Automated system of monitoring professional skills development of food production operators based on a computer simulator

Elena Litvinova1 and Ivan Polevshchikov1,2,3*

1Russian Biotechnological University, Moscow, Russia
2Moscow State University of Technology and Management named after K.G. Razumovsky, Moscow, Russia
3Perm National Research Polytechnic University, Perm, Russia

Abstract. Research is devoted to the development of a computer simulator complex (CSC) to develop the professional skills of food production operators. The structure (conceptual model) of CSC for training of food production operators is developed, the distinctive features of which for solving the problem of professional training of operators is the integration of the simulator, which allows to reproduce real technological processes of food production for training purposes, with the automated information system (AIS) of control over the formation of professional skills in the course of exercise courses on CSC. The sets of parameters that determine: the structure and properties of the technological operation modeled in the exercise on CSC for the generation of individual exercise variants; the actions performed by the trainee in the exercise depending on the features of the simulated technological operation with the use of physical models of real equipment or elements of virtual and augmented reality (VR/AR); evaluation of the process and results of the exercise in the virtual automated training environment CSC are described. The application of CSC in the training process allows to flexibly customize exercises for professional training of operators of different branches of food industry (meat, dairy, bakery, confectionery, etc.), which helps to improve the quality of training results, as well as to reduce the labor intensity of creating and controlling the implementation of training courses in CSC by operators.

1 Introduction

An important task for the food industry in modern socio-economic conditions, in connection with solving the problems of food security and import substitution, is the quality training of personnel. The food industry requires qualified specialists for the organization of automated production, including technologists, operators, specialists in informatization and robotization.

* Corresponding author: i.s.polevshchikov@mail.ru
When solving the problem of effective training of specialists from different branches of the economy, computer simulators are widely used in the educational process [1, 2]. It is worth noting the use of computer simulators for training employees of organizations in the most complex and dangerous areas of activity (especially at the initial stage of professional training), in particular, in medicine [3, 4], industry [5-7], maritime business [8]. For the food industry, simulators are being developed to train highly qualified specialists in the development of mathematical and software for automated control systems of production processes [9, 10].

However, the theoretical and practical aspects of creating computer simulator complexes (CSC) for training food production operators that allow solving the interrelated problems of modeling the real technological environment when performing exercises on the simulator and managing the formation of professional skills in this environment have not been fully developed.

The actual task, the solution of which is considered below, is the development of scientific and technical bases of CSC construction for food production operators, the application of which in the process of professional training contributes to increasing the level of formation of the required skills of operators and reducing the labor intensity of teachers' work for the preparation of training courses in CSC. These advantages are achieved through the use of mathematical methods and information technologies that allow the development of exercise courses in CSC through flexible customization in accordance with the specifics of specific types of production processes and training methods for operators, as well as automatic control of exercise performance in the process of passing the operators of these courses.

2 Computer simulator complex modeling for training of food production operators

The distinctive features of the developed structure of CSC (conceptual model) for training operators, shown in Fig. 1, is the integration of the simulator itself, which allows to reproduce real technological processes of food production for training purposes (in particular, physical and mathematical modeling, 3d-modeling), with the automated information system (AIS) of control over the formation of professional skills of operators in the course of exercise courses on CSC. In the software of the intellectual AIS a set of interconnected functions of formation of courses of exercises on the basis of modeling of technological process, collection of primary data on results of performance by trainees of technological operations in the course of exercises, complex evaluation of the level of formation of skills of operators on the basis of analysis of primary data, generation of advising influences to the trainee in the process of exercises, evaluation of the effectiveness of various courses of exercises as they develop and modify the process of training of operators. The CSC structure includes application program subsystems, e.g., testing of the trainee's initial knowledge.
Let us distinguish 3 sets of parameters that determine the specificity of the processes of forming exercise variants on CSC for trained operators, exercise execution with the use of simulator and evaluation of exercise execution:

1. Set of parameters $Y_{\text{tech.}} = \{y_{i\text{tech.}}\}_{i = 1}^{N_{\text{tech.}}}$ defines the technological operation modeled in the exercise (its structure and properties) to generate individual variants of the exercise for the trained operators.

