# DEVELOPMENT OF VIRTUAL INTELLIGENT TRAINING WORLDS

**A. Afanasyev, N. Voit, S. Bochkov, T. Afanasyeva**

*Ulyanovsk State Technical University (RUSSIAN FEDERATION)*

## Abstract

The use of virtual worlds for acquisition of certain skills and competences increases an effectiveness of training through the maximum approximation to real conditions, from both the point of the objective environment's view and possible actions.

We have developed the virtual workplaces for radio assemblers, adjusters and fitters; the mathematical models of these workplaces are offered, including a composition and description of the permitted actions. The software for the said virtual workplaces has been developed on basis of the UNITY platform. Intellectualization of virtual worlds is connected with the developed expert system (ES) for trainee's actions assessment. This ES knowledge base is founded on the production rules. The direct logical inference is used to issue the recommendations to a trainee.

These virtual workplaces have been embedded into the corporate training environment of a company which is one of the Ulyanovsk State Technical University's (UlSTU's) partners, and are used to upgrade its employees' skills.

These virtual workplaces are also widely used by the UlSTU for students' training in both bachelor's degree program and secondary vocational training program in "Radio-engineering systems and complexes". Students and postgraduates of the Information Systems and Technologies Faculty of the UlSTU are involved to the development of the virtual workplaces' software and 3D models.

The conducted pedagogical experiment demonstrates that the use of intelligent virtual workplaces has sufficiently favored to improve a quality and effectiveness of training in fitting, assembly and adjustment of the radio electronic equipment, as well as to reduce the total period of training by 20-30% and to increase the trainees' motivation.

Keywords: virtual world, virtual workplace, intellectualization.

## 1 INTRODUCTION

Development and implementation of virtual simulation systems with the means of automated control and evaluation into training process is currently an urgent task related to the need to realize training in large enterprises and universities. This process requires shortening of terms and improving the quality of training. Unlike traditional e-courses, virtual systems allow you to fully "immerse yourself" in training close to reality.
At the same time, such systems should take into account the specifics of training, evaluate the trainee's actions. Formation of the necessary recommendations for students via expert systems will increase the effectiveness of their training.

## 2 STRUCTURE OF VIRTUAL INDUSTRIAL WORLD

The virtual world is understood as a simulated environment, "populated" by users communicating with each other through "avatars" – graphic characters. In the industrial virtual world, the organization's production processes are modeled.

Virtual industrial worlds can be represented as a set of special technologies that simulate the tools of real workplaces, the nomenclature of components and accompanying documents and intended for use in both enterprises and universities [1].

For the expert system's (ES's) operation, it is necessary to develop workplace's models, simulators of which are used in a virtual industrial environment, and analyze the actions that will be an object of a research in the ES.

The logical-algebraic models of workplaces presented in a virtual industrial environment and using the ES as a module of the action's evaluation are developed and described below.


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## 3 VIRTUAL WORKPLACE FOR A RADIO ASSEMBLER

The model of a radio assembler's workplace is given as:

$$\mathrm{R_M} = \{SIT,\ BR,\ CIR,\ Z,\ SI,\ ROT,\ BRUSH,\ TW,\ HS,\ NIP,\ E \mid sit,\ bracelet,\ solderiron,\ brush,\ tweezers,\ heatsink,\ setheatsink,\ getelement,\ setelement\},$$

where

$SIT$ – a parameter that indicates whether a student is sitting in a given workplace,

$BR$ – a parameter that indicates whether a student has worn an antistatic wrist strap (bracelet),

$CIR$ – a radioelement that is in the student's hand at the moment,

$Z$ – an indicator of camera's approach,

$SI = \{S, T, H\}$ – a soldering iron model, $S$ – a parameter that indicates that there is a solder, $T$ – temperature of a soldering iron, $H$ – a parameter that indicates that there is a soldering iron in the student's hand,

$ROT$ – a parameter that indicates whether the printed circuit board is rotated by 180°,

