The development of rolling-stock virtual simulator

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Abstract. In the article, development stages of the virtual simulator Duomatic 09-32 hardware-software complex intended for drivers-operators training in driving of the special self-moving Duomatic 09-32 rolling stock are considered. In the presented research the data domain is studied, the concept of the virtual model basis of the Duomatic 09-32 simulator is developed and the system is designed. The bearing – tamping - leveling machine Duomatic 09-32 is the special machine on railway transport for railway track bearing in a longitudinal and cross profile and in respect of and also for tamping of ballast. It is applied at construction, repair and the current maintenance of a railway. The simulator considers many aspects of railway transport management process (structures, people on the ways, railway signs, traffic lights etc.) that allows the operator to gain qualitatively skills of the analysis and information processing and actions execution for management of train structure depending on a situation. Considering responsibility of the engineer not only for himself, but also for other participants of the movement, management of train structure is considered as difficult process. It demands emotional pressure, ability to constantly analyze a surrounding situation and to predict development of the situation. The simulator allows to receive necessary skills and makes drivers training activity more convenient and safe.

1. Introduction

Development and use of the virtual simulators modeling the technical systems functioning is the relevant and intensively developing field of science now. Simulating technologies arose and gained the greatest development in fields where training at real objects errors can lead to extraordinary effects, and their elimination – to big financial expenses: in military science, medicine, natural disaster response, in nuclear power, chemical industry, aircraft, space, etc. Training technologies are difficult complexes, the systems of modeling and simulation, the system of visualization, the computer programs and physical models, special techniques created to prepare the person for acceptance of qualitative and fast solutions that became very serious scientific task and even a problem in the 21st century.

Modern simulators and the training programs based on them contain the principles of practical skills development with simultaneous theoretical grounding. The simulator is capable to develop together with the trainee. Such approach implementation became possible in connection with rapid development and reduction in cost of the computer equipment and progress in the field of virtual reality technologies creation, machine vision, the systems of artificial intelligence, etc [1, 2]. On the basis of these technologies the training systems applied in military science, medicine, at natural disaster response, in nuclear power, chemical industry, aircraft and space, are developed.
In process of development and reduction in cost of the firmware training technologies begin to get also into other industries: the industry and production, a car - and navigation industry, school and high school training and other. Training and simulation technologies were so far created in successfully developing sphere of the world industry [3].

Any computer simulator at the heart is the system of virtual reality where the person carries out navigation, managing virtual model of transport or any other technological adaptation.

The hardware-software simulator has a mechanical part imitating management of a modeled object which transfers accelerations and vibrations, and computer part which actually provides the illusion of management by actions coordination with visual, audio and other effects. A computer part, in turn, is subdivided into the system of visualization, a so-called "scene from a window" ("Outofthewindowscene") and a control and managing part ("hostcomputingsystem"). Modern virtual reality and 3D - visualization technologies are actually the element base for new multimodal person-computer generations interfaces creation which allow to create simulators, the interactive training virtual environments, virtual prototypes, digital planetaria, different solutions for advertizing and marketing (wow-technology), etc [4, 5].

Use the simulators in the transport industry has rather wide circulation, including a various complexes set for training in skills of technical and control, beginning from the "simplest" auto exercise machines to the most difficult hardware-software space industry training complexes.

One of private options of the virtual training technologies systems use is the sphere of railway transport. The different companies and the countries impose to training systems different requirements, depending on type of railway equipment and conditions of its operation. For example, the VR exercise machine for the HTC Vive platform, allows to provide training in the main repair operations and service of the arrow electric drive of using of the Virtual Reality technology [6, 7]. Process of the international trains Paris-Berlin and Paris-London drivers training means not less than 20 hours of training at the electronic simulator imitating all traffic conditions on the respective line [8, 9] including working off of negotiations regulations with managers of railway stations. Railway stations of France, Great Britain, Germany, Belgium and the Netherlands because negotiations should be conducted in language of that country over which the train goes [10].

