-order polynomial, and the denominator is a second-order polynomial;

b) the numerator is a first-order polynomial, and the denominator is a third-order polynomial;

c) the numerator is a second-order polynomial, and the denominator is a third-order polynomial. The required accuracy of calculations was 4 significant positions.

To identify the maximum number of errors in the analysis of student papers, we simulated the student's calculations even after errors were detected. Thus, 95 different errors were detected.

The classes detected are presented below (Table 1).

Let us disclose the essence of the classes presented.

The conceptual error "Ignorance of the condition of the physical implementation of the object" is caused by the failure to understand that the numerator order of the transfer function cannot be greater than the denominator order, and such control objects are not implemented at this stage of engineering progress [10].

The "Loss of Sign in Calculations" class is caused by widespread errors made due to inattention during calculations.

Inattention errors can be ignored at this stage - this point is not something that can be influenced in the process but is a marker for personal work with the student.

The class "Errors in the multiplication of polynomials" includes errors made when multiplying a numerator and a denominator by an expression conjugated with the denominator (omission of a polynomial term, error in working with powers, loss of sign, etc.).

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

The classes "Missing a double product when squaring an expression" and "Writing a single product instead of a double product when squaring an expression" are related to the conceptual error of not knowing the formulas of reduced multiplication.

Based on this kind of mistake, it is already possible to offer students to repeat certain topics, as well as to pay attention to the teaching of these topics in the institution.

An example of an error with an imaginary unit exponent is shown in Figure 1. This happens when the student does not know the following facts: an imaginary unit raised to the odd power is a complex number, and an imaginary unit raised to the even power is a real number.

The class «Imaginary part contains imaginary unit» includes conceptual mistakes presented in Figure 2. It doesn't allow passing on to characteristics building.

An error when dividing the real and imaginary parts - their transposition.

The class "Ignorance of dependencies for constructing characteristics" includes errors when calculating expressions: for AFR, a radical or squares are missing; for PFR, an error in the argument of the arctangent function or a loss of sign in the arctangent function.

The Negative Frequency class is concerned with finding values for negative frequency values. The frequency can only take a zero value (constant signal) or a positive value (sinusoidal signal).

The Spelling Error class includes typical spelling or typing errors such as single transcriptions, character deletions, and character additions.

The Rounding Error class covers rounding errors and ignorance of calculation accuracy requirements.

The "Other errors" class includes errors for which the cause is unknown.

$$W(s) = \frac{2}{s^2 + 2s + 3}$$

$$\hat{W}(j\omega) = \frac{2}{-\omega^2 + 2j\omega + 3}$$

Reference Model

$$\tilde{W}(j\omega) = \frac{2}{\omega^2 + 2j\omega + 3}$$

Real Model
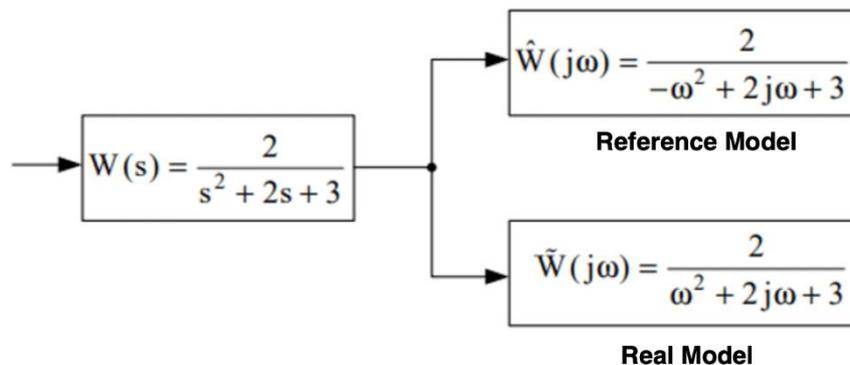
Fig. 1. An example of the mistake at exponentiation of imaginary unit

$$\hat{U}(\omega) = \frac{-2\omega^2 + 6}{\omega^4 - 2\omega^2 + 9}; \quad \hat{V}(\omega) = \frac{-4\omega}{\omega^4 - 2\omega^2 + 9};$$

$$\hat{W}(j\omega) = \hat{U}(\omega) + j\hat{V}(\omega)$$

$$W(j\omega) = \frac{-2\omega^2 - 4j\omega + 6}{\omega^4 - 2\omega^2 + 9}$$

Reference Model

$$\bar{U}(\omega) = \frac{-2\omega^2 + 6}{\omega^4 - 2\omega^2 + 9}; \quad \bar{V}(\omega) = \frac{-4j\omega}{\omega^4 - 2\omega^2 + 9}$$