$BRUSH$ – a parameter that indicates that there is a brush in the student's hand,

$TW$ – a parameter that indicates that there are tweezers for the transfer of radioelements in the student's hand,

$HS$ – a parameter that indicates that there is a heat sink in the student's hand,

$NIP$ – a parameter that indicates that there are nippers in the student's hand,

$E = (E_i \mid i = 1 \ldots n)$ – a set of radioelements that will be soldered,

$E_i = \{t_i,\ P_i, C_i\}$ – a radioelement model, $t_i$ – temperature at which the radioelement $E_i$ should be soldered, $P_i = \{N_i,\ F_i\}$ – the position of $E_i$ on the printed circuit board,

$C$ – a parameter that indicates that there is a soldering iron in the student's hand,

$P_i = \{N_i,\ F_i\}$ – a description of the position on the printed circuit board, $N_i$ – a position name, $F_i$ – a parameter of applying the flux to $P_i$,

$sit : \mathrm{R} \times SIT \to \mathrm{R}$ – a function of sitting in a workplace,

$bracelet : \mathrm{R} \times BR \to \mathrm{R}$ – a function of wearing / removing a wrist strap (bracelet),

$solderiron : \mathrm{R} \times SI.H \to \mathrm{R}$ – a function of taking a soldering iron / returning a soldering iron to the place,

$brush : \mathrm{R} \times BRUSH \to \mathrm{R}$ – a function of taking a brush / returning a brush to the place,

$tweezers : \mathrm{R} \times TW \to \mathrm{R}$ – a function of taking tweezers / returning tweezers to the place,

$heatsink : \mathrm{R} \times HS \to \mathrm{R}$ – a function of taking a heat sink / returning a heat sink to the place,

$setheatsink : \mathrm{R} \times HS \to \mathrm{R}$ – a function of set / removal of a heat sink,

$getelement : \mathrm{R} \times CIR \to \mathrm{R}$ – a function of getting a radioelement,

$setelement : \mathrm{R} \times CIR \times E_1 \to \mathrm{R}$ – a function of setting a radioelement on a printed circuit board,

$settmpr : \mathrm{R} \times SI.T \to \mathrm{R}$ – a function of setting up a soldering station,

$flux : \mathrm{R} \times BRUSH \times E_1 \to \mathrm{R}$ – a function of applying flux to a pad,

$solder : \mathrm{R} \times E_1 \times \mathrm{B} \to \mathrm{R}$ – a function of soldering an element,

$rotation : \mathrm{R} \times ROT \to \mathrm{R}$ – a function of rotation of the printed circuit board by 180°.

## 4 VIRTUAL WORKPLACE FOR A RADIO ADJUSTER

The model of a radio adjuster's workplace is given as:

$$\mathrm{R_C} = \{BR,\ SIT,\ FP,\ TOOL, DIH,\ LAMP,\ TR,\ OR$$
$$NR,\ TH,\ FORK,\ CAP,\ RES,\ FRAME,\ M_1,\ M_2,\ M_3,\ M_4,\ ST_1,\ ST_2,\ ST_3,\ ST_4,\ ACT \mid$$
$$sit,\ bracelet,\ radiator,\ frameRotation,\ capacitor,\ transformer,\ throttle,$$
$$fork,\ rack,\ bind,\ screw,\ setCapacitor,\ setResistor,\ setThrottle,\ setFork,$$

