Computer Simulation Complex for Training Operators of Handling Processes

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Abstract: The paper is dedicated to the development of the architecture of computer training simulation complexes (TSCs) for training operators of handling machineries as well as models and operation algorithms of their components. We introduce a unique training complex, Ganz TSC, for portal crane operators, developed according to the models and methods proposed. It demonstrates its effectiveness in the training process. In particular, our case study shows that operators trained with the use of Ganz TSC move cargoes 27% faster on average, preserving the required quality of work.

1 INTRODUCTION

There is a high need in increasing the effectiveness of the training of technological process operators with the aim of acquiring a required level of knowledge, abilities, and skills based on scientifically well-founded models and methods within a relatively short-time interval. Computer-aided training systems (referred to as CTSs) and training simulators of computer training simulation complexes (referred to as training simulation complexes or TSCs), leveraged for that, are addressed in research literature such as (Dozortsev, 2013; Chistyakova, Petin & Boykova, 2012; Lisitsyna & Lyamin, 2014; Bouhnik & Carmi, 2012; Zhuravlev & Shikov, 2015). CTSs are typically utilised for monitoring theoretical knowledge and for training the logics of professional thinking in various regular and extreme cases. Training simulators are, in turn, developed to simulate comprehensive technological processes and mould out necessary skills with the help of an instructor.

Contemporary training simulation complexes implement a limited set of specific training cases and have, therefore, a limited simulation environment. In contrast, in this paper, we present a comprehensive end-to-end system, Ganz TSC (Fayzrakhmanov & Khabibulin, 2014), with advanced full-fledged training simulator, Ganz, which has the following innovative advantages.

1) An instructor can control various configuration parameters of exercises and adapt the education process based on the knowledge and skills of the trainee.

2) On the example of the portal crane, with realistic simulation environment, the trainee can better understand the physics and peculiarities of the real working environment as well as the tools and objects he interacts with.

3) Ganz is a complex system with the software component used for simulating the virtual reality and the hardware component for simulation of the control panel of the portal crane. This therefore allows to reflect the environment with high precision. This system can be used as an independent system to simulate different kinds of portal cranes and various relevant objects of ports.

In this paper, we describe the architecture of training simulation complexes and their main functional components by example of Ganz TSC.

2 THE ARCHITECTURE OF GANTZ TSC

We developed a computer training simulation complex, Ganz TSC, for operators of the portal crane, Ganz. It is intended for training future operators with the aim of acquiring professional knowledge and skills. A generic view of Ganz TSC is illustrated in Figure 1.

Ganz TSC comprises two interconnected components:

1) a training simulator for the handling process;

2) a computer-aided training system, which collects and analyses data related to performance of the trainees who are in the process of acquiring relevant knowledge and skills.

The training simulator models the real environment with all relevant aspects of the load-unload (handling) process and gives the trainee a unique experience which can be further used at the workplace. The trainee can acquire his experience of interacting with the system through visual, audio and tactile channels, i.e., with visual simulation of physical objects and processes, simulation of the background and foreground noises, and providing a physical control panel corresponding to a specific model of a crane, respectively. Thus, the training simulator consists of a module of mathematical modelling of physical processes, a visualisation module, a control panel, and input devices.

A modelling module implements the physics of all relevant objects of the environment related to the overall handling process; those are the modelling of the vibration of constructions (e.g., the tension of the cable, jerks, the vibration of the crane), external factors (e.g., wind, rain, light), collisions (e.g., the destruction of containers on impact, a breach of the cable), and friable cargoes.

A modelled environment of the port has the following types of key objects: static (a moorage, storage facilities, railroad tracks, accesses for motor vehicles) and dynamic (a ship on the moorage, cargoes in warehouses, holds, port personnel). An open source framework, Unity, is used for visualising 3D models of the key objects.

Figure 1: A generic view of Ganz TSC.

The high-quality visualisation of the environment allows the trainee to experience the whole picture of relations between all objects in the handling process as well as their features and functions. The simulator also realistically simulates all relevant background and foreground noises.

Our training simulator has mobile controls, an operator chair, joysticks, the keyboard as a control panel, and input devices.

Virtual simulation of the handling (load-unload) process, as it is seen by the trainee on screen, is represented in Figure 2.

