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CONCEPT OF CREATION OF AN IMPROVED ARTIFICAL INTELLIGENCE SYSTEM AND COMPUTERIZED TRAINER FOR VIRTUAL WELDING

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One of the effective ways to solve the problem of shortage of highly qualified welders is application of virtual welding systems for their training. Such systems are based on artificial intelligence, used to develop a computerized trainer fitted with an interface adapted to learning objectives. Now already such systems enhance the training capabilities through increasing the number of modeled welding technologies and welding techniques. It can be anticipated that in the future they will help various institutions to significantly reduce the cost of training specialists. The objective of the work was creation of artificial intelligence for training welders, allowing development of a virtual system for real-time training in welding with functions of prediction and modeling of morphology, as well as intellectual evaluation of weld quality. Performance of work led to development of an artificial intelligence system for a network of welding trainers V60, having the following advantages: capability of modeling a realistic appearance and quality of weld; capability of modeling the stress-strain state of welded parts and temperature fields in real time; data base for modeling a large number of welding technologies and applied materials; capability of modeling 3D printing processes; availability of a system for virtual testing and analysis of welded part quality; certification system; entertainment module; access to expert department and high cost-effectiveness. It was found that the quality of welding process simulation by virtual trainer depends on the graphic component speed and it is the higher, the higher the level of taking into account the thermal impact of welding source on heating of the sample being welded and the arising stress-strain state. 13 Ref., 1 Table, 10 Figures.

Keywords: *welding trainer, manual arc welding, nonconsumable arc welding, consumable arc welding, artificial intelligence, virtual welding*

As noted by leading welding specialists from different countries of the world, the issues of training and improving the qualifications of welders should be given constant attention [1]. Another important point is correct organization of welding operations and compliance with relevant labour protection standards in industrial enterprises. In recent years work in these areas has been insufficient, either in Ukraine, or in other countries of the world, including China. This led to reduction of the number of trained welders, as well as a drop in the interest of such workers in finding a job in their specialty. So, vice-president of one of the companies, located in the zone of Yangtze river delta, notes: «We are facing a serious challenge. We cannot find highly-qualified welders, who would agree to work for 280000 Yuan ($40000) a year». There is a catastrophic shortage of highly-qualified welders in the city of Wuhan (PRC).

Different attempts are made in China to try to solve the problem of shortage of highly-qualified welders. So, in order to implement the project of construction of high-speed railways, the Chinese government sent the best Chinese welders to advanced training courses in Germany. The expenses for such training reached 1 mln Euros. The usual practice for China is training welders at courses within the country. But in this case also dozens of millions are spent. This problem, however, is not only economic in its nature. The social aspect of the problem includes the prejudices associated with this profession. This involves beliefs about the low social status associated with the profession, poor labour conditions and low salary. All this leads to unwillingness of young people to study the welding trade. Technical problems that reduce the popularity of the profession include: high level of workplace contamination (aerosols, spatter, etc.) and professional risks. There are also problems, directly related to personnel training: complexity of implementation of educational process and assessment of trained specialists, use of large quantities of consumable welding materials and energy carriers, allocation of study time and equipment, etc.

One of the effective ways to solve the problem of shortage of highly-qualified welders is application of virtual welding systems for their training. Such systems use artificial intelligence, which is the base of computerized trainer, fitted with an interface adapted to training objectives. International Institute of Welding already began application of such systems for training welders [2]. Now already such systems enhance the training capabilities through increase of the number of modeled welding technologies and methods. It is anticipated that in the future they will help different organizations to significantly reduce the cost of specialist training.

The objective of this work is creation of artificial intelligence for training welders, which allows development of a virtual system for real-time welding training with the functions of prediction and modeling of the morphology, as well as intellectual evaluation of weld quality. The following tasks were addressed to achieve this goal:

1. Analysis of currently available virtual welding trainers, determination of their advantages and disadvantages.

2. Virtual real-time modeling of various processes of welding joints of different types for a certain range of welded materials, including modeling of weld pool, metal spattering from it, arising thermal fields, prediction of weld formation, as well as displaying the working parameters of welding processes and evaluation of weldment quality.