Real Model
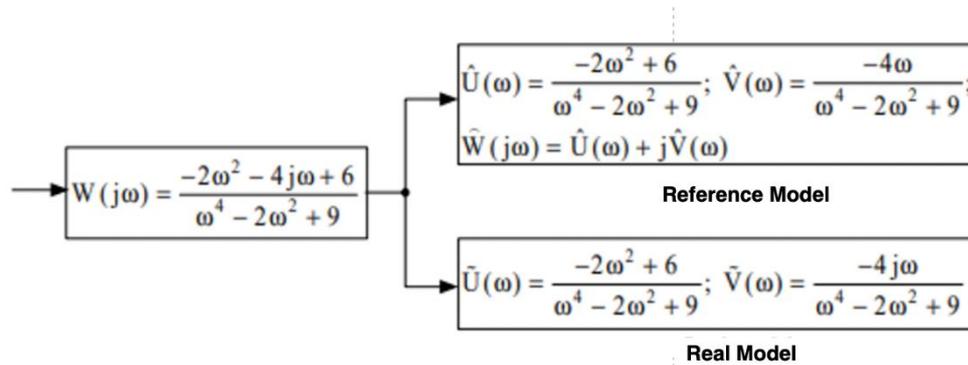
Fig. 2. An example of the mistake – imaginary part contains imaginary unit

By analyzing this sample it is possible to determine, which kinds of errors are the most difficult for students - also on the frequency of their occurrence it is possible to draw conclusions about the massiveness of failures in knowledge on certain topics of the subject - thus the sample can be useful also in analyzing the work and productivity of teaching various topics and subjects at a certain educational institution.

3. Diagnostic models

A diagnostic model (DM) is a mathematical model that relates an error to its symptom and allows solving the inverse problem [11, 12].

For each of the errors detected in the process of testing students (Table 1), a different DM was built. The use of diagnostic models on the basis of real and reference models is one of the key factors of the system - it will build the basis for the future intelligent system.

DM's in this iteration will serve as a productive knowledge base and a mechanism for responding flexibly and adapting to each individual learner.

Let us introduce notations: $\tilde{x}$ is the value calculated by the student, $\hat{x}$ is the reference value calculated by the tutoring program.

Then the DM for error detection is $\tilde{x} \neq \hat{x}$.

Once an error is detected, we must determine the cause of the error. So we use the DM to find the class.

For example, the DM for finding the class "Ignorance of the physical realization condition of the object" is $\tilde{n} > \tilde{m}$.

The DM for "Loss of sign in computation" is defined as follows $\tilde{x} = -\hat{x}$.

DM for "Mistake at exponentiation of imaginary unit" may be written as

$$\left((\text{pow}(\hat{b}_i)\text{mod}2 <> 0) \wedge (\tilde{b}_i \in R)\right) \vee$$

$$\vee ((\text{pow}(\hat{b}_i)\text{mod}2 = 0) \wedge (\tilde{b}_i \in C),$$

where $\text{pow}(\hat{b}_i)$ is an argument of B(s) i-th member exponent.

Before creating DM „Omission of the double product at expression squaring" for a transfer function denominator as a polynomial of second order let's

$$y = B(j\omega)B^*(j\omega) = (x_{L1} + x_{L2})^2 - x_R^2.$$

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

$$\tilde{y} - \hat{y} = -2\hat{x}_{L1}\hat{x}_{L2}.$$

For finding the "missing a polynomial member" we can use DM

$$|\{\tilde{k}_0, \tilde{k}_1, ..., \tilde{k}_a\}| \leq |\{\hat{k}_0, \hat{k}_1, ..., \hat{k}_b\}|,$$

where $\tilde{k}_i \neq 0$ is a coefficient at i-th member of a reference polynomial; $\hat{k}_i \neq 0$ is a coefficient at i-th member of a real polynomial.