At the same time, most of developers meet that in the developed training system not only constructive and operational modules [11, 12], but also high-quality simulation external, including weather, conditions should be implemented. So, the Microsoft train exercise machine presents the scenario of a trip 1,000 km long with different climatic conditions (including the wheels slipping modeling) and authentic noise, meeting the requirements of the instruction [13, 14]. The simulators developments for training of specialists in the field of planning and system management of the railway ways routes movement communication are also in certain demand [15, 16, 17].

The purpose of this work is the virtual simulator imitating the special self-moving Duomatic 09-32 rolling stock functioning creation (figure 1). Its achievement includes a solution of the following tasks: studying and analysis of a modeling subject; an electric and pneumatic circuits status emulation modules and their components development, the negotiations management and process operations system development, the world around processes simulation.
The on-track machine is used on railway transport for bearing of a railway track in a longitudinal and cross profile and also for consolidation of ballast. It is applied at tracks construction and repair, and their maintenance in working order [5, 6, 13].

Operating parts of the machine are located over each rail thread: there are lining blocks, the lifting and leveling devices (LLD) and the ballast vibrosealants at the end faces of cross ties. Lining blocks have 16 vertical packers. Their lower ends at rotation of an eccentric shaft fluctuate in the horizontal plane with amplitude of 10-15 mm. During the operation of the machine the vertical hydraulic cylinders action submerges the packer in ballast between cross ties on depth of 0.4-0.6 meters and approaches it, pressing out a cross tie and condensing the ballast under it. The machine lines at the same time ballast under two cross ties and moves to the following crossties. Each block can move in the cross direction, providing tamping of a way in curvilinear sections.

Ballast vibrosealants of cross ties end faces are located on both sides of the machine and represent vibrating plates with vibrators of directional effect with a hydraulic actuator. Lifting and leveling devices are supplied with a set of roller captures for a lifting of a way, the preparing rollers for shift of a way and a hydraulic actuator. The leveling device works irrespective of lifting device. The leveling system of the machine turns on five measuring carts with the rope chord tensed between it, being the base of measurement. On the 2nd and 3rd carts there are variable potentiometer transducers measuring an arrow of a way deflection in the plan relatively a rope chord in two points. The electric signals from the 2nd and 3rd carts sensors come to the comparison device. The relation of these signals depends on a ratio of the measuring chord shoulders lengths; it is approximately equal to 1.34 that corresponds to the design provision of a way. At the relation different from this value, the mechanism of straightening carries out bearing of assembled rails and cross ties. There is the control rope chord tensed between the 5th and 3rd carts, and the arrows deflection control sensor of the aligned way on 4th cart is installed.

The operating cycle of the machine consists of the following operations:
- A machine stops for cyclic action machines or a satellite stop from the lifting and leveling device for continuous and cyclic action machines
- Capture of rails with the rectifying unit rollers
- Lowering of lining blocks and movement of a way by means of LLD
- Packers burying in ballast
- The ballast sealing by the packers vibrationing and compressioning
- Packers release
- Return of the lining block
- Disconnection of rail captures or weakening of the rails captures compression.

The operating cycle duration is up to 6 seconds. For increase in capacity, the machines are equipped with the coupled lining blocks.
The complexity of the traveling machine driving process consists in variety of the external factors capable in the shortest periods to change a road situation. Operator not only has to be able to keep attention and to constantly analyze the situation, predicting development of the situation, but also be able to act correctly in emergence of non-staff situations. The program models used in the simulation computer should to display realistic the component interaction and the systems of the modelled process. Therefore, the completeness of the developed simulator mathematical model should include models of electrical, hydraulic, pneumatic and mechanical systems and modules of simulation of weather and external conditions.

The characteristics of the modeled Duomatic 09-32 system are given in table 1.