$setTransformer,\ setLamp,\ setRack\}$,
where
$BR$ – a parameter that indicates whether the student has worn an antistatic wrist strap (bracelet),
$SIT$ – a parameter that indicates whether a student is sitting in a given workplace,
$FP$ – a frame position value,
$TOOL$ – a taken tool,
$DIH$ – a detail in the student's hand,
$LAMP = \{AP,\ RAD\}$ – a lamp model, $AP$ – a parameter that indicates whether the lamp is placed on the frame, $RAD$ – a type of a radiator attached to the lamp,
$RAD \in \{NR,\ OR,\ NoR\}$, where $NR$ – "new radiator", $OR$ – "factory radiator", $NoR$ – "without a radiator",
$TR = \{AP,\ SCST_1,\ SCST_2,\ SCST_3, SCST_4\}$ – a transformer model, $AP$ – a parameter that indicates whether the transistor is placed on the frame, $SCST_1 \ldots SCST_4$ – the condition of the screws to which the transformer is attached. $SCST_i \in (AT,\ SCRD,\ STPD,\ NoS)$, where $AT$ – "started", $SCRD$ – "screwed", $STPD$ – "built", $NoS$ – "there is no a screw",
$NR = \{AP,\ SCST_1,\ SCST_2,\ SCST_3, SCST_4\}$ – a radiator model set on the lamp, $AP$ – a parameter that indicates whether the radiator is placed on the frame, $SCST_1 ... SCST_4$ – the condition of the screws on which the radiator is fixed $SCST_i \in (AT,\ SCRD,\ STPD,\ NoS)$,
$OR = \{AP,\ SCST_1,\ SCST_2,\ SCST_3, SCST_4\}$ – a radiator model removed from the lamp, $AP$ – a parameter that indicates whether the radiator is placed on the frame, $SCST_1 \ldots SCST_4$ – the condition of the screws on which the radiator is fixed $SCST_i \in (AT,\ SCRD,\ STPD,\ NoS)$,
$TH = \{AP,\ SCST_1,\ SCST_2\}$ – a throttle model, $AP$ – a parameter that indicates whether the radiator is placed on the frame, $SCST_1 \ldots SCST_2$ – the condition of the screws on which the throttle is fixed $SCST_i \in (AT,\ SCRD,\ STPD,\ NoS)$,
$FORK$ – a parameter that indicates whether the fork is placed on the frame,
$CAP$ – a parameter that indicates whether the capacitor is placed on the frame,
$RES$ – a parameter that indicates whether the resistor is placed on the frame,
$FRAME$ – a parameter that indicates whether the sealing frame is placed on the frame,
$M_i$ – a parameter that indicates whether an appropriate bind for the sealing frame is set down,
$ST_i = \{AP_i,\ SCST_i\}$ – rack models, $AP_i$ – a parameter that indicates whether the rack is placed on the frame, $SCST_i$ – a state of the rack's fixity, $SCST_i \in (AT,\ SCRD,\ STPD,\ NoS)$,
$ACT = \{DN,\ AN\}$ – a general state of the detail, with which a student operates, $DN$ – the name of the detail, $AN$ – a type of an action, $AN \in \{DR,\ TK, 0\}$ where $DR$ – "setting", $TK$ – "taking", 0 – "no action",
$sit: \mathrm{R_c} \times SIT \to \mathrm{R_c}$ – a function of sitting in a workplace,
$bracelet: \mathrm{R_c} \times BR \to \mathrm{R_c}$ – a function of wearing / removing a wrist strap (bracelet),
$radiator:\ \mathrm{R_c} \times RAD \to \mathrm{R_c} \times DIH$ – a function of removal / set of a radiator,
$radiator:\ \mathrm{R_c} \times BR \to \mathrm{R_c} \times DIH$ – put an old (new) radiator on the table,
$frameRotation:\ \mathrm{R_c} \times FP \to \mathrm{R_c}$ – a function of the frame's rotation,
$capacitor:\ \mathrm{R_c} \times CAP \to \mathrm{R_c}$ – a function of taking a capacitor / returning a capacitor to the place,
$transformer:\ \mathrm{R_c} \times TR \to \mathrm{R_c}$ – a function of taking a transformer / returning a transformer to the place,
$throttle:\ \mathrm{R_c} \times TH \to \mathrm{R_c}$ – a function of taking a throttle / returning a throttle to the place,
$fork:\ \mathrm{R_c} \times FORK \to \mathrm{R_c}$ – a function of taking a fork / returning a fork to place,