DM for "Mistake at the division of the real and imaginary parts" is $(\tilde{u} = \hat{v}) \wedge (\tilde{v} = \hat{u})$ and DM for "Imaginary part contain 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 within h digits after the point:

$$r\_f(x, h) = (-1)^t * (z_0 + z_1 * 10^{-1} + $$
$$ + z_2 * 10^{-2} + ... + z_h * 10^{-h}) * 10^P,$$

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 construction of the characteristic" is defined as follows:

$$\widetilde{A} = r\_f\,(\hat{u}^2 + \hat{v}^2, h)$$

means that a radical is missed for AFR;

$$\widetilde{A} = r\_f\left(\sqrt{u + v^2}, h\right)$$

signifies that a square of real part is missed for AFR;

$$\widetilde{A} = r\_f\,(\sqrt{\hat{u}^2 + \hat{v}}, h)$$

stands for the missed square of imaginary part for AFR;

$$\widetilde{\varphi} = r\_f(\arctan\frac{\hat{u}}{\hat{v}}, h)$$

implies the transposition of real and imaginary parts for PFR;

$$\widetilde{\varphi} = r\_f(\arctan\hat{u}, h), \widetilde{\varphi} = r\_f(\arctan\hat{v}, h)$$

means the presence of mistakes in the argument of arctangent function for PFR;

$$\widetilde{\varphi} = r\_f(-\arctan\frac{\hat{u}}{\hat{v}}, h)$$

matters the loss of a sign in arctangent function for PFR.

DMs for the "Round off mistake" class is defined by two following models.

$$(r\_f(\tilde{x}, h) - r\_f(\hat{x}, h) =$$
$$= -1 * 10^{ex(r\_f(\hat{x},h))-h})\wedge(\hat{z}_{h+1} \geq 5)$$

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 $\exists b(\tilde{z}_b \neq \hat{z}_b) \wedge (\forall s \in \{0, 1, \ldots, h\} - \{b\}\tilde{z}_s = \hat{z}_s)$.

For finding all of the "Misspelling" mistakes similar s strings detecting methods [13, 14] can be used.

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

This DM is a factual description of the possible flow of the system, as well as the basic scenario of the system's response to errors and calculation of possible results.

If the student has made a mistake, the program will tell that a mistake has been made, analyze the mistake, and allow the student to correct it. If the mistake is made twice, the program will say again that the mistake was made, analyze the error and offer to repeat the steps.

Only if the student makes a mistake at step i, the program will give a diagnostic message about the error, indicating its class [15].

This approach is consistent with the principle that the student should first work on the error without any additional help. That is why the diagnostic message with a hint about the cause of the error is not given immediately. Instead, the student is given an opportunity to find and correct the error. The results of error analysis, which the program performs at every step, are saved in the student's model [16, 17].

We implemented such an intelligent tutorial system in Delphi, screenshots of which are shown in Fig. 4. This system includes all the diagnostic models defined above. When a student's misunderstanding is detected, the system returns him to the study of theory [18]. The system is used in the practical classes on "Theory of automatic control" for the third-year students of our university. According to the results, we increased the efficiency of training, as each student correctly solves his problem without the help of the teacher, the system helps the teacher to understand where the gaps in knowledge and adaptively correct the training [19, 20].

Conclusion

The main contribution of this paper is, firstly, the results of the experimental study of students' professional errors and, secondly, the diagnostic models proposed on their basis to form a diagnostic service as part of an intelligent tutoring system for teaching professional skills without the help of a teacher. Currently, we implement diagnostic models in an interpreted language and store them in a database. This approach allows us to add/modify diagnostic models without making any changes to the software shell. Moreover, the shell is able to generate new diagnostic models in self-learning mode, store them in the database, and then interpret them. We are also going to create an intelligent tutor web portal.