3. Development of user interface for use of virtual reality glasses (helmet), different kinds of welding tools and working platform with parts fastened to it.

4. Development and testing of virtual welding trainer with artificial intelligence system and comparison with currently available analogs.

Developments in the field of virtual welding systems have been conducted from the beginning of 1980s. Display trainer ETS, developed in 1981 at PWI together with G.E. Pukhov Institute of Modeling Problems in Power Engineering of the NAS of Ukraine, allowed for the first time evaluating in practice the prospects for application of information technologies in welder training [3] and was the prototype of a whole gamma of trainers, developed later on. In cooperation with PWI, development of welding training systems was carried on by SLV Halle (Germany) and, as the first European Institute, they proposed a welding trainer useful in training [4]. At the start of 2000s, two tendencies clearly stood out in the field of development and improvement of technical means for welding personnel training (welding trainers), namely development of purely virtual and semi-virtual systems [5]. The latter at that time were recognized as the closest to real welding processes, allowing effectively creating, perfecting and consolidating the required persistent psychomotor skills of welders. At present it is more correct to divide the available welding trainers into the following kinds:

Computerized. They are maximum close to real welding processes. They use low power electric arc, and have no the real weld, welder's motions are followed in the form of melting line on a metal plate, modes and their variation depending on welder's motion, are recorded by a computer program [6]. Trainers of this type include: TSDS-05M1 (PWI, Ukraine) [7], GSI SLV Welding Trainer (GSI SLV, Germany) [5], and Real Weld Trainer (Real Weld Systems, Inc. USA) [6].

Semi-virtual. They use virtual technologies for partial modeling of welding equipment and parts being welded. Physical models of welded parts are applied. This type of trainers is also called augmented reality trainers. They include Soldamatic Augmented Training (Seabery Soluciones, Spain) [8], and Miller Augmented Arc (USA).

Virtual. They use virtual technologies for modeling the environment, parts being welded, welding equipment, etc. Presence of physical objects is minimized. Examples of such trainers are The Lincoln Electric VRTEX 360 (USA) [9], 123 Certification ARC®+ (Canada), Fronius Virtual Welding (Fronius, Austria) [10], «Volzhanka-1» (Nyzhny Novgorod, RF) [11], and Weihan V60 (PRC).

Let us consider in greater detail the main of the above models, belonging to these three kinds of welding trainers.

PWI developed TSDS-06M1 trainer, belonging to computerized trainers [5]. Its main advantage is maximum closeness to real welding conditions through application of low amperage arc. This trainer, however, is designed only for coated-electrode manual arc welding (MMA) and inert-gas nonconsumable (tungsten) electrode manual welding (TIG) with and without filler wire feeding, as well as for inert/active gas consumable electrode welding (MIG/MAG). It has operational automatic feedback to training system in the form of speech signals. TSDS-06M1 model is one of the best in computerized welding trainer class. GSI SLV Welding Trainer (GSI SLV, Germany) is a development close to it [5]. Unlike TSDS-06M1 trainer, Soldamatic Augmented Reality Trainer allows using virtual welder's helmet to simulate the main welding technologies: MMA, TIG and MIG/MAG (inert/active gas consumable electrode manual welding) [8]. For complete simulation of welding processes it uses physical models of parts being welded (or their plastic simulation) with QR-code applied on their surface.

The welding process is simulated in Augmented Reality helmet display due to presence of QR-codes on the models of parts and welding torches. This trainer is one of the most popular in the world. It is used by such companies as Abicor Binzel, Miller, etc. Welding trainer VRTEX 360 of Lincoln Global, Inc. Company (USA) is designed similarly [9]. Unlike Soldamatic trainer, VRTEX 360 trainer is fitted with virtual welding helmet with individual focus adjustment in each of the eyepieces. Virtual Welding Trainer of Fronius Company can be regarded as virtual one to a greater degree [10]. It supports training both with application of physical models, and without them. Here, the welder should work standing. Welding trainer «Volzhanka-1» developed at Sormovskii Mechanical College (Nizhnii Novgorod, RF) is virtual in its pure form [11]. It is fitted with a helmet completely recreating virtual reality of three above-mentioned welding processes without the need for physical model application. Welder can work both sitting and standing.