$rack: \mathrm{R_c} \times ST \to \mathrm{R_c}$ – a function of taking a rack / returning a rack to the place,

$bind: \mathrm{R_c} \times \mathrm{M} \to \mathrm{R_c}$ – a function of taking a bind / returning a bind to the place,

$screw: \mathrm{R_c} \times SC \to \mathrm{R_c}$ – a function of taking a screw / returning a screw to the place,

$setCapacitor: \mathrm{R_c} \times DIH \times CAP \to \mathrm{R_c}$ – a function of set a capacitor on the frame,

$setResistor: \mathrm{R_c} \times DIH \times RES \to \mathrm{R_c}$ – a function of set a resistor on the frame,

$setThrottle: \mathrm{R_c} \times DIH \times TH \to \mathrm{R_c}$ – a function of set a throttle on the frame,

$setFork: \mathrm{R_c} \times DIH \times FORK \to \mathrm{R_c}$ – a function of set a fork on the frame,

$setTransformer: \mathrm{R_c} \times DIH \times TR \to \mathrm{R_c}$ – a function of set a transformer on the frame,

$setLamp: \mathrm{R_c} \times DIH \times LAMP \to \mathrm{R_c}$ – a function of set a lamp on the frame,

$setRack: \mathrm{R_c} \times DIH \times ST \to \mathrm{R_c}$ – a function of set a rack with a bind on the frame.

## 5 VIRTUAL WORKPLACE FOR A RADIO FITTER

The model of a radio fitter's workplace is presented as:

$$\mathrm{R_P} = \{SIT,\ SCREW,\ V,\ BVTOP,\ LB,\ OB,\ DIV,\ REG \mid sit,\ screw,\ offsetblock,\ offsetblockswitch,\ forkswitch,\ voltswitch,\ regulatorswitch,\ dividor,\ rotpot1,\ rotpot2,\ bvtop\},$$

where

$SIT$ – a parameter that indicates whether a student is sitting in a given workplace,

$SCREW$ – a parameter of a screwdriver state, $SCREW \in (NO,\ HAND,\ POT_1, POT_2)$, where $NO$ – "inactive", $HAND$ – "in the hand", $POT_1$ – "on a potentiometer 1", $POT_2$ – "on a potentiometer 2",

$V = \{VO,\ VS,\ VV\}$ – a voltmeter model, $VO$ – a parameter that indicates whether the voltmeter is switched on on, $VS$ – a parameter that indicates whether the fork is connected to a voltmeter, $VV$ – the voltage value,

$DIV$ – a parameter of a voltage divider state,

$BVTOP$ – trigger of opening / closing the check panel cover,

$LB = \{LBO,\ LBD\}$ – a model of a load panel, $LBO$ – an indicator of switching on the load control panel; $LBD$ - a parameter that indicates that there is a voltage divider on the load panel,

$REG = \{RO,\ RW_1, RW_2, RW_R\}$ – a regulator model (operation panel), $RO$ – an indicator of switch-on; $RW_1$ – a parameter that indicates that there is an offset block connected to a wire regulator from an upper connector; $RW_2$ – a parameter that indicates that there is an offset block connected to a wire regulator from a lower connector; $RW_R$ – a parameter that indicates that there is an optical cable connected to a controller from the offset block,

$OB = \{STATE,\ POT_1,\ POT_2,\ U_1,\ U_2\}$ – a model of an offset block, $STATE$ – a state of an offset block, $STATE \in (NO,\ HAND,\ INBV)$, where $NO$ – "inactive", $HAND$ – "in the hand", $INBV$ – "in the check panel", $POT_1$ – a rotation angle of a potentiometer 1, $POT_2$ – a rotation angle of a potentiometer 2, $U_1$ – a parameter that indicates whether the wire is connected to the upper connector of the offset block, $U_2$ – parameter that indicates that whether the wire is connected to the lower connector of the offset block,