The next steps will be to further develop the system and improve the adaptability of the diagnostic models. At the moment, the models are not flexible enough and it is necessary to deepen their ability to morph themselves.
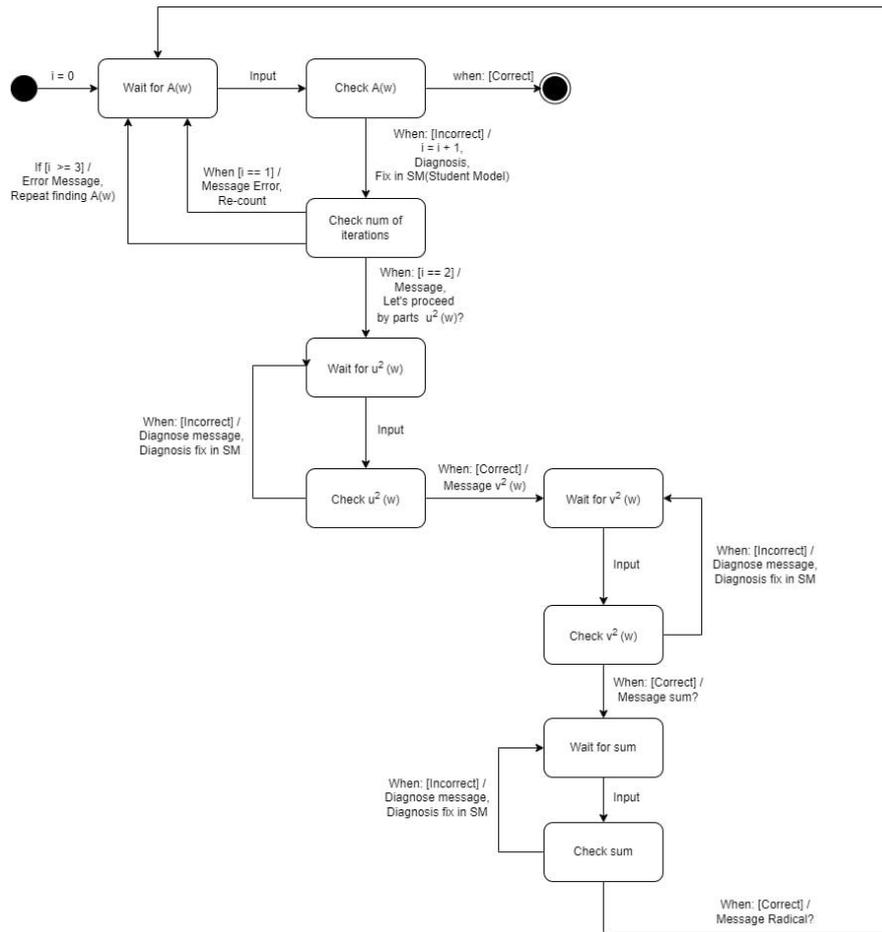
Fig. 3. Fragment of diagnostic models application scenario
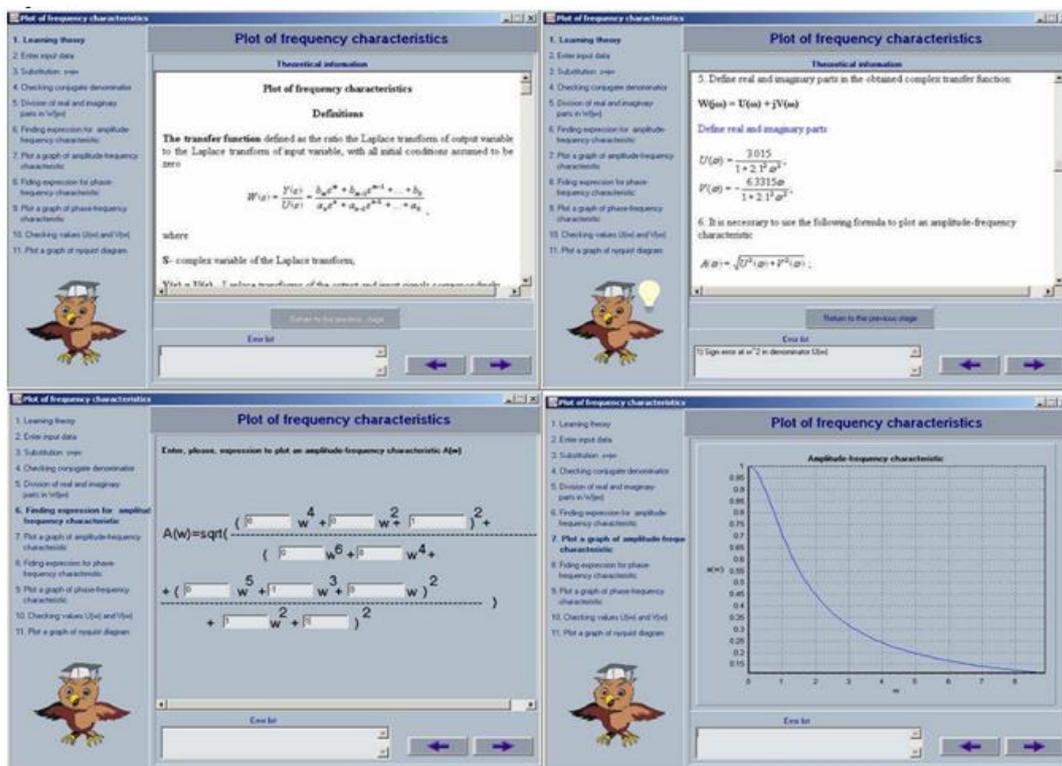
Fig. 4. Intelligent tutor system screenshots