In modern computerized trainers, reading and calculation of various welding parameters occur during welding at low-amperage welding current, through application of sensor cameras, computerized feedback systems and special software. This can be regarded as an essential drawback of the training system, as the welding process is not reproduced completely — there arises the need for application of consumables and specially equipped classrooms, capability of full adjustment of current is absent, real-time adjustment of gas flow rate, selection of these gases and their mixtures, selection of filler material type and composition, etc., become difficult. In virtual systems all that is available in full. Advantages of computerized systems are the capabilities of working with the welding torch under the conditions maximum close to real welding, familiarization with the welding arc, and training in its excitation. In their turn virtual systems provide the following advantages:

1. Monitoring of the process of each student training from teacher (instructor) computer-trainer or direct observation of student's progress in the display of the trainer, on which he is working.

2. Possibility for the teacher (instructor) to render assistance and correct the student's work in real time.

3. Optional capability is provided of online/offline monitoring and correction of the work directly by specialists of trainer developer-company, or leading welding specialists of international training and research institutions, with which the developer company has cooperation.

4. Access to the forum for discussing with instructors and specialists the questions of interest to students.

5. Lectures of leading welding specialists in online/offline mode.

6. The student receives visual and sound prompts from the system proper during welding.

7. Elimination of the risk of injury to students during training.

8. Capability of using several levels of training complexity; for instance three levels — beginner, advanced, professional. Welding parameters, materials and defined objectives vary, depending on the level of complexity. This helps the instructor in development and implementation of his own training plans.

9. Automatic evaluation of student performance by the system. After completion of each welding process/stage, the student and instructor obtain the calculations in the form of diagrams and graphs, which indicate second by second welding parameters, presence of defects, etc., that facilitates the work of the teacher (instructor).

The above advantages, as well as a larger number of developments of welding trainer models (for instance, [8–11]), is indicative of prevalence of the interest of leading world companies dealing with welding, in application of virtual and semi-virtual welding trainers, compared to computerized ones.

The main advantages of the considered virtual and semi-virtual welding trainers include:

- possibility of considerably reducing the training cost through saving materials of samples, power, gases and welding consumables;
- possibility of simulating the main welding processes in different positions in space;
- visual operative demonstration of welder's errors;
- recording all the welding process parameters with the capability of their repeated reproduction to better understand the influence of welder's actions on the quality of the obtained result.

Features of a particular welding trainer design are the level of allowing for thermal impact of the welding source on heating of the sample being welded and level of allowing for the arising stress-strain state (SSS). The higher these levels, the closer to reality are the results of virtual simulation of welding processes. Quality of welding process simulation in virtual environment directly depends on the engine, in which the graphic component is created. The disadvantages of the considered trainers include:

- limited number of modeled welding processes (usually MMA, TIG, and MIG/MAG);
- limited number of welding consumables and welded sample materials;
- application of individual approach in training, lack of use of network resources and remote access;