$sit: \mathrm{R_p} \times SIT \to \mathrm{R_p}$ – a function of sitting in a workplace,

$screw: \mathrm{R_p} \times SCREW \to \mathrm{R_p}$ – a function of taking a screwdriver/returning a screwdriver to the place,

$offsetblock: \mathrm{R_p} \times OB \to \mathrm{R_p}$ – a function of taking an offset block,

$offsetblockswitch: \mathrm{R_p} \times U_1 \times U_2 \to \mathrm{R_p}$ – a function of connecting the wire to the offset block / disconnecting the wire off the offset block,

$forkswitch : \mathrm{R_p} \times VS \to \mathrm{R_p}$ – a function of connecting the fork to the voltmeter,

$voltswitch : \mathrm{R_p} \times VO \to \mathrm{R_p}$ – a function of switching on / off the voltmeter,

$regulatorswitch : \mathrm{R_p} \times RO \to \mathrm{R_p}$ – a function of switching on / off the regulator block,

$dividor : \mathrm{R_p} \times DIV \times LBD \to \mathrm{R_p}$ – a function of setting up the divider in the load panel,

$rotpot1 : \mathrm{R_p} \times POT_1 \to \mathrm{R_p}$ – a rotation function of potentiometer 1,

$rotpot2 : \mathrm{R_p} \times POT_2 \to \mathrm{R_p}$ – a rotation function of potentiometer 2,

$bvtop : \mathrm{R_p} \times BVTOP \to \mathrm{R_p}$ – a function of opening / closing the cover.

## 6 DEVELOPMENT OF EXPERT SYSTEM

In order to analyze trainee’s actions, an ES was developed. It is a separate service that receives a record of trainee’s actions, analyzes it and makes the necessary recommendations [2, 3].

The analysis of data is based on the production model of knowledge with a direct inference. This model allows us to present knowledge as the following type of sentences: "IF condition, THEN action1, OTHERWISE action2". The expert systems of the production type include a rule’s (knowledge’s) base, working memory and a rule’s interpreter (solver) that implements a certain technique of logical inference. The direct inference realizes the strategy "from facts to conclusions".

Rules for a virtual workplace of a radio fitter are given as:

1. IF "$!REG.RW$", THEN "You inserted the operation panel into the wrong connector of the special voltage pad".
2. IF "($SCREW.POT_1 \| SCREW.POT_2$) && ($!REG.RW_R$)", THEN "You did not connect the optical cable before adjustment".
3. IF "($SCREW.POT_1 \| SCREW.POT_2$) && ($!LB.LBO$), THEN" You did not connect the load panel up before adjustment ".
4. IF "($SCREW.POT_1 \| SCREW.POT_2$) && ($!DIV$)", THEN "You did not set the divider before adjustment".
5. IF "($SCREW.POT_1 \| SCREW.POT_2$) && ($!V.VO$)", THEN "You did not switch on the voltmeter before adjustment".
6. IF "($SCREW.POT_1 \| SCREW.POT_2$) && ($!V.VS$)", THEN "You did not connect the voltmeter up before adjustment".
7. IF "($SCREW.POT_1 \| SCREW.POT_2.$) && ($!LB.LBO$)", THEN "You did not switch on the operation panel before adjustment".

## 7 IMPLEMENTATION OF EXPERT SYSTEM

A virtual industrial environment was designed and developed on basis of the OpenSim and Unity-3D platforms [5, 6].

The ES structure is shown in Fig. 1. The ES has a "Rule’s editor" web interface [4] for making, editing, deleting and checking rules.

A report of trainers' actions is generated during the work with the simulator. It consists of the current state of the simulator, the object with which a student interacted, and the type of interaction. The REST JSON-based report is sent to the ES server. The received data are analyzed via "Rule’s base" module’s rule, then a message with a list of recommendations is formed.