2. Set of parameters $Y_{\text{act.}} = \{y_{j\text{act.}}\}_{j = 1}^{N_{\text{act.}}}$ determines the actions to be performed in the exercise (depending on the specifics of the simulated technological operation), which must be performed by the trainee using physical models of levers, consoles, buttons, corresponding to real equipment, as well as using elements of virtual and augmented reality (VR/AR).

3. Set of parameters $Y_{\text{ass.}} = \{y_{k\text{ass.}}\}_{k = 1}^{N_{\text{ass.}}}$ defines the specifics of evaluation of the process and results of the exercise in the virtual automated training environment CSC.

CSC models and algorithms based on the following parameters $Y_{\text{tech.}}$, $Y_{\text{act.}}$, $Y_{\text{ass.}}$ provide simulation of the technological process in a virtual production environment for the purpose of automated design and passing by food production operators of training courses of typical exercises for the formation of professional skills for effective and safe performance of technological operations.

Based on the $Y_{\text{tech.}}$, $Y_{\text{act.}}$, $Y_{\text{ass.}}$ parameter settings, With the knowledge of the specifics of a certain technological process, CSC implements mathematical models of specific technological operations, which are used to form individual variants of one or a sequence of exercises when training personnel on CSC.

Application of CSC in the training process allows customizing exercises for professional training of operators from different areas of the food industry - meat, dairy, bakery, confectionery and others.

The parameters $Y_{\text{tech.}}$, $Y_{\text{act.}}$ allow to describe in an interconnected way:

- logical and temporal features of the technological process execution, determined by the sequence of human (operator) actions and the results of these actions, transitions between the states of the virtual production environment and its individual components during the exercise;
- objects of the virtual production environment and parameters of the technological process (modeling of parameters of technological equipment, personnel, typical abnormal and emergency situations, etc.).

The parameters $Y_{\text{ass.}}$ allow to describe in an interconnected way: primary data on the results and quality of technological process execution (e.g., signals about pressing a certain button, lever, moments of pressing time, etc.); quality indicators obtained on the basis of primary data processing (e.g., accuracy, time and error-free execution of technological operations); moments of time of primary data collection and determination of quality indicators on their basis.

The effectiveness of training on CSC, based on the relationship between the simulator and intelligent AIS, is largely determined by the complex of physical and mathematical models implemented in the simulator and allowing to adequately reproduce the real production process. The main objects and processes of technological operations that require modeling in CSC: movement of various mechanisms of technological equipment, manufactured products, personnel, visualization of the scene. The methods of construction of digital doubles widely used for automation of technological processes and productions in the food industry are applicable [11, 12].

A mathematical model describing exercise difficulty levels and transitions between them when a trained operator performs an exercise course on CSC has been developed in a general form. Let us represent the model by means of a Markov graph of transitions $V_{\text{op.}} = (S_{\text{op}}, E_{\text{op}})$, where $S_{\text{op}} = \{s_i | i = 1, N_{\text{st.}}\}$ is a set of permissible levels of exercise difficulty determined by the values of the parameters $Y_{\text{tech.}}, Y_{\text{act.}}, Y_{\text{ass.}}$, and $E_{\text{op.}} = \{e_k | k = 1, N_{\text{tran.}}\}$ define many transitions of an exercise from one complexity level to another. Difficulty level $s_i \in S_{\text{op}}$ is determined by the specifics of the process of performing and evaluating the exercise, and the transition $e_k \in E_{\text{op.}}$ denotes an increase, decrease or retention of the current level of difficulty of the exercise when it is repeated.

Fig. 2 shows an example of a special case of the mathematical model reflecting the change in the level of difficulty of the exercise, for the formation of sensorimotor skills of the operator to transport a load using a technological unit.

**Fig. 2** Example of a model for changing levels of exercise difficulty

States (levels of complexity) $s_1, s_3$ in Fig. 2 correspond only to the lifting and lowering operations simulated in the exercise, states $s_2, s_4$ define simultaneous lifting, lowering and turning operations, states $s_1, s_2$ define the presence of cues to the trainee during the
exercise, the state of the trainee's $s_3$, $s_4$ denote absence of hints. The complexity of the exercise in this example is determined by the actions performed by the trainees (using mockups of levers of real equipment or VR/AR) and the presence of advisory influences.