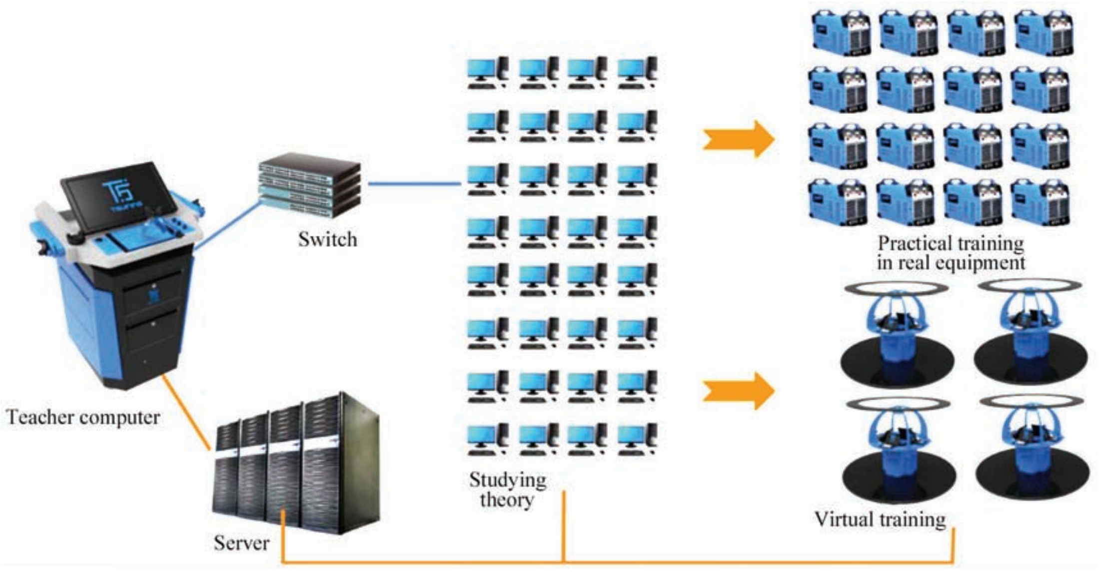

Figure 1. Concept of the complex for welding training, including real and virtual trainers

● no possibility of gaining real experience of conducting welding processes;

● incomplete application of virtual reality capabilities.

To eliminate the above drawbacks, and allow for the above features, it is rational to apply the following concept of development of welding training complex (Figure 1). Virtual training of a welder should be interspersed with real training, and should be based on deep study of the theory. Transition to welding practice is possible only after studying the theory and only under the conditions of continuous monitoring of the training process by the teacher. Such monitoring can be carried out both directly and in remote access mode that will provide one of feedback variants. Virtual welding trainers should be integrated into a single network, allowing students with good progress helping slow students that will ensure another feedback variant. Databases for modeling welding processes should be stored in remote servers and should be supplemented as far as possible with updated information about the used materials and processes. Individual virtual welding trainers should have the structure shown in Figure 2. For the first time we suggest adding an entertainment module alongside the teaching modules. As shown by practice, periodic short-term switching of students' attention from the object of instruction to entertainment object increases the efficiency of assimilation of knowledge.

Implementation of the proposed concept of welding training system requires realizing artificial intelligence common for its entire virtual part (Figure 3). It should consist of a database for modeling the studied welding processes, system of working with these data, system of dialogue mode for communication with the welder trainee and shell-program combining these three parts in a single whole.