Calculation of the model of pneumatic system air behavior allows to imitate real passing of air on the system of all structure, operation of distributors, cranes (including animation of this work in what channels will be, to pass air and with what pressure), creation of leaks in the certain places affecting all structure and also to keep track of the pneumatic system behavior on the long compound trains, etc.

Table 1. The characteristics of the Duomatic 09-32 system.

| Parameters                                      | Characteristics |
|------------------------------------------------|-----------------|
| Productivity, cross ties/hour                  | 2200-2400       |
| The maximum course of the of a way shift       | 100             |
| mechanism with rails of P65 and steel concrete |                 |
| cross ties, mm                                 |                 |
| The passable curves radius in an operating     | 180             |
| mode, m                                        |                 |
| The motion velocity in the transport mode under| 90              |
| the own steam                                   |                 |
| The motion velocity in the measuring mode      | 10              |
| The main sizes, mm                             |                 |
| - total length on automatic coupling axes       | 27630           |
| - height                                       | 3700            |
| - width                                        | 3300            |
| Power of the power unit, kW                    | 354             |
| Machine lump with the platform, tons           | 76±2            |
| Service staff of the machine, persons          | 4               |

2. Materials and methods

The presented virtual simulator development was implemented using Microsoft Visio, CorelDraw, C#, Unity 3D, AxureRP, 3DMax software.

AxureRP Pro is the popular software solution for creation of web projects prototypes and specifications.

The models and prototypes received by means of Axure RP are as close as possible to a final output in cause of the interface elements programming possibility. Using this software, it was designed the work area prototype of the program, contained correct transitions, user interface and necessary functionality.

The MicrosoftVisio application allows describing flowcharts of the program functionality and gives to programmers an opportunity for the correct software product creation. This application was used in flowchart implementation of the negotiations regulations for creation the specialized software and also the designing of the interface prototype, type of saving, logging.

"Regulations of negotiations" this software representing speech - to- text synthesis by means of ASR Kaldi. ASR uses the neural network recurrent model trained in nnet-3. The program system consists of the server, two clients and of the UI - application. The server is integrated with any programmatically hardware systems by means of the universal Data Adapter module. Asynchronous recognition is carried out on the server. Clients in turn use technology of the speech automatic
detecting, or detecting by means of the hardware devices connected through COM interfaces. Clients have a unique identifier for signing all messages with the detected audiophiles sent to the server. The server receiving audio data recognizes the speech and gives results to the integration bus. The server uses the database and file storage. The database is intended for storage of all messages from clients and integrators, there is also a possibility of introduction of session data, all audiophiles written by clients go to storage.

The world around and 3D-animation of the project was carried out in Unity 3D. This application allowed to describe 3D animation in the required sequence and under certain conditions.

The project in Unity is divided into stages (levels) — the separate files containing the game worlds with the set of objects, scenarios, and settings. Scenes may contain as, actually, objects (models), and empty game objects which have no model ("dummy"). Objects, in turn contain sets of components with which scripts interact. Objects also have a name (in Unity existence of two and more objects with identical names is allowed), there can be a tag and a layer it should be displayed. Any object at the stage surely has a Transform component — it stores in itself fix-up values, turn, and the object sizes on all three axes. Objects with visible geometry also by default have a «Mesh Renderer» component making object model visible.

Unity supports solid state physics and also physics of Ragdoll-type. The editor includes an objects inheritance system; child-objects will repeat all changes of a position turn and scale of a parent object. Scripts in the editor are attached to objects in the form of separate components.

Importing the texture to Unity allows to generate the alpha-channel, mip-levels, normal-map, light-map, the card of reflections, however directly on model the texture cannot be attached — the material the shader of which when assigned will be created, and then material will be attached to model. The editor of Unity supports shaders writing and editing.

The editor of Unity has the animation creation component, but animation also can be created previously in 3D - the editor and to import together with model, and then to break into files.

One more advantage of this editor — the support of the C# language which was used for writing of internal functionality, so-called "BackEnd" of the developed client-server application.