An integrated CTS of Gantz TSC has extensive courses that allow the trainee to receive training both through theoretical (to obtain knowledge) and practical (to get required skills) phases, which are automatically controlled and monitored by the system. Gantz TSC also has a framework with a convenient user interface that is leveraged by the instructor to configure the system accordingly as well as the overall educational process. By setting the configuration parameters, the trainer takes into account the knowledge and abilities of the trainee as well as the goal that he wants to achieve in his training program.

The overall architecture of Gantz TSC is illustrated in Figure 3.

Figure 2: A screenshot of the virtual environment.

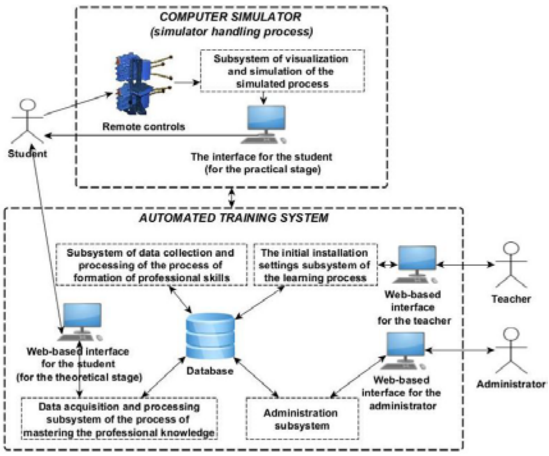

Figure 3: The overall architecture of Gantz TSC.

In the theoretical phase of the course, aimed at acquiring professional knowledge and implemented by CTS, a future operator studies the required theoretical material with the use of an electronic textbook and performs a control test afterwards.

Further in this section, we introduce models describing the structure, functional requirements, and functional peculiarities of the CTS based on our developed mathematical models of the computer-aided control system for acquiring skills, as well as the corresponding methods (Fayzrakhmanov & Polevshchikov, 2013, 2016).

We developed a mathematical model of the computer-aided control system for acquiring professional skills by operators (trainees) who perform exercises with the CTS. Each exercise forms specific professional skills, i.e., a proper action as well as reaction for a certain real situation. This model is a set-theoretic description of the input data and the functioning of each of the functional blocks, responsible for various constituents of the process of control. The set of these mathematical interdependencies is demonstrated in Figure 4.

Each exercise is associated with a planned performance trajectory that can be presented as a pair $T_{pl} =< M^{pl}_{sost}, M^{pl}_{vozd} >$, in which M^{pl}_{sost} is a set of planned states of the modelled environment, M^{pl}_{vozd} is a set of planned impacts affecting the modelled environment. The correlation between planned states and impacts can be presented as functions $M^{pl}_{sost} \times M^{pl}_{vozd} \to \{0,1\}$ and $M^{pl}_{vozd} \times M^{pl}_{sost} \to \{0,1\}$. The trainee interacts with the modelled environment with the use of physical simulators of control panel of the TSC with multiple levers $M_R = \{R_l \mid l = \overline{1, N_R}\}$, where $R_l = \{r_k \mid k = \overline{1, N_{pol}}\}$ is a set of positions of the l's lever. $V_{pl} \in M^{pl}_{vozd}$ can be represented as a set $V_{pl} = \{r_q(t_q) \mid q = \overline{1, N_{rych}}\}$, where $r_q(t_q) \in \bigcup_{l=1}^{N_R} R_l$ is a position in which the trainee should move a certain lever l in a specific time t_q. The quality assessment of performing a technological operation depends on the correlation between the planned T_{pl} and the actual T_{fct} task trajectories.

Figure 5 illustrates a use case diagram with functional requirements for the CTS to form necessary professional knowledge and skills in trainees, in their practical phase of the course.