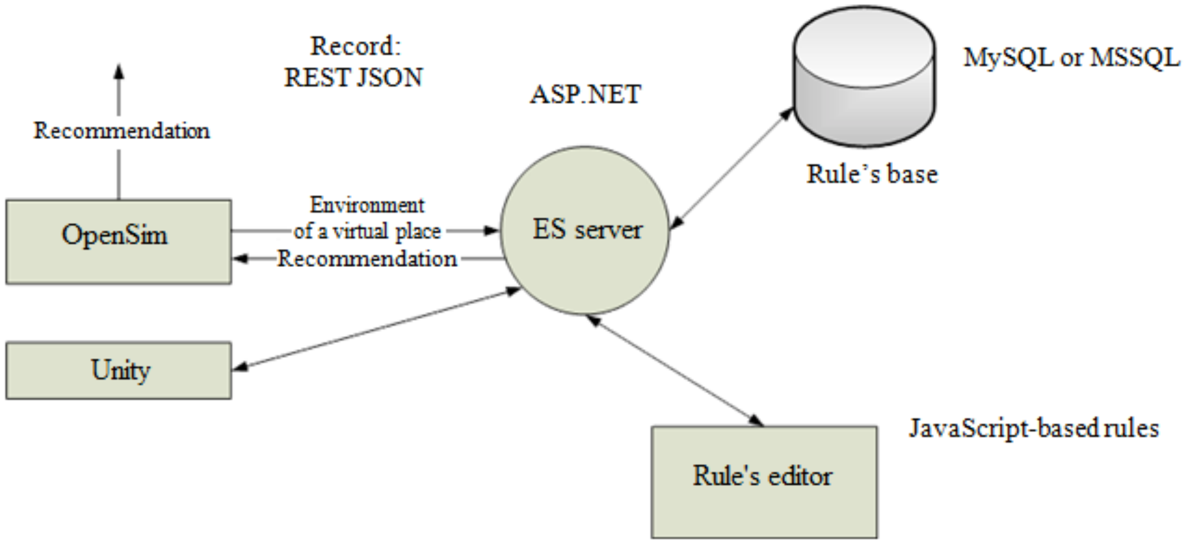


*Figure 1. The structure of the expert system.*

Below it is described an example of the ES operation. Let us assume that a student inserted the operation panel into the wrong connector when adjusting the radioelectronic equipment. The JSON state object passed by the expert system is given as:


```
{
"object":"50",
"action":"click",
"context":"adjuster",
"state":
{
"OperationPanelFork":
        {"rightParent":false},
    "VoltmeterFork":
        {"rightParent":true},
    "CableToLoadUnit":
        {"greenWire":false},
    "CableIntoCheckUnit":
        {"redWire":false},
    "kVC":
        {"blueWire":false},
    "kVZ":
        {"yellowWire":false},
    "PlaceForTheDivider":
        {"Divider":false}
      ...
        }
}
```


After processing the request and searching for the erroneously inserted parameter, the following message will be sent: "You inserted the operation panel into the wrong connector of the special voltage pad".

## 8 CONCLUSION

The use of virtual industrial worlds facilitates increasing the effectiveness of training and reducing the cost of expendables.

Virtual workplaces are designed taking into account the scalability of the virtual system and the requirements for technological processes [7, 8]. The mathematical support of the ES is universal and does not depend on the implementation of virtual workplaces.

The introduction of the ES allows reducing the terms for upgrading the skills of radio assemblers, adjusters, fitters on average by 40%.

These virtual workplaces are also widely used by the UISTU for students' training in both bachelor's degree program and secondary vocational training program in "Radio-engineering systems and complexes". Students and postgraduates of the Information Systems and Technologies Faculty of the UISTU are involved to the development of the virtual workplaces' software and 3D models.

The conducted pedagogical experiment demonstrates that the use of intelligent virtual workplaces has sufficiently favored to improve a quality and effectiveness of training in fitting, assembly and adjustment of the radio electronic equipment, as well as to reduce the total period of training by 20-30% and to increase the trainees' motivation.

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