Conditions of transitions $e_k \in E_{op}$ between the levels of complexity, exercises can be explicitly set by the instructor before the beginning of operator training, as well as performed automatically, taking into account the adaptation to the individual capabilities of each trainee and the results of processing data on the training of a certain number of operators on the CSC over a period of time.

### 3 Structure and criteria for evaluation of exercises in the training complex

An example of the structure of an exercise in CSC for training operators in the meat industry - an exercise to develop and assess the skills of cutting a pork carcass into half carcasses while preserving the integrity of the spinal column. Table 1 presents a description of the exercise, including the sequence of tasks to be performed by the trainee, the actions performed by the trainee during each task (using VR/AR or mock-ups of real equipment consoles), the specifics of interactive interaction of the trained operator with the virtual environment of the simulator. The program implementation of the exercise is based on correct setting of parameters of sets $Y_{tech}$, $Y_{int}$, $Y_{ass}$, describing an exercise of the specified structure.

#### Table 1. Example of an exercise to train an operator to cut a pork carcass

<table>
<thead>
<tr>
<th>Training task number and title</th>
<th>Actions performed by the trainee</th>
<th>Observed results of the learner's actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Occupy a workstation.</td>
<td>The operator occupies the workstation.</td>
<td>The operator is on the job.</td>
</tr>
<tr>
<td>2. Check the condition of the electric saw control panel for the initial position of the controls.</td>
<td>Move the control lever to the operating position.</td>
<td>The power interlock mechanism is disabled in the same way as the real equipment.</td>
</tr>
<tr>
<td>3. Turn on power to the equipment.</td>
<td>Press the power button.</td>
<td>A simulation of the power supply being turned on and applied to the simulated real equipment takes place.</td>
</tr>
<tr>
<td>4. Raise the hanging band saw 5 cm above the hip cut of the pork carcass.</td>
<td>Press the buzzer button. Bring the suspended saw to the red mark of the color zone, which indicates the necessary lifting of the saw.</td>
<td>The suspended band saw starts to rise. When the required lifting level is reached, the mark lights up green.</td>
</tr>
<tr>
<td>5. Stop the lifting mechanism at the set height and hold for 3-5 seconds, waiting for the power saw to stop.</td>
<td>Move the electric saw lift control lever forward.</td>
<td>Lift control lever in zero position. The suspended band saw is in the defined travel zone. An object in the form of a pig carcass appears on the special platform under the band saw blade.</td>
</tr>
<tr>
<td>6. Lower the suspended electric saw to the area of red, which characterizes the surface of the pork carcass.</td>
<td>Press the buzzer button. Move the control lever forward.</td>
<td>When the saw enters the cutting zone, the backlight will change from red to green. The pig carcass on the overhead track will contact the saw blade in automatic mode (simulation of the interaction between the saw and the carcass).</td>
</tr>
</tbody>
</table>
7. Rotate the lever to the right. Step back from the center of the spinal column 5 mm to the right to maintain its integrity. Press the buzzer button. Move the sawing mechanism control lever to the rear. Bring the saw to the red mark. The electric saw is guided to the right of the center of the spinal column. When the band blade aligns with the cutting area, the backlight turns green.

8. Perform sawing along the spinal column of a pork carcass from femoral to cervical region. Press the buzzer button. Move the cutting control lever forward. Bring the electric saw to the red highlighted area on the platform, which characterizes the neck area. The electric saw moves from the thigh to the neck area of the pork carcass strictly along the trajectory.

9. Stop the sawing mechanism. Move the control lever forward. Lift control lever in zero position. The electric saw is positioned between 2 pork carcasses.

10. Lift the suspended electric saw. Press the buzzer button. Move the lift control lever to the rear. Bring the suspended saw to the red mark. The suspended electric saw starts to rise. When the required lifting level is reached, the mark lights up green.