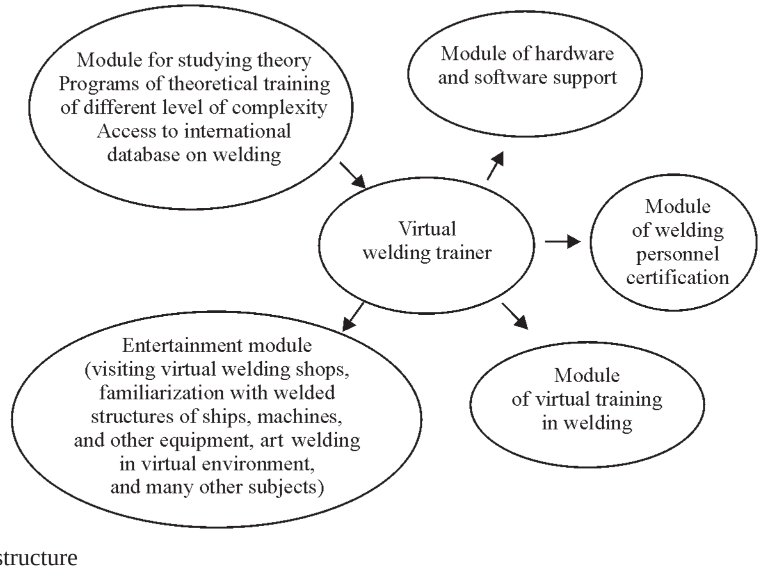

Figure 2. Welding trainer structure

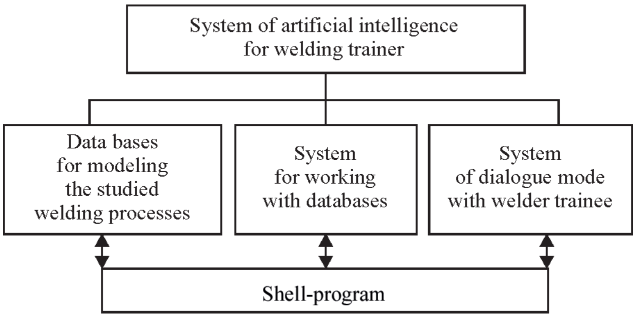

Figure 3. Structure of artificial intelligence for virtual welding trainer

One the objectives of artificial intelligence operation, is realization of feedback to teacher (instructor) computer during training. The instructor should be able to remotely give assignments in real time, adjust welding parameters and follow the process, either from his computer or directly in trainer displays. The welder trainee should be able to get advice in online mode both from the educational establishment experts, and from specialists of developer-company (in our case Weihan Science and Technology Company), including specialists of partner-institutions, among which are welding institutes and leading world companies.

Based on described approaches, Weihan Science and Technology Company (Shenzhen, PRC), using the experience of PWI and NTUU «Kiev Polytechnic Institute», developed virtual welding trainer Weihan V60 (Figure 4). Beginning of serial production of Weihan V60 model, belonging to Virtual welding Trainer Line, by Weihan Science and Technology Company, is planned for June, 2017.

When developing the concept of creation of Virtual Welding V60 system, the above-mentioned features were taken into account and characteristic drawbacks inherent to welding trainers, were eliminated as far as possible. So, to make the virtual trainer maximum close to reality, it uses real welding torches, on which

Figure 4. Virtual welding trainer V60: *1* — mobile platform; *2* — touch screen; *3* — virtual blank; *4* — bracket for welding simulation in different positions in space; *5* — virtual welding torch; *6* — box for storing virtual reality glasses (helmet); *7* — box for blanks; *8* — box for torches

Vive tracker controllers are installed, which serve as a marker for torch modeling in virtual reality (Figure 5). Such controllers allow following the position and displacement of welding torches in space. MMA torch is of a special modification. Its design and operating principle are similar to that of MMA torch in Augmented Arc Welding Simulator of Miller Company (USA) (Figure 6). To achieve maximum closeness to conditions of operation with a real electrode, this torch simulates its melting with shortening during welding. Application of virtual reality glasses or helmet HTC Vive of HTC Company (Korea), allows per-

Figure 5. Application of Vive tracker controller for modeling virtual welding torches based on real ones and tracing their movement in space: *a* — Vive tracker controller; *b* — real welding torches with controllers put on them

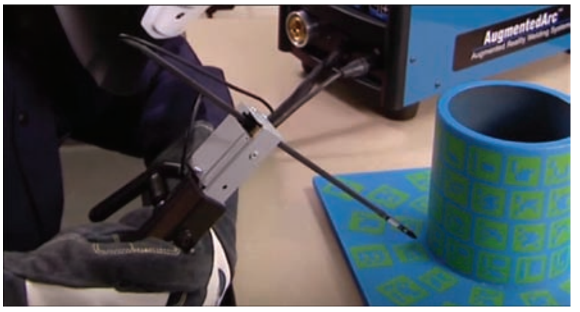

Figure 6. Virtual MMA torch simulating electrode melting with its shortening during welding

formance of virtual welding in any position on virtual sample (Figure 7), and additional bracket (position *4* in Figure 4) also allows using real physical samples. Virtual reality helmet HTC Vive is considered one of the best to date [12]. It allows simulation of characteristic sounds of welding processes. An additional accessory (Vive tracker controller) allows adding any new object to virtual reality. Note that modern technologies made virtual reality helmet a comparatively inexpensive and accessible accessory, application of