In figure 2 the prototype of the touch panel imposed on C# in which it is presented business – logic of operation of buttons, switches, regulators are presented.

A hardware-software complex includes 15 touch monitors for full simulation of a road situation in a cabin of the rectifying - lining - leveling machine Duomatic 09-32: there are 9 monitors of ASUS – diagonal 40 inches; 6 monitors of ASUS – diagonal 43 inches.

![Figure 2. The Touch Panel Prototype.](image)

Figure 3 shows the ready concept of the virtual simulator.
Figure 3. The driver's cabin simulator.

It is equipped with touch buttons, switches, regulators, the way 150 km, a surrounding situation is implemented, the sounds describing realistic behavior models of the environment, train structure, switching of buttons, acceleration, braking are picked up. The developed technologies can be programmatically and technically implemented in the true train structures therefore, they will have an opportunity of remote and/or program control.

3. Results
The developed simulator considers aspects of railway transport control process (structures, people on the ways, railway signs, traffic lights, etc.) that allows the operator to gain qualitatively skills of the analysis and processing of the arriving information and execution of actions for train control depending on a situation.

Deep simulation of safety devices operation logic, electric and pneumatic circuits, physical processes of train maintaining, physical processes of the world around is implemented.

Training activity is followed with registration of all of the rolling stock parameters and driver's actions in the special trips analysis program. The similar program of the stationary decoding device is included in a package of the complex locomotive safety control. The program allows to wiretap conversations of the driver with the manager, the driver with the assistant, to control their correctness, also makes the semi-automatic analysis of a trip.

Except the specified parameters the instructor can choose the train movement display mode: 3D, 2D, the mode with a land relief and objects on the card, mode of free flight and binding to the rolling stock. The figure 4 shows 3D – mode of train motion.

Figure 4. The 3D model.

Simulation of the processes which are taking place in the environment allows to reproduce most precisely all conditions corresponding to a real trip. For example, there is a possibility of the choice
not only time of day, season, intensity of rainfall, but also the possibility of the choice of ambient air temperature is provided. The program of the exercise machine in this case itself changes the wheel coupling coefficient with a rail, visibility conditions of signals, the train brakes functioning, especially in the conditions of low temperatures, etc.

For each car of the rolling stock mathes detailed calculation of electric and pneumatic circuits status and their components, such as air distributors, cranes of drivers, pneumatic relays, reservoirs, contactors, switches, power units. In the course of modeling of the electric current behavior in electrical circuitry elements (the relay, starting resistors, automatic machines, safety locks, etc.), all elements, work similarly real, that is the dependence of train structure behavior (collecting/analysis of draft, a rise/omitting of pantographs, rheostat braking, etc.) on any electric element is implemented.

Calculation of behavior model of air in a pneumatic system allows to imitate real passing of air on the system of all structure, operation of distributors, cranes (including animation in what channels will be takes place air and with what pressure), creation of leaks in the certain places affecting all structure and also to keep track of behavior of a pneumatic system by long compound trains, etc.

Training activity includes registration of all drivers and operator's actions and also parameters for special self-propelled train structure and action of the trainee within the special trips analysis program. In the simulator, the negotiations of the assistant and driver, the manager and the next locomotives are implemented. The program complex is capable to define correctness of a negotiation and to display assessment of quality of a talk within regulations of negotiations in percentage ratios.

The exact simulation of processes of the environment reproduces the following conditions: a rain, snow, the sun, non-staff situations, drops on a windshield, time of day, ambient temperature. According to them, the program changes the coupling coefficient, a condition just for show, system operation of braking, a condition of low temperature.

This system is put into operation in the course of which proved to be as the modern training complex implementing high-quality emulation of processes and allowing to gain correct and relevant knowledge and abilities of train control.

4. Discussion
The simulator complex was put into operation, during which it showed itself as a modern effective training tool.