11. Stop the lifting mechanism at this height and hold for 5 seconds to stop the oscillation of the process equipment. Move the lift control lever forward. Lift control lever in zero position, the suspended electric saw is in the target zone. The illumination is removed.

12. Press the button on the control panel to start band saw irrigation. Press the button on the remote control. The suspended band saw is irrigated with water.

13. Stop the band saw cutting edge irrigation mechanism. Press the brake button. Irrigation control lever in zero position, suspended power saw is not irrigated.

14. Exposure of the electric saw to water drainage. Press the buzzer button. Move the lift control lever forward. Bring the saw to the red illuminated area. The suspended electric saw starts moving. When it enters the travel zone, it lights up green, i.e., the saw is ready for the next cut.

15. Stop the sawing mechanism. Move the control lever forward. Control lever in zero position.

16. Turn off the power supply. Press the power button. This simulates the shutdown of the power supply that is applied to real process equipment.

Table 2 summarizes the quality indicators calculated automatically during this exercise.

<table>
<thead>
<tr>
<th>Quality indicator</th>
<th>Method of calculating the quality indicator</th>
<th>Unit of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pork carcass sawing accuracy</td>
<td>The deviation of the load relative to the center of the spinal column is calculated.</td>
<td>mm from center of vertebral column</td>
</tr>
<tr>
<td>Smoothness of saw operation</td>
<td>Work on sawing strictly along the spinal column of a pork carcass from femur to neck area.</td>
<td>qualitative assessment - presence of rejects</td>
</tr>
<tr>
<td>Number of rejects</td>
<td>The number of carcasses with sawing abnormalities is calculated: damage to the backbone, presence of fringes, presence of flesh-bone sawdust, etc.</td>
<td>unit (1 carcass, 2 half carcasses)</td>
</tr>
<tr>
<td>Saw lift time</td>
<td>The time for the trainee to perform the saw lift is calculated.</td>
<td>sec</td>
</tr>
<tr>
<td>Pork carcass sawing time</td>
<td>The time for cutting the carcass into half carcasses is calculated.</td>
<td>sec</td>
</tr>
<tr>
<td>Saw stopping time</td>
<td>The execution time of the saw stop is</td>
<td>sec</td>
</tr>
</tbody>
</table>
Based on the values of the quality indicators from Table 2, the CSC automatically calculates a comprehensive evaluation of the exercise and can provide additional corrective actions to the trainee during and after the exercise to optimize the performance of the process operation.

### 4 Conclusions

1. The structure (conceptual model) of CSC for training of food production operators is developed, the distinctive features of which for solving the problem of professional training of operators is the integration of simulator, which allows to reproduce real technological processes of food production for training purposes (based on physical-mathematical and 3d-modeling), with AIS of control over the formation of professional skills in the course of exercise courses on CSC.

2. described sets of parameters that determine: the structure and properties of the simulated technological operation in the exercise on CSC for the generation of individual exercise variants; the actions performed by the trainee in the exercise depending on the features of the simulated technological operation with the use of physical models of real equipment or elements of virtual and augmented reality (VR/AR); evaluation of the process and results of the exercise in the virtual automated training environment CSC.

3. CSC models and algorithms, based on the described parameters, provide simulation of the technological process in a virtual production environment for the purpose of automated design and passage of food production operators training courses of typical exercises for the formation of professional skills for effective and safe performance of technological operations. In particular, the method of modeling the complexity levels of exercises in CSC based on the automata approach is proposed, the software implementation of which in CSC contributes to the adaptation of the training process to the individual capabilities of the trained operator.

4. examples of the structure of the exercise in CSC for training operators of the meat industry (the exercise on formation and assessment of skills of sawing of a pork carcass into half carcasses with preservation of the integrity of the spinal column) and quality indicators calculated automatically during the fulfillment of this exercise are described. Application of CSC in the training process allows to flexibly customize exercises for professional training of operators of different food industry sectors (meat, dairy, bakery, confectionery, etc.), which helps to improve the quality of training results, as well as to reduce the labor intensity of creating and controlling the performance of operators' training courses in CSC.

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### References