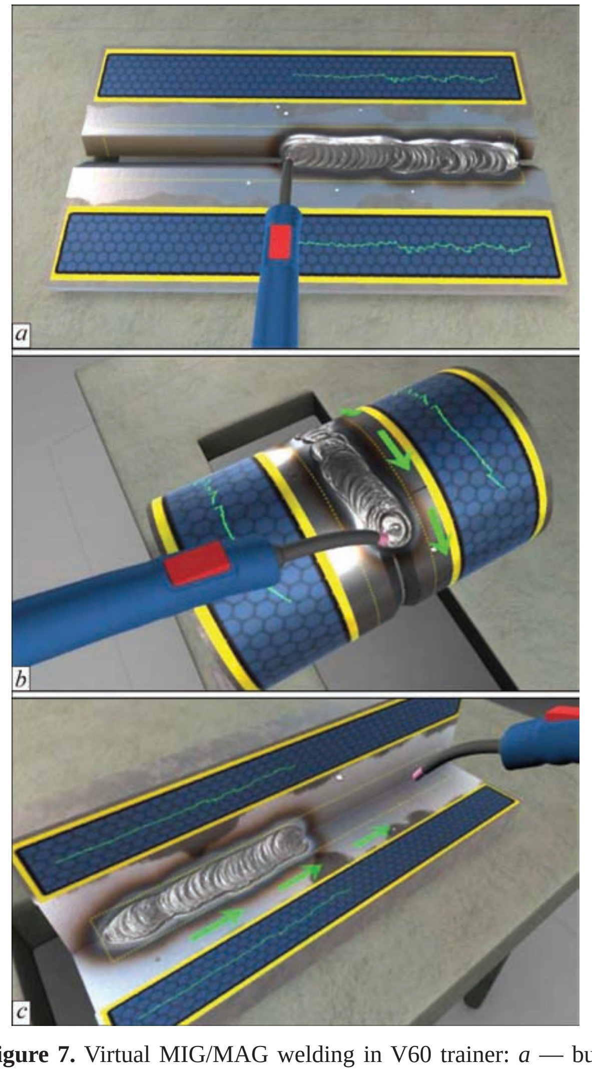

Figure 7. Virtual MIG/MAG welding in V60 trainer: *a* — butt weld in the downhand position; *b* — orbital welding of position butt weld; *c* — fillet weld

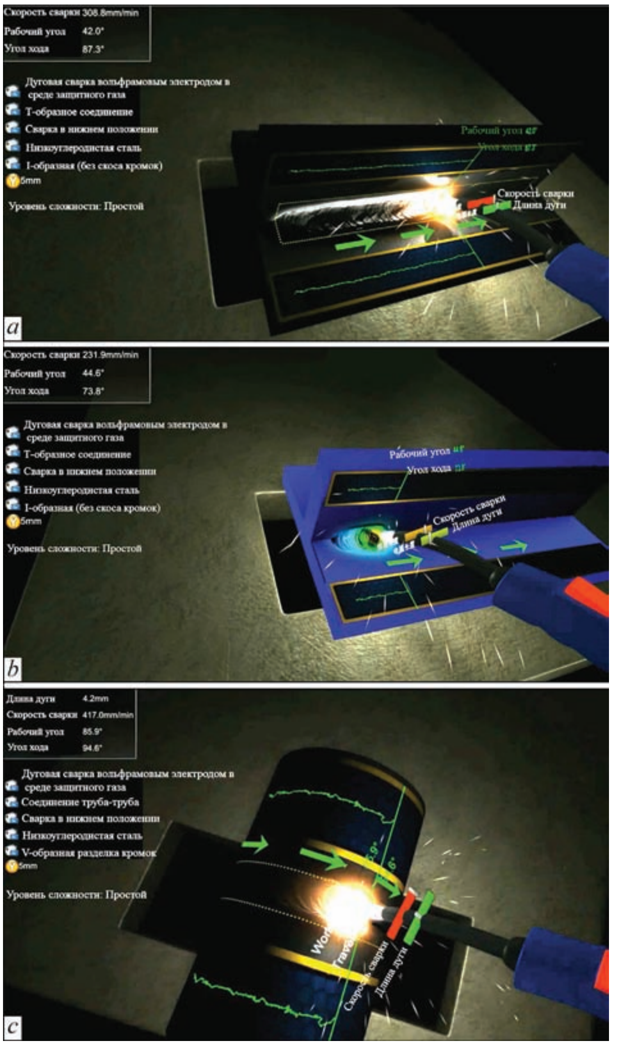

Figure 8. Displaying TIG welding process parameters in real time, allowing for dynamics of temperature fields and spattering from the pool in V60 trainer: *a*, *b* — tee joint; *c* — orbital welding of position butt weld

which is capable of improving the teaching process in any of the three types of welding trainers. Unity software, which is one of the best now, was used to achieve a high quality of welding process simulation in virtual environment in V60 trainer [13].