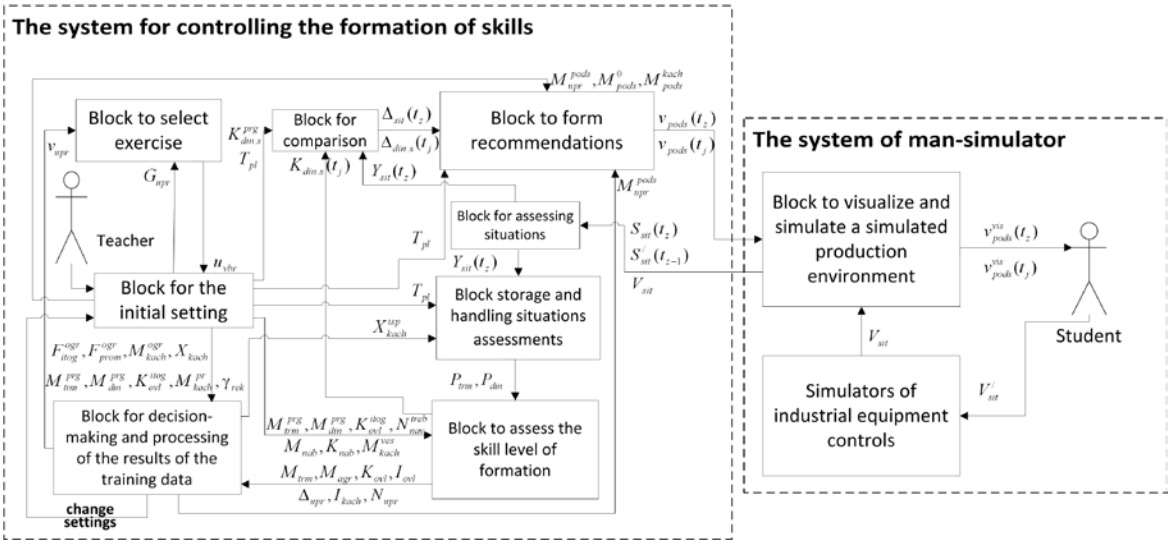

Figure 4: A schema of the process of computer-aided control.

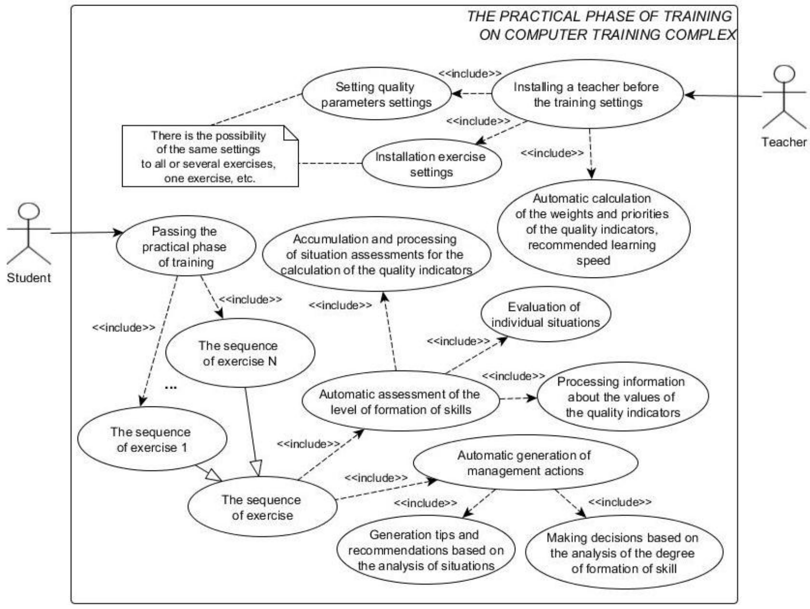

Figure 5: Use case diagram of the practical phase of the training course.

An activity diagram presented in Figure 6 reflects the algorithm of controlling the training process. This algorithm is based on mathematical models and methods described in (Fayzrakhmanov & Polevshchikov, 2016; Beiranvand, Khodabakhshi, Yarahmadi & Jalili, 2013; Mortaza Mokhtari Nazarlou, 2013).