The complex allows to provide simultaneous training of personnel, in the following directions:

- drivers and assistants to drivers: driving, the correct actions in abnormal and unusual situations, rational expending of fuel and energy resources and also ability to work with safety devices;
- operator teams: working and the correct actions at execution of a full works stroke of construction, diagnostics and repair of railroad tracks and the track equipment, according to the Operation manual on specific special self-moving rolling stock;
- drivers, driver assistants and operators: actions for detection and elimination of possible faults of the equipment.
- training in the special self-moving rolling stock device, working off of skills of their operation and service.

In the process of using the simulator, students acquire the necessary skills for driving and adjusting the state of railways, negotiating, and developing scenarios of behavior in emergency and emergency situations. The use of the simulator has a high efficiency, because the application of skills acquired during training in real situations, gives the correct result. Thus, the process of training operators of the rolling stock becomes more secure for students and for other people.

5. Conclusions
The results received in this work represent the functioning virtual simulator for training of the special self-moving rolling stock Duomatic 09-32 operators. It contains functions emulating of hydraulic, pneumatic, electric and mechanical systems with a possibility of malfunctions setting. Modules setting
of a route, weather conditions, creations of emergency situations and regulations of negotiating are realized.

The received results have the big practical importance. Besides, thanks to modular structure of the simulator, the results can be useful in developing of simulators for the other trains operators training.

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References
[1] Mueller W et al. 2012 Virtual prototyping of cyber-physical systems 17th Asia and South Pacific Design Automation Conference IEEE
[2] Tamburri D A, Van den Heuvel W J, Lauwers C et al. 2019 SICS Softw.-Inensiv. Cyber-Phys. Syst. 34 163
[3] Zeyda F, Ouy J, Foster S and Cavalcanti A 2017 Formalising Cosimulation Models Lecture Notes in Computer Science 10729 453-68
[4] Kögl B and Bungers O 1996 Fahrsimulatorenfür die Ausbildung von Triebfahrzeugführern Elek. Bahnen. 94(8, 9) 261–6
[5] Railway J 2001 Railway simulators become more diversified Railway Int. 41(4) 29–31
[6] Sutherland J and Sutherland J J 2015 Scrum: El revolucionario método para trabajar el doble en la mitad de tiempo (Grupo Planeta Spain)
[7] Derler P, Lee E A and Vincentelli A S 2011 Modeling cyber–physical systems Proceedings of the IEEE 1(100) 13-28
[8] Lee E A 2008 Cyber physical systems: Design challenges 11th IEEE International Symposium on Object and Component-Oriented Real-Time Distributed Computing (ISORC) pp 363-9
[9] Sridhar S, Hahn A and Govindarasu M 2011 Cyber–physical system security for the electric power grid Proceedings of the IEEE 1(100) 210-24
[10] Sha L et al. 2008 Cyber-physical systems: A new frontier IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing pp 1-9
[11] Sridhar S, Hahn A and Govindarasu M 2011 Cyber–physical system security for the electric power grid Proceedings of the IEEE 100 1 210-24
[12] Largman K 2016 Application of UML of 2.0 templates Electronic Materials p 736
[13] Takeuchi Y, Ogawa T and Morimoto H 2017 Development of a train operation power simulator Japanese Railway Engineering 197 13-5
[14] Miyachi T, Imamoto K, Teramura K and Takahashi H 2018 Evaluating the accuracy of railway total simulator compared with actual, measurement data IEEJ Journal of Industry 7(5) 416-24
[15] Takeuchi Y, Ogawa T et al 2018 Development of a train operation power simulator using the interaction between the power supply network, rolling stock characteristics & driving patterns, as conditions Quarterly Report of RTRI 58(2) 98-104
[16] Rajkumar R et al. Cyber-physical systems: the next computing revolution Design Automation Conference, IEEE pp 731-6
[17] Madsen E S, Bilberg A and Hansen D H 2016 Industry 4.0 and digitalization call for vocational skills, applied industrial engineering, and less for pure academics Proceedings of the 5th P&OM World Conference, Production and Operations Management, P&OM