Modeling of the weld, weld pool, spattering from the pool and temperature fields is applied in V60 trainer (Figure 8). Working parameters of welding process, as well as the entire welding scene, is visualized in real time. All this gives a realistic picture of the weld, produced during virtual welding (Figure 9).

At present V60 trainer works with three main welding processes (MMA, TIG and MIG/MAG), but modeling of the processes of plasma and laser welding is actively pursued. Furtheron, it is also intended to model such hybrid welding processes as laser-MIG, plasma-MIG and laser-plasma.

It is intended to integrate virtual trainers V60 into training stations, each of four trainers (Figure 10). Stations in their turn are combined into classroom net-

Figure 9. Displaying a realistic view of the weld produced during virtual welding in V60 trainer

work, allowing realization of «student-student», «student–teacher», «student–specialist-consultant» communication. Compared to existing analogs, developed system of artificial intelligence and training network of welding trainers V60 offers a number of additional advantages (Table). The following main advantages can be mentioned:

- modeling a realistic appearance and quality of the weld;
- modeling stress-strain state of welded parts; modeling temperature fields in real time;
- modeling a large number of welding technologies and applied materials, as well as 3D printing processes;
- virtual testing and analysis of welded part quality;
- certification system; entertainment module; access to expert department;
- high cost-effectiveness.

It should be separately noted that the applied in welding trainer Virtual Welding V60 database, concept and virtual software can be the basis for development of augmented reality helmet for welding. In such a helmet, the virtual picture of the welding process is superposed onto the real one. It allows the welder correcting the torch position and process speed directly during welding, so as to obtain the best result. Creation of an augmented reality helmet can be the next step in development of various welding technologies.

Figure 10. Design of virtual training station with four welding trainers V60

Advantages of the developed system of artificial intelligence and learning network of V60 welding trainers, compared to currently available analogs (differences from analogs are underlined) [3–11]

System of virtual training of welders			
Training module	**Certification module**	**Entertainment module**	**Hardware support module**
Study of theory Process animation visualization Lectures of leading welding experts Access to the most common data on welding	International certification system National certification system Certification system of nuclear welders	Virtual engineering Art welding Graffiti by welding Visiting virtual welding shops, automatic welding lines	Trainer working platform Optical following of displacement virtual Welding helmet Welding torches Touch-panel Host computer Projector Defect simulation
Virtual training module			
Part position in welding	**Welding materials**	**Welding technologies**	**Joint types**
Downhand position Overhead position Vertical position Horizontal position	Titanium and titanium alloy Magnesium and magnesium alloy Low-carbon steel Aluminium and aluminium alloy Stainless steel Copper and copper alloy Zinc-plated steel	Manual arc welding Consumable electrode welding TIG welding Laser welding Plasma welding Stud welding	Horizontal butt joint T-joint Pipe-pipe joint Pipe-plate joint Overlap joint of plates

Conclusions

1. An artificial intelligence system for welder training has been developed, which allows conducting real time virtual training with functions of prediction and modeling of the morphology, as well as intellectual assessment of weld quality.

2. Proceeding from analysis of available virtual welding trainers it was found that their main disadvantages are limited number of modeled welding processes (usually, MMA, TIG and MIG/MAG); limited quantity of welding consumables and materials of samples being welded; lack of application of network resources or remote access; no possibility of gaining real experience of conducting the welding processes; and incomplete use of virtual reality capabilities.

3. It is found that quality of welding processes simulation by virtual trainer depends on graphic component engine and is the higher, the higher the levels of allowing for thermal impact of welding source on heating of sample being welded and arising stress-strain state.

4. Developed artificial intelligence system for network of welding trainers V60 has the following advantages: capability of modeling a realistic appearance and quality of the weld; capability of real time modeling of stress-strain state of welded parts and temperature fields; database for modeling a greater number of welding technologies and applied materials; capability of modeling 3D-printing processes; availability of a system of virtual testing and analysis of welded part quality; certification system; entertainment module; access to expert department; and high cost-effectiveness.

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