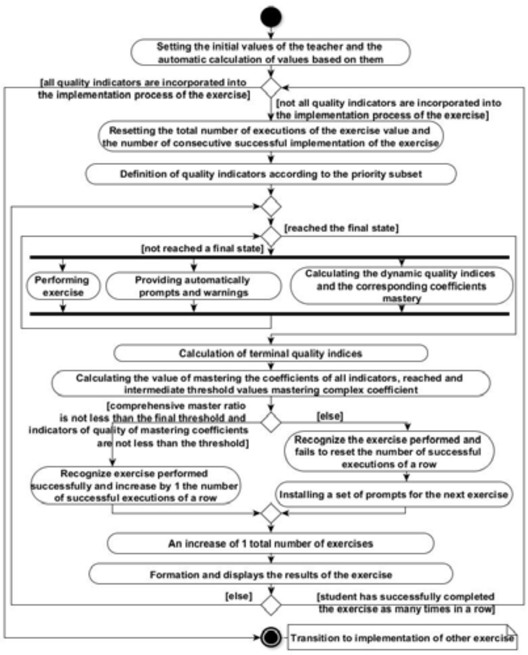

Figure 6: The algorithm of controlling the training process.

Figure 7 illustrates a quality assessment web form, one of interfaces of a rich Internet application developed for setting initial parameters.

The central database stores all information required for ensuring the effective training in consistent and systematic fashion, in particular: user profiles, initial configuration parameters, the progress trainees make as well as their results. Figure 8 represents a slice of the database schema, storing data of the process of acquiring professional skills by trainees, performing exercises in Ganz TSC.

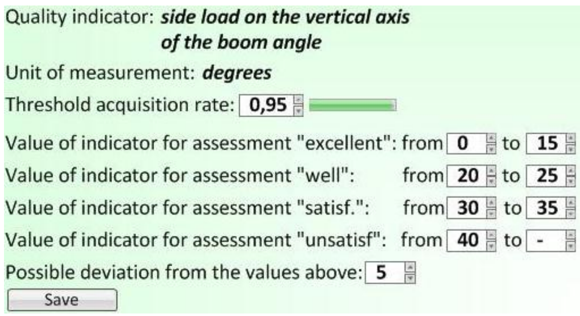

Figure 7: Configuration form for setting initial parameters of the quality assessment.

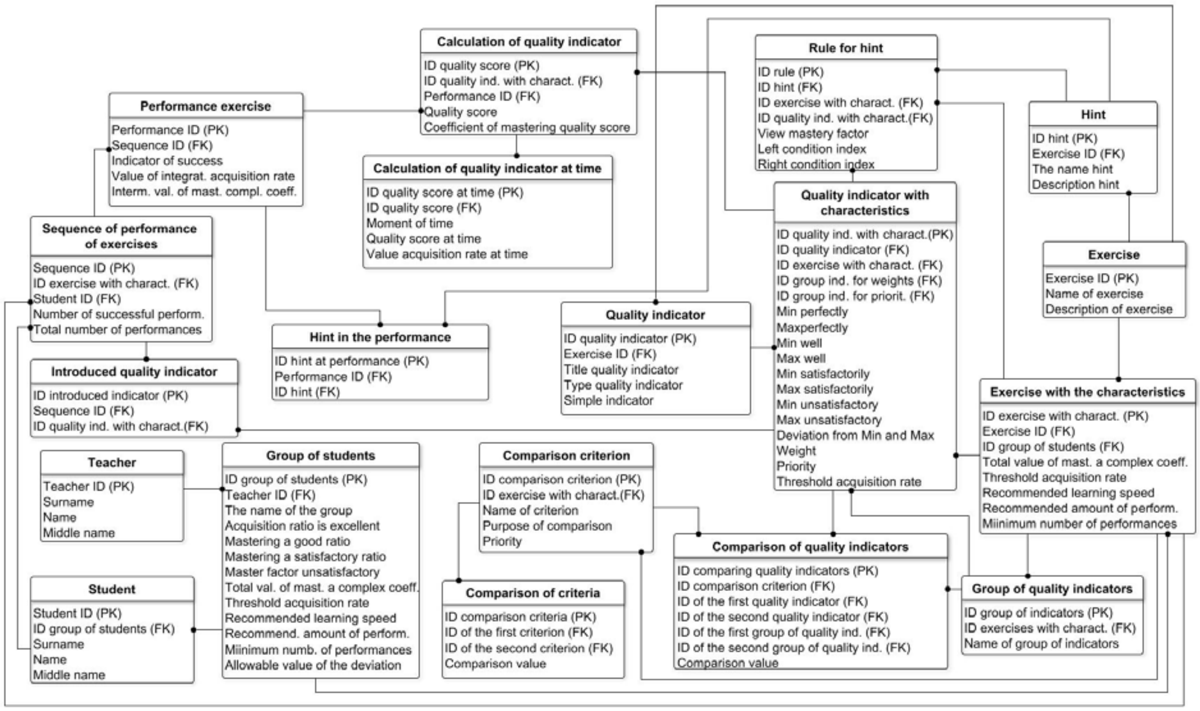

Figure 8: The logical database schema.