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ДІАГНОСТИЧНЕ ЗАБЕЗПЕЧЕННЯ ІНТЕЛЕКТУАЛЬНОЇ КОМП'ЮТЕРНОЇ СИСТЕМИ ДЛЯ НАВЧАННЯ НАВИЧКАМ ПОБУДОВИ ЧАСТОТНИХ ХАРАКТЕРИСТИК ОБ'ЄКТА УПРАВЛІННЯ

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У цій статті описується одне з рішень для побудови методу частотних характеристик об'єкта управління. В даний час рівень компетенцій, необхідних у роботі сучасного інженера, стає все вищим і вищим, і тим складніше забезпечити необхідний рівень знань і навичок, використовуючи тільки традиційний підхід. Вирішити цю проблему можна за допомогою автоматизованих систем навчання, що може дозволити розвантажити викладачів, покрити більший обсяг студентів, а також уніфікувати якість роботи. **Предметом** дослідження є можливість побудови певної абстрактної системи, яка зможе забезпечити отримання комплексних навичок студентами в автоматичному режимі. Основою для цих досліджень буде комплексне завдання, що вимагає різнопланових навичок від того, хто навчається. Як систему, що потребує добре розвинених навичок, можна навести систему побудови частотних характеристик об'єкта управління. **Метою** даної роботи було обрано дослідження методів побудови таких систем, а також дослідження навчання студентів та відокремлення найчастіших і можливих помилок студентів. **Завданням** даної роботи є проектування та запуск системи, що дозволяють студенту набути навичок у побудові частотних характеристик об'єкта. Дана робота дозволяє використовувати один з можливих методів реалізації такого завдання, а також визначити проблеми, що найчастіше зустрічаються на етапі навчання даної методики і найбільш вдалим чином підготувати систему для використання. **В результаті** роботи отримано наступне: виявлено та класифіковано помилки студентів. На основі сигнально-параметричного підходу до діагностики несправностей у динамічних системах створено математичні діагностичні моделі, що дозволяють виявити класи помилок шляхом порівняння результатів розрахунку студента та результатів розрахунку системи. Наведено особливості застосування запропонованих діагностичних моделей. Інтелектуальна система-тьютор розроблена та використовується на практичних заняттях з "Теорії автоматичного управління" студентами третього курсу Національного аерокосмічного університету ім. М. Є. Жуковського «Харківський авіаційний інститут».

Ключові слова: інтелектуальна тьюторська система; помилка студента; діагностична модель.

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