We also developed an educational program for trainees of the portan crane, Ganz, which includes exercises on the following main tasks:

1) lifting and pulling down a cargo in different realistic circumstances;

2) moving a cargo with different allowed movements of the derrick (e.g., only moving it back and forward or changing the angle);

3) loading and unloading the goods transport (water and land transport).

3 EFFECTIVENESS OF GANTZ TSC IN THE TRAINING

To evaluate the effectiveness of our training complex, we conducted a case study with two groups with 10 participants in each; the first group trained on a real portal crane, the second one trained on Ganz TSC. After the completion of their training course, we asked them to perform the following type of similar exercises 10 times: given the same conditions, move a cargo on a real portal crane. We measured the time they spend to successfully move a cargo on a real portal crane. The assessment of this criterion has a high importance as it reflects both the efficiency and accuracy of operators.

The second group was able to achieve better results, spending 27% less time than the first group on average. In particular, an average duration of the transfer for the second group was 48.6 sec., against 66.4 sec. for the first group.

We present detailed results of our study in Figure 9. As we can see, the overall time interval for the second group is within the range from 25 sec. to 75 sec., and with the frequency 0.4 (the highest bar in the histogram) they spent from 35 to 45 seconds. In contrast, the overall time interval of the first group is wider and ranges from 28 to 110 seconds, and with the frequency 0.27 they require more time to move the cargo — from 60 to 70 seconds. The frequency is a ratio of the quantity of measurements, in which the duration of the transfer has a specific value, to the total number of measurements.

The length of the time interval in the second group is smaller than in the first one, this indicates that Ganz TSC, training in a systematic and a goal-oriented fashion, greatly reduces the discrepancy in knowledge and skills obtained after the course.

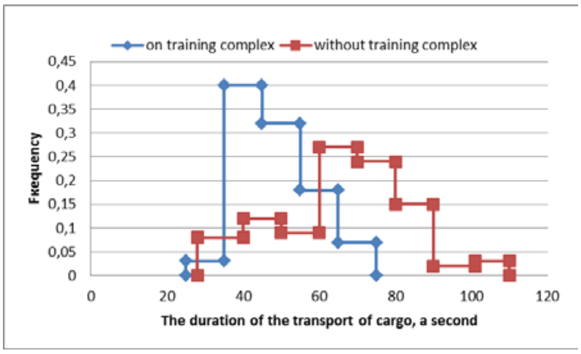

Figure 9: Graphs of the time required for moving cargoes in our case study.

Our experiment demonstrates the advantage of using Ganz TSC in training crane operators, that is reflected in a considerable reduction of the time required for transferring cargoes and more consistent and systematic training.

4 CONCLUSION

In this paper, we introduced a unique training simulation complex, Ganz TSC, which can help to effectively train professional crane operators and ensure the required level of knowledge and skills. It has an advanced training simulator, quite realistically modeling the environment of the process.

To conclude, the computer-aided training system of Ganz TSC has the following advantages.

1) It provides trainees with effective information support while doing exercises and success criteria, required for adequate self-control and self-assessment.

2) it is possible to schedule the process of acquiring the skill of manipulating every mechanism of the crane by gradual addition of individual quality factors into the training process.

3) All the exercises can be precisely reproduced with the same initial parameters that give the trainee the possibility to learn various peculiarities of the technological process and, thus, improve his skills considerably.

4) By leveraging the information provided by Ganz TSC about the progress of the trainee, an instructor can adapt the configuration parameters of the system in an according way to help him achieve better results in training.

5) All information regarding training processes and user profiles is collected, stored and processed by Ganz TSC to help instructors perform scheduling, accounting, monitoring, analysis, and control as the main constituents of the automated control process for acquiring professional skills.

The proposed system can be adapted for other machines and technological processes according to their specifics.

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